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Carbon Storage in Mountain Land Use Systems in Northern Thailand

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Conversion of forested land for agriculture has obvious detrimental effects on its ecological functions, but these effects are not uniform. Mountain land use systems are diverse, encompassing managed forests and cultivated land. This study examined land use systems in 3 mountain villages in northern Thailand with different patterns of cultivation and evaluated the amount of carbon they have accumulated. Land use and management by individual farmers and communities were determined by interviews, field verification, and mapping. Biomass carbon in trees was determined nondestructively, and carbon in ground cover, litter, and soil organic matter was determined by chemical analysis of replicated samples. The 3 villages, with access to land ranging from 1.3 to 6.3 ha per capita, managed largely pristine headwater forests for security of water supply and made a living from crop production supplemented by harvests of timber, firewood, and other forest products from managed community forests. Cultivated land varied in composition and management among the villages, from shifting cultivation with fallow periods of different lengths to permanent cultivation of food and commercial crops. Per capita carbon storage in the villages well exceeded average per capita carbon dioxide emissions in Thailand, with most of the carbon stored in the forests. This has important implications for programs that offer incentives to mountain villages to maintain or enhance their carbon storage, such as the United Nations' REDD (Reducing Emissions from Deforestation and Forest Degradation) program.

Keywords: *Carbon; cash crops; forest; land use systems; rotation; shifting cultivation; Thailand.*

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Introduction

Conversion of large expanses of forested land to monoculture of food and industrial crops has obvious detrimental effects on ecological functions, especially the maintenance of biological diversity and carbon storage. Such effects are less clear in the complex land use systems of montane mainland Southeast Asia (Cramb et al 2009; Fox et al 2009; Rerkasem, Lawrence, et al 2009). In Thailand, mountain villages are populated by people belonging to many different ethnic groups, who numbered about 1 million by the turn of the millennium (HRDI 2010). Slash-and-burn or shifting cultivation, still practiced in a number of mountain villages, is perceived by most governments in the region to be destructive and unacceptable (Cramb et al 2009; Fox et al 2009). However, it has been demonstrated that biodiversity can be enhanced instead of destroyed by shifting cultivation (Sabhasri 1978; Rerkasem, Yimyam, and Rerkasem 2009).

Carbon is released to and extracted from the air and soil in a number of different processes associated with forests and agriculture, as summarized in Figure 1. Land use systems in the mountains involve permanent agriculture, shifting cultivation and management of forests that affect these processes differently in the carbon cycle. Shifting cultivation of upland rice in villages inhabited by the Lua and Karen minority groups has long been recognized for careful management that encourages rapid restoration of the forest cover (Kunstadter 1978; Nakano 1978), but little is known specifically about how these practices affect carbon storage. Such information would be valuable in efforts to encourage land use and land management that keep carbon from being released into the atmosphere, such as the REDD (Reducing Emissions from Deforestation and Forest Degradation) program of the United Nations, which aims to create financial value for the carbon stored in forests (UN-REDD 2016). This article reports on land use systems in 3 mountain villages in northern Thailand with different cropping patterns and on the amount of carbon they have accumulated.

