Shifting Cultivation System and Crop Symbiosis with Arbuscular Mycorrhizal Fungi

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ABSTRACT

Farmers of the Karen ethnic group who live in Huai Tee Cha village, Mae Hong Son province in northern Thailand, still practice the rotational shifting cultivation or swidden agriculture system for food and some cash crops. This study investigated the association of upland rice (Oryza sativa cv. Bue Bang), other food crops [Job's tears (Coix lachryma-jobi), corn (Zea mays), sesame (Sesamum indicum) and sorghum (Sorghum bicolor)] and pada (Macaranga denticulata) with AM fungi in farmers' fields. Soils in the farmers' fields were mildly acidic to neutral (pH 5.2 to 7.0) and showed diversity in P status (6.8-271 mg kg^{-1} soil, Bray II) but not in N (0.29-0.35% total N) or K (103-130 mg kg^{-1}). The roots of all plants investigated were colonized by AM fungi with upland rice and corn the most infected (≥ 90%), followed by Job's tears (75%), then sorghum (50%) and sesame (45%). Rhizosphere spore density ranged from 160 spores 100 g-1 soil for pada and sorghum, to 120 for sesame and half of this in Job's tears, corn and upland rice.

This study suggests that swidden crops in northern Thailand have a strong relationship with indigenous AM fungi.

Key words: Arbuscular mycorrhizal fungi, Shifting cultivation system, Swidden crops

INTRODUCTION

Karen is the largest of the minority groups living in the mountainous areas of northern Thailand. Karen farmers in Huai Tee Cha village, Sob Moei district, Mae Hong Son province, located at 19° 78' N, 93° 84' E, 700 MASL, manage fields ranging in altitude from 600 to 900 m with steep slopes (Rerkasem and Rerkasem, 1994). These people have lived in this neighborhood for more than 200 years. Crop production in this area is generally referred to as rotational shifting cultivation. It involves clearing land for crop production by slashing and burning the forest. After one year of cropping, the field is left in fallow for several years, and then cleared and cropped again when the rotation cycle is completed. The Karen farmers at Huai Tee Cha village grow over 50 crops including upland rice (the major staple crop), maize, sorghum, sesame, cowpea, Job's tears, vegetables, some cash crops (passion fruit, coffee, chili, etc.) and other traditional crops in their swidden fields. Most soils in this region are reddish clay loams (Yimyam et al., 2003) and the climate is tropical monsoon with wet, cool and hot seasons. The shifting cultivation cycle at Huai Tee Cha village has been reduced from 10-15 to 7 years. In spite of this, farmers appear to have been able to maintain rice yields by managing their short fallow with *Macaranga denticulata* (local name is pada), one of the pioneer tree species in the area (Rerkasem et al., 2002; Yimyam et al., 2003). The successful management of this local fallow species by farmers is evident by the higher grain yield and grain N content in upland rice grown after dense pada stands (Yimyam et al., 2003). Pot trials have shown that pada is highly dependent on arbuscular mycorrhizal (AM) fungi in Huai Tee Cha field soil (Youpensuk, 2004). However, it is unknown whether these AM fungi also directly benefit the food crops and other crops in the farmers' fields. This field study was undertaken to provide baseline data on AM fungi and crops in Huai Tee Cha fields.

MATERIALS AND METHODS

Soil properties, plant sampling and spore density

In the 2005 cropping year, at the end of the hot season, about 2 months after upland rice had been sown, when the crop was approximately 20 cm high, 34 soil samples (0-15 cm depth) were collected by randomly coring (4.5 cm diameter and 15 cm deep) 3 farmers' fields (Kayo, Takae and Murkur) for determining soil properties [pH (water, 1:1); Bray II phosphorus (Wanatabe and Olsen, 1962); Kjeldahl nitrogen (Jackson, 1967); and extractable potassium (1 M NH_4OAc, pH7)] and for spore density assessment. Fine root samples from the root zone of five common upland crops, grown after slashing and burning the forest [Job's tears (*Coix lachryma-jobi* L.), corn (*Zea mays* L.), sesame (*Sesamum indicum* L.), sorghum (*Sorghum bicolor* L.) and upland rice cv. Bue Bang (*Oryza sativa* L.)] and seedlings of one fallow-enriching tree, pada (*Macaranga denticulata* (Bl.) Muell. Arg) were obtained by digging part of the root systems (15 cm depth; 10 cm from the base) of three plants species^{-1} from each farmer's field. Roots and soils were transported to the laboratory for determining root colonization and examination of spore density. Youngest fully-expanded leaf (YFEL) samples of each crop were taken from the farmers' fields to the laboratory and were dried at 75°C for 48 hours and then analysed: N by the Kjeldahl method (Jackson, 1967); P by dry ashing followed by the molybdovanado phosphorus acid method (Murphy and Riley, 1962) and K by dry ashing and atomic absorption spectrophotometry.

