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Stylosanthes guianensis as a short-term fallow crop for improving upland rice productivity in northern Laos

K. Saito [a,*], B. Linquist [b], B. Keobualapha [c], K. Phanthaboon [d], T. Shiraiwa [a], T. Horie [a]

[a] *Graduate School of Agriculture, Kyoto University, Kyoto 606-6502, Japan*
[b] *Department of Plant Sciences, University of California, Davis, CA 95616, USA*
[c] *Provincial Agriculture and Forestry Office, Luang Prabang, Lao Democratic People's Republic*
[d] *Northern Regional Agriculture and Forestry Research Center, Luang Prabang, Lao Democratic People's Republic*

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Abstract

In northern Laos, rapid population growth and government policies to reduce the area under slash-and-burn systems have resulted in increased cropping intensity, which has increased weed pressure and reduced yields of upland rice. Promising alternative cropping systems include the use of weed-suppressing and multi-purpose legumes as short-term fallow crops. In this study, *Stylosanthes guianensis* (stylo), a promising fodder species, was seeded into upland rice at different times to identify the appropriate time of seeding. The objective is to optimize the establishment and survival of stylo during the rice growing season, and achieve high stylo biomass accumulation during fallow period, while minimizing competition with the upland rice crop during stylo establishment period. Seeding times ranged from 0 day (seeded with rice) to 83 days after rice sowing (DARS) in two experiments. In experiment 1, stylo was grown as a one-year fallow crop while in experiment 2 stylo was grown as a dry season fallow crop. The effect of stylo fallows on the subsequent rice yield, weed biomass and soil nitrogen (N) and phosphate (P) availability was evaluated in comparison with a natural weedy fallow (control). In experiment 2, the effect of burning and mulching fallow residues prior to the rice crop was also evaluated.

Rice yields were reduced by an average of 55% when stylo was seeded at the same time as rice (0 DARS). When stylo was seeded later than 15 DARS, no competition effect on the accompanied rice growth was observed. Delaying stylo seeding substantially decreased total stylo and weed biomass at the end of fallow period. Following a stylo fallow, rice yields were up to 0.6 t/ha higher and weed biomass was up to 60% less compared to the natural fallow (control). Furthermore, soil available N content was higher following stylo fallows. In experiment 2, the rice yields were similar when fallow residues were burned or mulched but weed biomass tended to be lower when the residues were burned. In conclusion, either pruning stylo after seeding it at the time of rice sowing or seeding stylo 15 days after rice sowing minimizes competition with upland rice while optimizing establishment and biomass accumulation of stylo during fallow period. While relay-seeding stylo appears to improve rice productivity in the short-term, the long-term sustainability of the system needs further evaluation.

Keywords: Fallow; Laos; Mulch; Slash-and-burn; Soil nitrogen; *Stylosanthes guianensis*; Upland rice; Weeds

1. Introduction

Slash-and-burn agriculture systems remain the dominant land-use system in the hilly regions of northern Laos. Upland rice, as a subsistence crop, is grown in these systems. Recent government policies, that give high priority to reduce the area under slash-and-burn, combined with rapid population growth have resulted in increased cropping intensity, and consequently increased weed problems, declining soil fertility and lower rice yields (Asian Development Bank, 2001; Roder et al., 1995a, 1997). Unfortunately, there are few alternatives to slash-and-burn systems due to limited markets for cash crops (Roder, 2001).

* Corresponding author. Tel.: +81 75 753 6042.
E-mail address: kazuki@kais.kyoto-u.ac.jp (K. Saito).

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Considering the relatively low population density and hilly topography of northern Laos, intensifying livestock production is a promising alternative for the upland farmers (Horne, 1998; Roder, 2001). Livestock is the largest contributor to total cash income for upland farmers (Roder et al., 1996) and is central to the livelihood security of resource-poor farmers (Horne, 1998). While traditional feed resources for livestock are becoming scarce or degraded, there is potential for increased livestock production by replacing the fallow vegetation with fodder crops (Fahrney et al., 1998; Fujisaka, 1991; Horne, 1998). Improved fallow systems with fodder crops, especially legumes, could increase fodder availability, suppress weeds, accelerate nutrient cycling [especially nitrogen (N)] and provide cheap alternative inputs to upland fields (Fujisaka, 1991; Garrity, 1993; Roder and Maniphone, 1993). How residues of these improved fallows are managed during field preparation for the subsequent upland rice crop is an important consideration for maximizing fallow benefits. Residue management practices (such as mulching) that retain the organic matter and nutrients accumulated by the fallow vegetation may conserve soil and water, and reduce weeds (Gupta and O'Toole, 1986). Rice yields following legume fallows were increased, compared to those after natural fallow in West Africa (Akanvou et al., 2000, 2002; Becker and Johnson, 1998). Becker and Johnson (1999) showed that weed biomass was reduced following legume fallows. In contrast, previous studies in northern Laos have shown that legume fallows had no effect on the subsequent rice crop (Roder et al., 1998a,b; Roder and Maniphone, 1998). Furthermore, these studies reported that there was no positive effect of residue mulching on rice yield and weed suppression compared to burning residues. The reasons for this lack of response are unclear; it may be due to differences in fallow species and how these species were managed. Nevertheless, further research on improved fallow systems is required if these upland rice cropping systems are to be sustainable.