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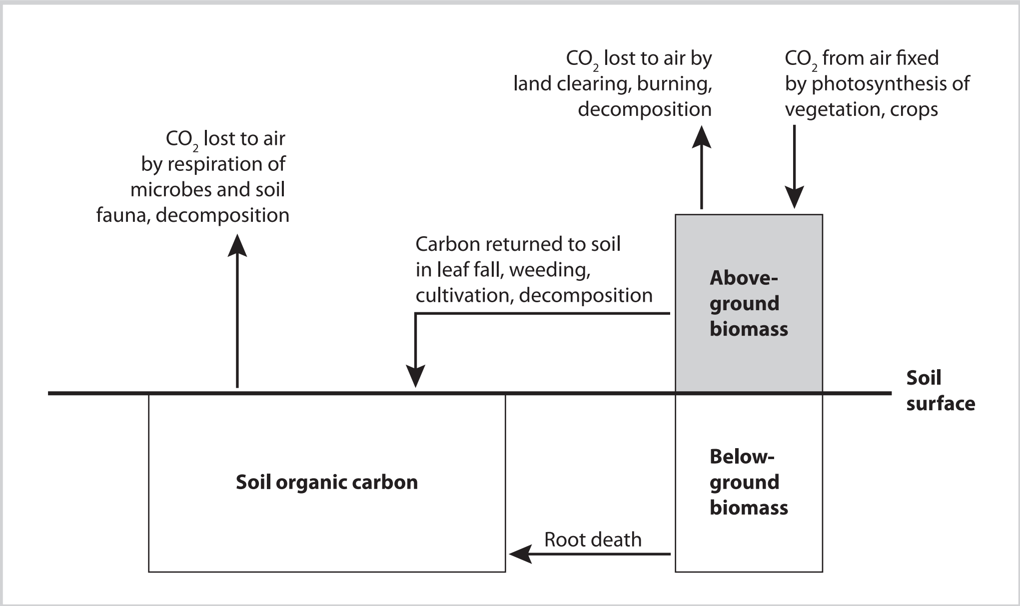
FIGURE 1 Carbon cycling. (Sketch by Benjavan Rerkasem)



Study area

This study was conducted in 3 mountain villages in northern Thailand that practice different combinations of subsistence and commercial production (Rerkasem, Yimyam, 2002): Teecha, Mae Rid Pakae, and Pah Poo Chom. The villages are under the influence of the southwestern monsoon, which bring rains from May to October. Crop and forest land are all on steep slopes, except for wetland rice grown on the valley bottom. The villages are described in Table 1, and their locations are shown in Figure 2.

Methodology and data collection

Information on land use and land management in each village was collected by interviews, field mapping with the aid of hand-held global positioning system devices, measurement in collaboration with farmers, and field verification. The interviews were conducted in 3 separate groups of farmers in each village to verify the information obtained.

Land use systems were characterized into *land use stages* that are clearly recognizable in the landscape and *field types* that are identifiable by land management practices (Brookfield 2002). Two land use stages were identified: forests, which were occupied by natural vegetation, and cultivated land, in which domesticated plant species were planted and cared for. Forests were further divided into headwater forest (*pa tonnam*, also called conservation forest, *pa anurak*) and community forest (*pa choom chon*); cultivated land was divided into shifting cultivation fields (*rai moon wian*) and permanently cultivated fields with food and commercial crops (Table 2). In any given year some shifting cultivation land is left fallow and natural vegetation is allowed to regenerate. This fallow land and the community forest are the source of firewood, grazing, wild food, and minor forest products.

Sampling and determining carbon in biomass and soil

Aboveground biomass in different field types was estimated nondestructively for plants that were taller than 1.5 m and determined destructively for ground cover with plant height lower than 1.5 m, using the formulas shown in Table 3. The ground cover and litter were collected from 2 × 2 m quadrats in 4 replicates and subsampled to determine biomass after drying for 48 hours at 80°C. Diameter and height of plants were measured, in 4 replicates of 20 × 20 m quadrats for those with >4.5 cm diameter at breast height (1.3 m from ground) and 10 × 10 m quadrats for those with <4.5 cm diameter at breast height.

Composite soil samples were collected at 0–30 cm depth with a soil auger from each field type in 4 replicates for determination of soil organic matter (Walkley and Black 1934), and soil organic carbon content was taken to be 58% of soil organic matter (Nelson and Sommers 1996). Upland and wetland rice yields in Mae Rid Pakae were determined after sun-drying to 12–14% moisture content from crop cutting samples from 2 × 2 m quadrats in 4 replicates.

Results

Land use and land management

The 3 mountain villages were similar in the relatively large allocation of land to forests and strict conservation of the headwater forest, in spite of their different modes of production (Tables 1, 2) and access to land

TABLE 1 Description of the study villages.