Arbuscular mycorrhizal fungi assessment

a) Determination of arbuscular mycorrhizal colonization

The root system was separated from the soil, washed over a 106 µm mesh sieve, then subsampled. Roots in the subsample were cut into pieces 1-2 cm in length, cleared in 10% KOH at 121°C, rinsed with water on a sieve and stained with 0.05% trypan blue in lactoglycerol at 121°C (Brundrett et al., 1996). Thirty root pieces were taken at random from each sample, mounted on glass slides and AM colonization determined, using the gridline intersect method (McGonigle et al., 1990) under a compound Olympus microscope, model CX41RF.

b) Determination of arbuscular mycorrhizal spore density

Spores of AM fungi in 50 g soil were obtained by wet sieving through 710, 250, 106 and 53 µm mesh sieves. The 250, 106 and 53 µm fractions were centrifuged for 5 minutes at 2000 r min^{-1} to remove floating debris, the spores were resuspended in 50% sucrose with vigorous shaking and centrifuged for 1 minute at 2000 r min^{-1}. The spores were washed with water, transferred to filter paper with gridlines and counted under a stereomicroscope (Brundrett et al., 1996).

Effect of soil profile on spore density

Soil pits were dug at random locations at high, middle and low slope positions in Kayo fields. Soil samples were taken at 0-5, 5-10, 10-15, 15-20, 20-30, 30-40 and 40-50 cm depth and spores were obtained by wet sieving (see above).

Yield and crop use

Grain yield and crop use data were obtained from farmer interviews after they finished crop harvesting.

Data analysis

Data are presented as means and standard errors (S.E.), rice yield of each farmer was explored as standard deviation (S.D.).

RESULTS

Soil properties

Soil pH_{water} in the farmers' fields was mildly acidic to neutral, ranging from 5.2 to 7.0 and soils varied considerably in their Bray II P status, ranging from 6.8 to 271 mg kg^{-1} soil. There was a wide range in the soil P among farmers' fields: it ranged from 53.5-271.0, 6.8-65.3 and 12.4-27.8 mg kg^{-1} soil in the fields of Takae, Kayo and Murkur, respectively. By contrast, the levels of N and K laid within a narrow range, 0.29-0.35% for N and 103-130 mg kg^{-1} for K (Table 1).

Leaf nutrient concentrations

Leaf nitrogen (N) concentrations were 2.10 to 2.46 %, P concentrations were 0.18 to 0.33 % and K concentrations were 1.83 to 8.44 %. There was a narrow range in N concentration for all crops sampled whereas the P concentration was lower in upland rice and pada (0.18, 0.20%) than in corn or Job's tears (0.33, 0.30%), respectively. Sesame and sorghum had intermediate foliar P concentrations. By contrast, corn and upland rice had higher K concentrations (6.74 and 8.44 %, respectively) than the other crop species (pada, Job's tears, sesame and sorghum: 2.08, 1.83, 3.05 and 2.08 %, respectively) (Figure 1).

Spore number with soil depth

Abundance of AM spores varied with depth with most concentrated in the 0-20 cm part of the profile. The highest spore density was at 5-10 cm [225 spores 100 g^{-1} soil], followed by 0-5 and 15-20 cm [36 and 27 spores 100 g^{-1} soil, respectively]. Spore numbers declined in soil deeper than 20 cm. Spore density differed with position in the landscape. Higher spore numbers occurred at the upper slope with 758 spores 100 g^{-1} soil than at the middle and low slopes, 109 and 105 spores 100 g^{-1} soil, respectively (Table 2).

Root colonization and spore density

The roots of all plants sampled were infected with AM fungi. The extent of root colonization was highest in upland rice, corn and pada (90-95%), followed by Job's tears (75%), then sorghum (50%) and was lowest in sesame (45%). Rhizosphere spore density was about 160 spores 100 g^{-1} soil for pada and sorghum, 120 spores 100 g^{-1} soil for sesame and half of this in Job's tears, corn and upland rice (Table 3).

Crop yield and usage

The dominant crop in the field area was upland rice and other swidden crops were sown as intercrop with rice in the main fields. Rice and sorghum were harvested at grain maturity and used for food and ceremonies. Some corn was harvested for eating at the green ear stage and the remainder harvested dry for animal feed. Seeds of Job's tears were collected for ornamental decoration of clothes. Job's tears and sorghum were also used for cooking by mixing with rice and for animal feed (Table 4). However, in this cropping year, the farmers left the sorghum in the field for birds as they believe that birds will eat sorghum in preference to eating rice. All farmers keep swidden crop seeds for growing the next crop. Rice yields from the fields of Kayo, Murkur and Takae were 555, 360 and 200 kg rai^{-1} or 3.47, 2.25 and 1.25 ton ha^{-1}, respectively (Figure 2).