Stylosanthes guianensis (stylo) has been mentioned as one of the most promising legume species for slash-and-burn systems (Roder, 2001; Roder and Maniphone, 1995; Shelton and Humphreys, 1972; Thomas and Humphreys, 1970). However, studies on establishment of stylo into upland rice in Laos have been limited and reported mixed results (Roder and Maniphone, 1995; Shelton and Humphreys, 1972). The climate in northern Laos is characterized by a dry season from November to April. Therefore, successful establishment of stylo, that is to survive the dry season, necessitates seeding stylo into the rice crop during the preceding rainy season. Relay seeding of stylo into a standing crop of upland rice may result in severe interspecific competition. The extent of competition-induced rice yield loss and the amount of accumulated stylo biomass are likely to depend on when stylo is seeded into rice.

The objectives of this study are first, to identify the optimal seeding time of stylo that is relay-cropped into upland rice, so that rice yields are not reduced and stylo survival and establishment is adequate for high biomass accumulation during fallow period; second, to evaluate the effect of a stylo fallow (and how the fallow residues are managed) on upland rice productivity, weeds and soil N and phosphate (P) availability in the subsequent rice crop season.

2. Materials and methods

2.1. Description of experimental sites

Two field experiments were conducted in Luang Prabang Province. Experiment 1 (Expt. 1) was conducted at the Northern Agriculture and Forestry Research Center (NAFReC) in Xiengngun district, and was initiated in 2002. Experiment 2 (Expt. 2) was conducted in two farmers' fields (Hatkho and Pathung villages) in Pak Ou district and was initiated in 2003. General information for these sites is presented in Table 1. Luang Prabang province has the highest proportion of upland rice cultivation in Laos with about 70% of total rice area being grown with upland rice. Traditional upland rice cultivars are generally cultivated on sloping land without tillage and fertilizer inputs. Rice is sown in May or early June without tillage using a dibble stick and is harvested in September/October. Average annual rainfall in the experimental sites is about 1300 mm and is highly erratic, and about 80% of rainfall falls during the growing season (May–October). Rainfall at the experimental sites was adequate without any extended dry spells in 2002 and 2004 but in 2003 total rainfall in May and July was low.

2.2. Stylo as a one-year fallow (Expt. 1)

A traditional glutinous cultivar 'Vieng' of medium duration was monocultured (control) or relay cropped with *S. guianensis* (CIAT 184; Fig. 1). Stylo was seeded at 4 different days after rice sowing (DARS): 0 (D1), 27 (D2), 55 (D3) and 83 (D4). The experiment was laid out in a randomized complete block design with three replicates. Individual plot size was 3 m × 5 m. As far as possible, areas with termite mounds and tree stumps were excluded from the experiment. Nevertheless, soil conditions were highly heterogeneous, as is common in slash-and-burn fields (Roder et al., 1995b; Roder, 2001). A soil sample (0–15 cm) was taken at the time of rice sowing in 2002. Rice was sown on 24 May 2002 by placing about 10 rice seeds into 3–5 cm deep holes (spaced at 0.25 m × 0.25 m) made with a dibble stick following the traditional sowing method. Stylo seeds were dipped in boiling water prior to seeding to break dormancy. For D1, about 10 seeds of stylo were seeded with rice in the same hills. For the other treatments, stylo was broadcasted into the rice crop at the rate of 8 kg/ha. Weeds were controlled manually as necessary.