Village	Description
Teecha	**Location:** 17°53′N, 97°54′E
	Elevation: 700–900 m above sea level
	Ethnic group: Pwo Karen
	Soil: Black loam, pH 4.0–5.0
	Main crop system: Subsistence rotational shifting cultivation on slopes with 1-year cropping (upland rice mixed with up to 30 other crops, including roots, tubers, legumes, gourds, cucumber, melons, cabbages, chilies, herbs, and spices) followed by a 6-year fallow phase
Mae Rid Pakae	**Location:** 18°11′N, 98°7′E
	Elevation: 700–1140 m above sea level
	Soil: Brown to black sandy loam, pH 5.0–6.5
	Ethnic group: Skaw Karen
	Main crop system: Subsistence wetland rice on bottomland and upland rice on slopes, in rotation with vegetables as cash crop.
Pah Poo Chom	**Location:** 19°8′N, 98°31′E
	Elevation: 600–900 m above sea level
	Soil: Brown to black sandy loam, pH 5.0–6.5
	Ethnic group: Hmong
	Main crop system: Commercial production of fruit (lychee), cabbage, and other vegetables.

(Tables 2, 4). Pah Poo Chom, with the lowest per capita access to land, allocated the largest proportion of its land to forest (84.6%), almost half of it as headwater forest. Mae Rid Pakae had access to the least land in total, only one-third of Teecha's and two-thirds of Pah Poo Chom's. With more than half of its land under cultivation, the village maintained 84.1% of its relatively limited forest area as headwater (conservation) forest. Teecha had the most land in total and per capita, but with its rotational shifting cultivation that required 6 years of fallow between cropping periods, roughly half the village's land was cultivated. The cultivated land under shifting cultivation in Teecha was different from that in the other 2 villages in that within 2 years after the rice harvest it was more like forest than cropland in terms of both composition and utilization, and it is recognized locally as fallow forest (*pa lao*). The headwater forest was considered key to the security of the village's domestic water supply in all 3 villages, and to irrigation, which was essential for crop production in Mae Rid Pakae and Pah Poo Chom.

In all 3 villages, land under permanent cultivation was held and managed privately, forests were communally held and managed, and land under shifting cultivation was managed privately during the cropping phase and communally during the fallow phase. Harvests from the community forest were mainly for home use, with some notable exceptions, such as harvest of bamboo (*Dendrocalamus* sp) shoots for sale from Pah Poo Chom. Some parts of the community forest were under the care of individuals, but with a communal agreement to allow harvesting of wild vegetables and other forest products by other village residents. The headwater or conservation forests were strictly conserved, allowing no conversion for agriculture and only nondestructive harvests such as deadwood, honey, orchids, and mushrooms.

For each type of cultivation, there were major differences in management from village to village. The cycle of shifting cultivation in Teecha was 7 years, with 6 years of fallow between cropping years, while the cycle in Mae Rid Pakae was 5 years, with 3 years of fallow between 1 year of upland rice followed by 1 year of cabbages grown for sale. In Mae Rid Pakae, vegetables were also grown in the dry season after the wet-season rice crop. In Pah Poo Chom, European and Chinese cabbages and other vegetables were grown on permanently cultivated land dedicated to commercial production or among young lychee trees. The vegetables were grown on fields cleared of wild vegetation dominated by *Mimosa invisa*, a leguminous weed that covered the soil for the first part of the wet season.

Carbon storage

Total carbon stored in each village is considered to reflect the impact of the combined private and communal land use and management (Table 5). Mae Rid Pakae

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FIGURE 2 Location of the study villages. (Map by Narit Yimyam and Ulla Gaemperli)