Table 1. Properties of the field soils at Huai Tee Cha village.

Soil property [a]	
Texture	Sandy loam
pH (water)	5.2 – 7.0 (6.2)
Bray II P (mg kg^{-1})	6.8 – 271 (81.9)
N (%)	0.29 – 0.35 (0.31)
K (mg kg^{-1})	103 – 130 (122)

[a] Values are the range with the mean in brackets

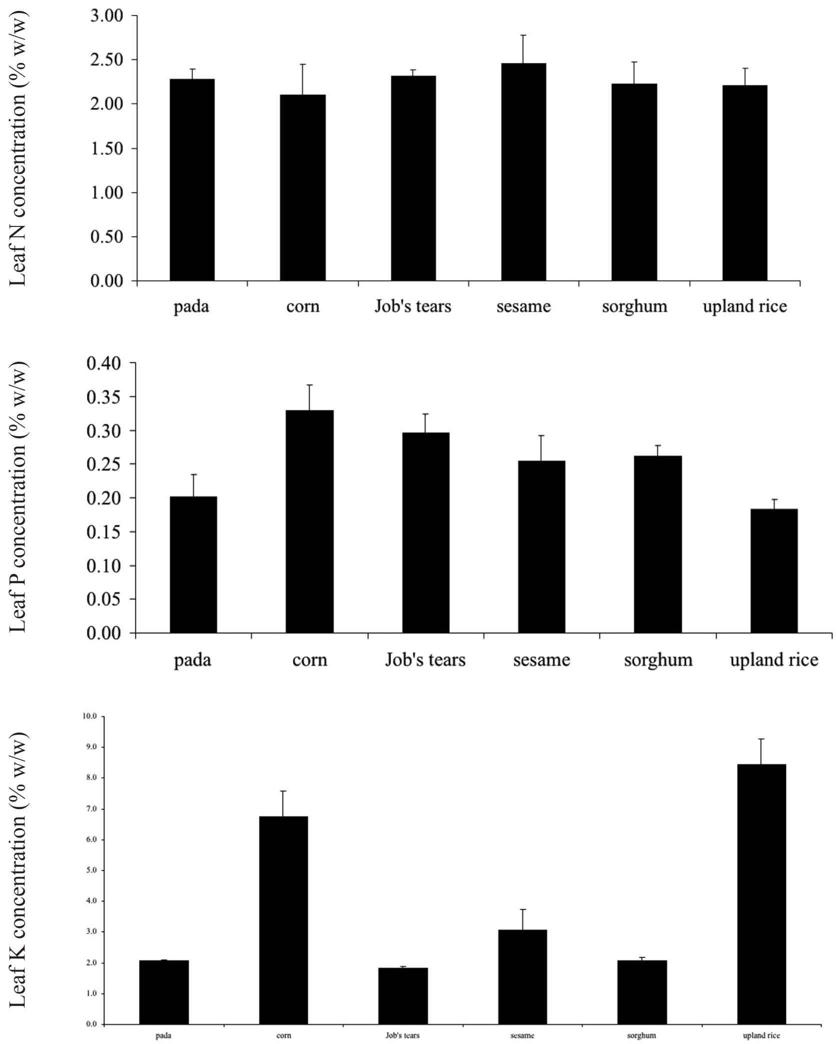

Figure 1. Foliar nutrient concentrations (N, P, K) in pada and swidden crops at Huai Tee Cha fields (vertical bar above each column represents one S.E.).

Table 2. Spore density of AM fungi in three soil profiles in Huai Tee Cha fields.

Soil depth (cm)	Spore numbers 100 g^{-1} soil				
	Upper slope	Mid slope	Lower slope	Average	S.E.
0-5	30	24	54	36	9.1
5-10	650	17	9	225	212.4
10-15	10	10	14	11	1.4
15-20	46	15	19	27	9.7
20-30	15	9	4	9	3.1
30-40	1	18	4	8	5.2
40-50	5	16	1	8	4.4
Total spore	758	109	105		
CV	221	32	121		

Table 3. Root colonization by AM fungi and spore density of pada and five swidden crops in farmers' fields at Huai Tee Cha village.

Plant species	Root colonization (%)	Spore numbers 100 g^{-1} soil
Pada	95 ± 2.1	163.9 ± 49.0
Corn	90 ± 2.8	64.4 ± 12.6
Job's tears	75 ± 10.2	82.8 ± 13.9
Sesame	46 ± 14.5	122.2± 40.3
Sorghum	50 ± 8.1	151.7 ± 60.8
Upland rice	95 ± 1.8	63.9 ± 11.5

values are mean ± S.E.

Table 4. The use of swidden crop seed in Huai Tee Cha village.