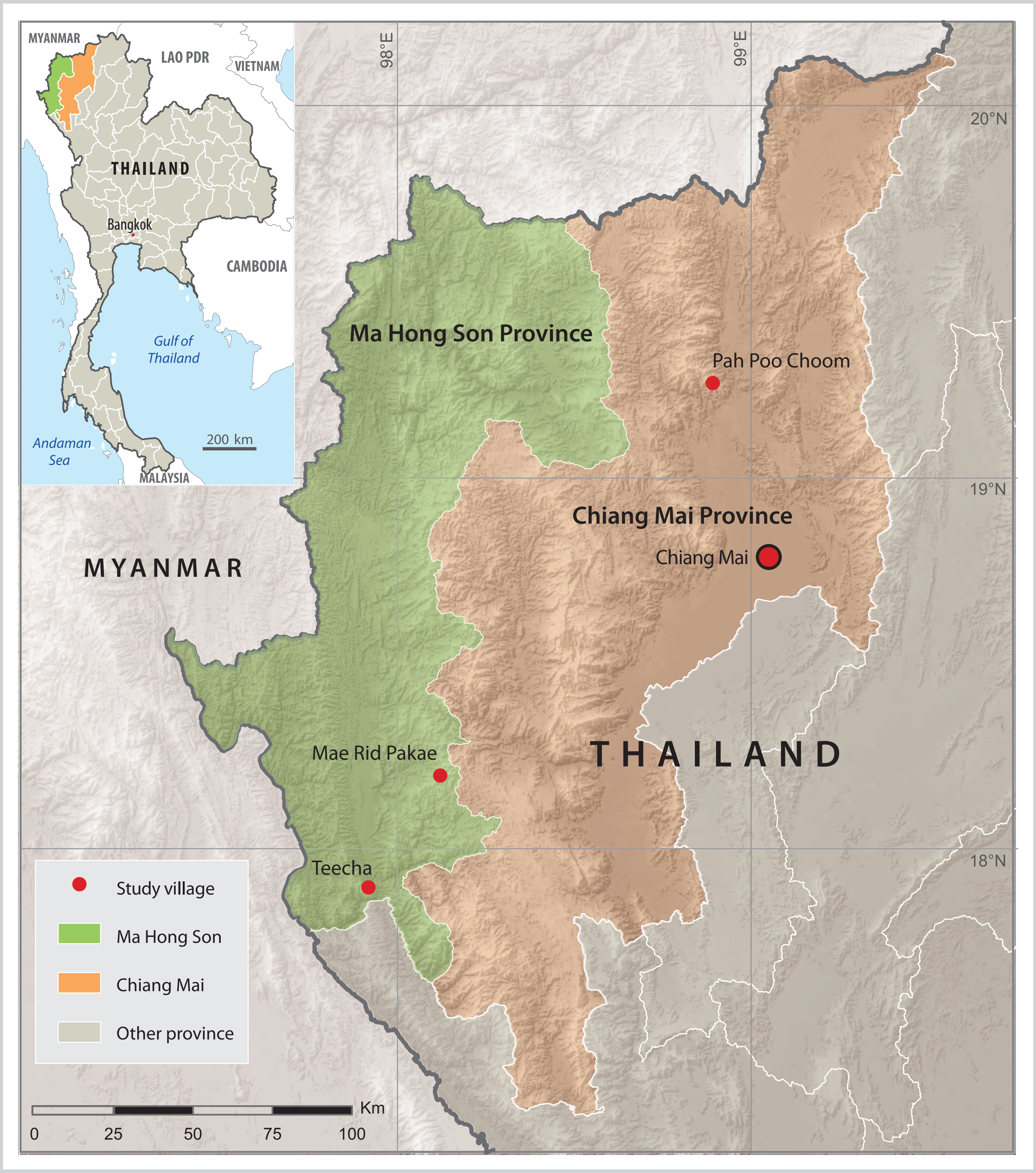

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TABLE 2 Land use systems.

Land use stage	Field type	Description
Forest	Headwater forest (*pa tonnam*)	Village common property,[a] usually occupies steep terrain and areas around village springs. Strictly conserved; conversion to agriculture not allowed; nondestructive harvest permitted, such as of deadwood, mushrooms, and medicinal plants. Prime function is considered to be providing security in water supply through the recharge of the springs. Also called conservation forest (*pa anurak*)
	Community forest (*pa choom chon*)	Village common property[a] communally managed for firewood, timber, grazing, and minor forest products. Parts may be more intensively managed, for example, for cultivation of medicinal plants or other special management practices, such as burning to encourage mushrooms or intensive harvests of products such as bamboo shoots and banana stems.
Cultivated land	Shifting cultivation	Private property, privately managed during the cropping phase, communally managed in fallow phase,[b] when natural vegetation is allowed to regenerate.
	Permanent cultivation	• Wetland rice: Privately owned and managed. Land on valley bottom and lower terraces is leveled and surrounded with low embankment to pond water for rice cultivation. • Fruit trees: Land planted to perennial fruit trees, converted from forest or shifting-cultivation land. • Vegetables: Intensive production of European and Chinese cabbages and other vegetables for cash, with gravitation-fed irrigation and heavy inputs of fertilizers and pesticides.