Common name or local name	Scientific name	Main use			
		F1	F2	Or	SC
Job's tears	*Coix lachryma-jobi* L.	*	*	*	
Glutinous corn	*Zea mays* L.	*	*		
Sorghum	*Sorghum bicolor* L.	*	*		
Rice	*Oryza sativa* L.	*			*
White/black seed sesame	*Sesame indicum* L.	*			*

Sources: household interview in 2005 (after crop harvests)
F1=Food, F2=Animal feed, Or=Ornamental, SC=Spirit ceremony

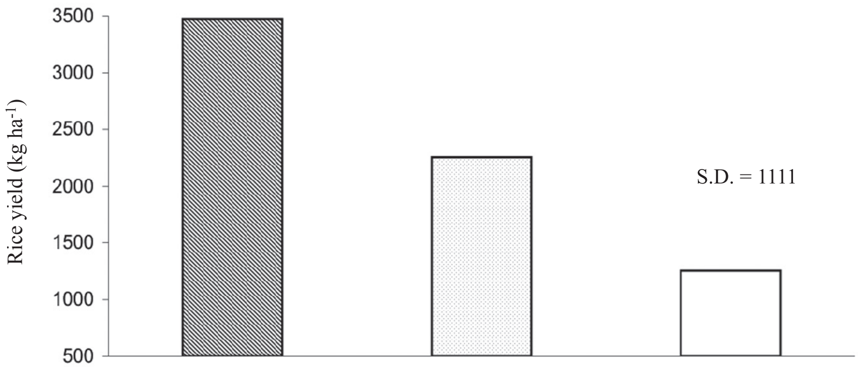

Figure 2. Rice yield (kg ha^{-1}) of Kayo, Murkur and Takae fields at Huai Tee Cha village in cropping year 2005.

DISCUSSION

Available soil P as measured in samples taken from Huai Tee Cha fields in 2005 were higher (average 81.9 mg kg^{-1} soil) and wide-ranging (6.8-271 mg kg^{-1} soil), compared to an earlier study of Yimyam et al., (2003) who reported 2-4 mg kg^{-1} soil. Yimyam sampled fields before burning and 30 days after sowing rice in 2000. The differences in soil P measured in the two studies may be due to location or crop rotation. Because the fields are used once and then returned to forest succession, different fields were sampled in these two studies. The fields sampled by Yimyam were also more acidic than those used in the present study. The rice fields of Takae were located near a valley floor that is the lowest point of the village's land use area, so the source of high P accumulation in these fields may have resulted from leaching by rain from fields higher up. Another factor likely to influence the soil P reserves is the distribution of pada trees in the fields before the cropping period. Yimyam (2006) found that the distribution of pada between shifting cultivation fields varied greatly, in 2000 was mostly dense whereas in 2003 was sparse, so the distribution of pada may have been dense in 1998, resulting in very high soil fertilities.

The percentage root colonization by AM fungi was lowest in sorghum (50%) and highest in pada and upland rice (95%). In a previous study at the same village,Youpensuk et al., (2004) reported that 81% of the fine roots of pada were colonised by AM fungi, and the spore density in pada rhizosphere was four times more than what is found in this study. These differences can be attributed to sampling time and variation between mountain slopes (the fields were different in the two studies).

Upland rice yields varied among farmers' fields, Kayo had the higher rice yield compared to Murkur and Takae. Rice yield of Takae was lowest although this soil had high P levels. The farmers in Huai Tee Cha village grow both glutinous and non-glutinous rice, and use 3-5 varieties each, depending on the conditions of the field and their preference. Rice yield of farmers was estimated for the total yield, and some of the difference between seed yield of each farmer may be due to differences in rice variety.

Another factor affecting yield may be weed control. The common practice for weed control is by hand, and is normally done three times during the entire cropping phase (Yimyam, 2006). Hence, farmers who are able to control weeds on time may achieve higher crop yield than farmers who have poorer weed control. Soil analysis revealed that the fields varied considerably in available phosphorus. It is not known whether the density of spores or the extent of root colonization by AM fungi varies with soil fertility within a field, and this is an area where further work is needed.

CONCLUSION

Although the addition of fertilizer P is probably a simple way for improving crop productivity on soils low in available P, most farmers in this area have severe poverty and have weak purchasing power to buy artificial fertilizers. Fortunately, the farmers in Huai Tee Cha village have tacit knowledge of using pada as a fallow-enriching tree species in their rotational shifting cultivation system as it helps benefit their crops. As this tree has high dependence on AM fungi and there is high diversity of AM fungi associated with its root system, it is possible that these fungi may also be contributing to nutrient uptake by the swidden crops, thus assisting farmers to increase their yields and decrease inorganic fertilizer inputs. This small field study has shown that swidden crops are also colonized by AM fungi. However, the dependence of swidden crops on AM fungi is yet to be determined.

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