[a] The Land Law of Thailand does not permit legal ownership of land on hills and mountains (Ratanakhon 1978), and land in the country's mountain villages generally does not have title deeds, although occupation may date back more than 100 years.

[b] Shifting-cultivation land in the fallow phase, together with community forest, are sources of firewood, grazing, wild food, and minor forest products.

TABLE 3 Formulas for determining biomass in different types of forests.[a]

Trees in headwater and community forests		
Stem (W_S)	$= 0.0509 \times (D^2H)^{0.919}$	Equation 1
Branches (W_B)	$= 0.00893 \times (D^2H)^{0.977}$	Equation 2
Leaves (W_L)	$= 0.0140 \times (D^2H)^{0.669}$	Equation 3
Trees in community forests and fallow land under shifting cultivation		
Stem (W_S)	$= 0.0396 \times (D^2H)^{0.9326}$	Equation 4
Branches (W_B)	$= 0.003487 \times (D^2H)^{1.027}$	Equation 5
Leaves (W_L)	$= (28.0 \div [Ws + W_B] + 0.025)^{-1}$	Equation 6
Further calculations		
Aboveground tree biomass	$= W_S + W_B + W_L$	
Belowground tree biomass	$= 0.24\ (W_S + W_B + W_L)$	
Total tree biomass	$= 1.24\ (W_S + W_B + W_L)$	

[a] Sources: for trees in conservation and community forests, Tsutsumi et al 1983; for trees in community forests and fallow land, Ogawa et al 1965; for belowground tree biomass, Cairns et al 1997 and Jobbágy and Jackson 2000. D = diameter at breast height; H = height. Different equations are needed for different types of forest because trees in headwater forests tend to be older.

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TABLE 4 Population, land use, and yield of subsistence rice crops.[a)]

	Teecha		Mae Rid Pakae		Pah Poo Chom	
Demographic data						
Number of residents	172		242		397	
Number of households	48		52		70	
Land data						
Land per capita	6.3 ha		1.5 ha		1.3 ha	
Total land in village	1080.9 ha		369.8 ha		532.0 ha	
Share of forest		51.4%		44.7%		84.6%
Share of cultivated land		48.1%		54.6%		14.9%
Share of home sites		0.5%		0.7%		0.5%
Breakdown by land use stage and field type						
Forest	555.7 ha		165.4 ha		450.0 ha	
Share of headwater forest		15.2%		84.1%		44.8%
Share of community forest		84.8%		15.9%		55.2%
Cultivated land	519.7 ha		201.9 ha		79.1 ha	
Share under shifting cultivation		95.4%		57.5%		0.0%
Share under permanent cultivation		4.6%		42.5%		100.0%
Land under shifting cultivation	495.6 ha		116.1 ha		0.0 ha	
Cropped in a given year		14.3%		40.0%		0.0%
Fallow in a given year		85.7%		60.0%		0.0%
Land under permanent cultivation	24.1 ha		85.9 ha		79.1 ha	
Wetland rice		33.2%		22.6%		0.0%
Other		66.8%		77.4%		100.0%
Rice yield (t ha^{-1} ± standard error)						
Upland rice	3.24 ± 0.94		3.71 ± 0.36		ND [b)]	
Wetland rice	ND		4.15 ± 0.23		ND	

[a)]Community forest and fallow land were both sources of firewood, timber, grazing, wild food, and other forest products. Rice yields that were not determined made little or no contribution to total production.

[b)]ND, not determined.

had the lowest total carbon, 39% of Pah Poo Chom's total and 24% of Teecha's. When access to land was taken into account, the difference became less marked and village ranking shifted. The carbon density (amount of carbon per hectare) in Mae Rid Pakae was 56% of that in Pah Poo Chom and 70% of that in Teecha.

Forest accounted for the major part of total carbon stored in all 3 villages, with varying proportions between headwater forest, which is strictly conserved, and community forest, in which some harvesting is allowed. Total carbon in cultivated land was greatest in land under shifting cultivation, especially with long fallow periods as in Teecha. Permanently cultivated land in Teecha, mainly in multistory gardens (with trees, shrubs, and herbs of different height), contained twice as much carbon as land permanently cultivated with fruit trees and vegetables in Pah Poo Chom and 5 times as much as land with double

TABLE 5 Carbon storage.

	Teecha		Mae Rid Pakae		Pah Poo Chom	
Basic data						
Village total	154,161 t		39,034 t		99,578 t	
Per capita	951 t		161 t		251 t	
Per ha	151 t		106 t		187 t	
Stored in forest		63.5%		74.1%		94.7%
Stored in cultivated land		36.5%		25.9%		5.3%
Breakdown by land use stage and field type						
Forests	103,893 t		28,918 t		94,319 t	
Share of headwater forest		22.1%		90.8%		60.6%
Share of community forest		77.9%		9.2%		39.4%
Cultivated land	59,738 t		10,116 t		5,259 t	
Share under shifting cultivation		81.7%		77.5%		0.0%
Share under permanent cultivation		18.3%		22.5%		100.0%
Land under shifting cultivation	48,821 t		7,843 t			
Cropped in a given year		6.8%		33.6%		
Fallow in a given year		93.2%		66.4%		
Land under permanent cultivation	10,917 t		2,273 t		5,259 t	
Share of multistory gardens		96.4%				
Share of orchards						43.4%
Share of vegetable crops				76.4%		54.5%
Share of wetland rice		3.6%		23.6%		
Share of upland rice						2.1%

crops (wetland rice followed by vegetables) in Mae Rid Pakae.

Carbon density (t C ha^{-1}) allows comparison to be made of the effect of different land use stages and field types within and between villages (Figure 3). Headwater forest had the highest carbon density, followed by community forest, and there were only minor differences among the villages. The average carbon density in the headwater forest was 260 t C ha^{-1}, 62% in the biomass and the rest in the soil, while the community forest averaged 150 t C ha^{-1}, half in the biomass and half in the soil. Carbon density in cultivated land was much lower than in the forests and mostly in the soil. It ranged from about 50 t C ha^{-1} in permanently cultivated wetland and upland rice fields to almost 100 t C ha^{-1} under shifting cultivation with 6 years of fallow in Teecha and in the fruit tree orchard in Pah Poo Chom. Carbon density under shifting cultivation was significantly higher than under permanent cultivation but considerably lower than in community forest. Although soil carbon density was about the same in the 2 field types, biomass carbon in shifting cultivation was only a fraction of that in community forest. Because carbon accumulated during the fallow phase of shifting cultivation is lost during slash-and-burn land preparation, there was only 17% as much biomass carbon in shifting cultivation land as in community forest in Teecha and 10% in Mae Rid Pakae with its shorter fallow period.

In addition to the large pool of biomass carbon, carbon density in forests was boosted by their high soil organic matter content, which exceeded 5% in almost all cases (Figure 4). The community forest in Mae Rid Pakae was an exception, with only 3.55 ± 0.16%. Among different types of permanently cultivated land, the orchard in Pah Poo Chom had the highest soil organic matter content at 3.41 ± 0.07%; other permanent crop

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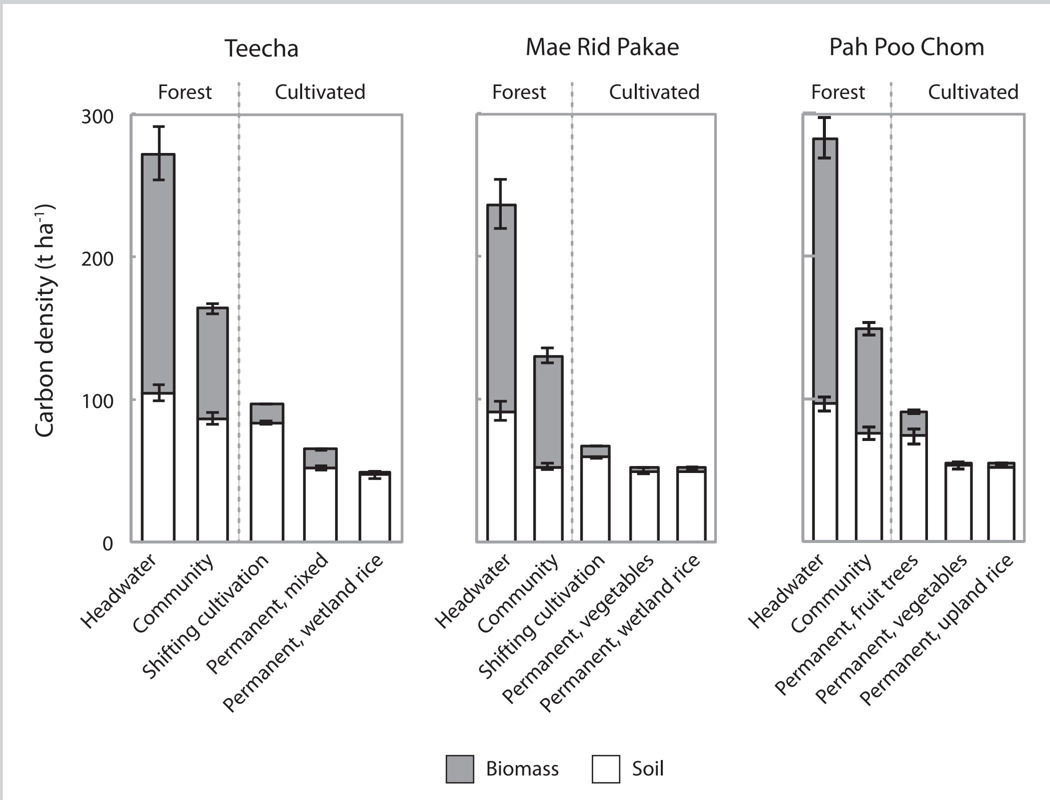
FIGURE 3 Carbon density.



fields all had similarly low soil organic matter content, at ≤3%, regardless of their composition and management. Soil organic matter under shifting cultivation in Teecha built up to 4.90 ± 0.26% under fallow and declined to 4.05 ± 0.05% under crop. The values were lower in Mae Rid Pakae, with its more intensive rotation: 3.92 ± 0.05% under fallow and 3.40 ± 0.20% under crop.

Discussion

As previously reported by others for the whole of Southeast Asia (Cramb et al 2009; Fox et al 2009), land use systems in these mountain villages were complex. The 3 study villages also reached their current cultivation and land management systems from very different paths (Rerkasem, Yimyam, et al 2002). Teecha was one of very few villages in Thailand with access to sufficient land to allow half to remain as forest and 85.7% of the balance to lie in fallow in a given year. In contrast, pressure on the land was clearly evident in Mae Rid Pakae's shortened fallow period. In Pah Poo Chom, mountainsides denuded under a failed system of opium production had become forested again since the 1990s, when the village took up irrigated fruit trees and vegetables as cash crops. In spite of their different histories, different current modes of production, and up to 5-fold difference in access to land per person, the villages shared a common characteristic in the prominent role played by forests in their land use and livelihoods.

The strict conservation of the headwater forest was based on a belief common in all 3 villages that a well-preserved headwater forest was key to security of their water supply by ensuring continued flow of the village springs. This is especially important in remote mountain villages that rely on their own water resources in a region with a dry season lasting more than half of the year—a common feature in montane mainland Southeast Asia. Security of the water supply is doubly important where water from the springs is used to irrigate cash crops, as in Mae Rid Pakae and Pah Poo Chom. Community forest and shifting cultivation land in fallow were managed to provide wild foods, minor forest products, timber, grazing, and firewood—which are important sources of food and income for the poor but are becoming increasingly inaccessible in the open forest due to public conservation policies (Rerkasem, Yimyam, Rerkasem 2009).

In common with other mountain villages in Thailand, the land in the study villages had no title deeds because legal ownership of land on hills and mountains is not allowed by the country's Land Law (Ratanakhon 1978). Nevertheless, land management in these villages also provided an ecological service in carbon storage in addition to the support to local livelihoods. The CO_2

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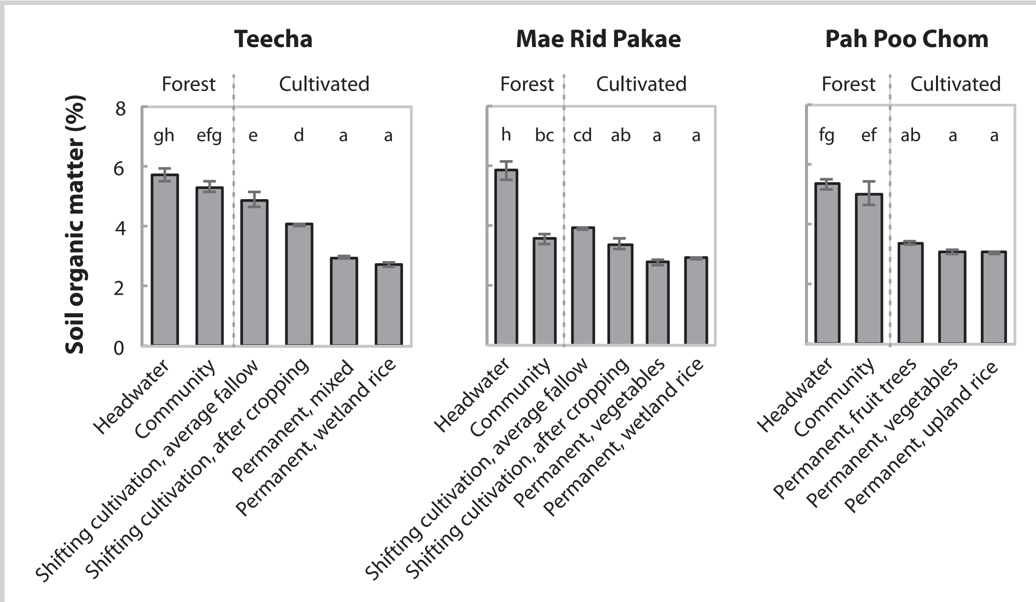
FIGURE 4 Soil organic matter. Significant differences between field types, based on Duncan's multiple range test ($P \leq 0.05$), are designated by different letters above the bars.



emissions in Thailand average 4.5 t per person (World Bank 2016). The carbon stored on the land per person was 131 times that in Mae Rid Pakae, 204 times in Pah Poo Chom, and 775 times in Teecha. Permanently cultivated land in the study villages had the lowest soil organic carbon content, which was in the same range reported for permanently cultivated land in tropical India (Venkanna et al 2014). It is well established that soil organic carbon is lost when forest land is converted for cultivation, by reduction of organic matter input as well as loss of protection from the elements that accelerate the rate of decomposition (Schlesinger 1986; Post and Mann 1990; Post and Kwon 2000). Most carbon was stored in forest biomass and soil. The high carbon density of forests and the amount of village land dedicated to them together contributed to total and per capita carbon storage in each village.

In conclusion, this study has established how land use in mountain villages can provide an ecological service in the storage of carbon, which can be up to several hundred times the CO_2 emissions per person of the general population of a country, based on the prominent roles played by forests in land management. These findings are relevant to the various efforts made to encourage land use and land management that enhance carbon extraction from, and slow down its release into, the atmosphere. With a means to rapidly and precisely estimate the amount of carbon stored in the different types of forests, villages in the mountains and others that already manage forests as an integral part in their land use and livelihoods could be offered incentives to maintain or even enhance the capacity to store carbon, with a special focus on forested land.

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