At rice maturity, the height of rice and stylo was measured from 8 plants per plot. Rice was harvested on 26 September from a 2 m^2 area for yield determination

Table 1
Description of experimental sites

	NAFReC[a] (Expt. 1)	Hatkho (Expt. 2)	Pathung (Expt. 2)
Previous fallow length (year)	2	3	3
Slope gradient (%)	25	39	45
Elevation (m)	350	320	320
pH (H_2O)	5.1	6.1	6.1
Total C (g/kg)	18	18	19
Total N (g/kg)	2.5	1.7	1.8
Available N (mg/kg)[b]	23	17	18
Bray-2 extractable P (mg/kg)[b]	10	8	11
Rice yield in the initial year (t/ha)[c]	1.7	0.8	1.7
Main weed species[d]	*Chromolaena odorata*	*Oxylum indicum*	*Chromoleana odorata*
	Bambusa tulda Roxb.	*Chromoleana odorata*	*Bauhinia varietata*
	Padederia cavalerieri	*Digitaria radicosa*	*Lygopodium flexuosum*
	Zygostlma benthami Baill.	*Lygopodium flexuosum*	*Mollugo pentaphylla*
	Imperara cylindrical	*Euphorbia hirta*	*Ziziphus oenoplia*

[a] Northern Agriculture and Forestry Research Center.
[b] Extractable P was analyzed by Bray No. 2 (Nanjo, 1997). Available N as NH_4–N was determined by the indophenol method (Hidaka, 1997) and as NO_3–N by Griess–Ilosvay method after reduction to NO_2 (Hidaka, 1997).
[c] Rice yield in the control treatment.
[d] Observation was conducted at slashing time in 2004 (Expt. 1) and on July 2004 (Expt. 2).

(reported at 14% moisture). Stylo density and cover were recorded in a 2 m^2 area within each plot after rice harvest.

From October 2002 to April 2004, fallow vegetation including stylo remained in the field until the subsequent rice cropping (Fig. 1). Before slashing in April 2004, stylo cover and total fallow biomass (includes stylo and weeds) were determined from the whole plot. All fallow vegetation was slashed and burned in April 2004. Rice was sown on 17 May 2004 following the same method as used in the first year. Weed biomass was measured at the time of weeding on 14 May (before rice sowing), 21 June, 22 July and 22 August from two randomly placed frames of 1 m^2. Rice was harvested on 24 September 2004 from a 8 m^2 area in each plot. Soil samples (0–5 cm) were collected from the control, D1 and D2 treatments five times: before burning, after burning, at rice sowing (0 DARS), 60 DARS and rice harvest. A soil sample consisted of 8–10 cores per plot.

2.3. Stylo as a dry season fallow (Expt. 2)

Stylo seeding dates, seeding methods and seeding rate were modified based on experiences of Expt. 1 in which we found: (1) during the first four weeks, stylo cover and biomass were extremely sensitive to the time of stylo seeding; (2) stylo establishment was poor when seeded in the same hills with rice or broadcasted using a low seeding rate; (3) broadcasting stylo made it difficult to weed. For these reasons, D1–D4 were set at 0, 15, 30 and 45 DARS, respectively. Stylo seeding methods were changed to row seeding and the seeding rate was increased to 15 kg/ha. Two

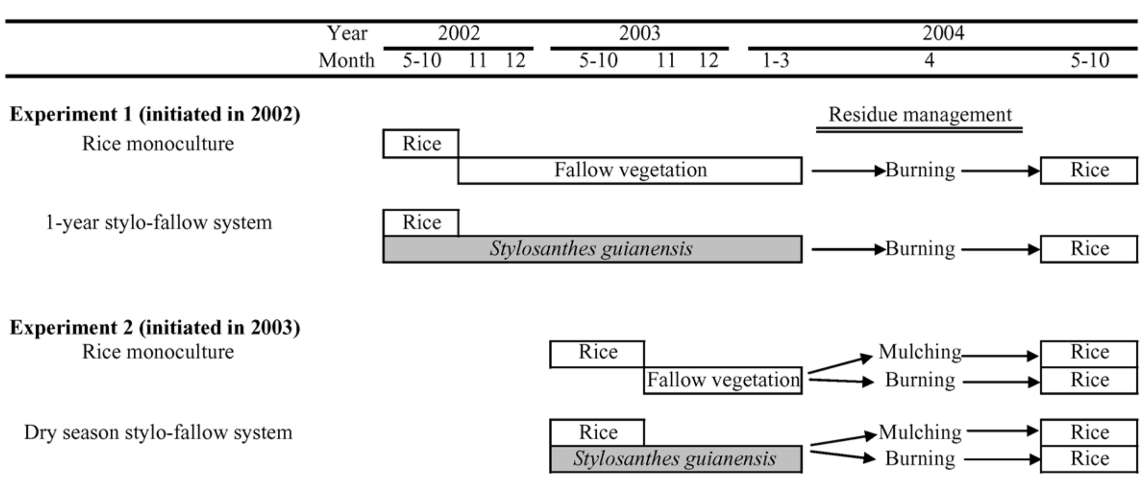

Fig. 1. Experiment cropping calendars.

additional treatments were added to the previous treatments, resulting in a total of seven treatments. They were a rice monoculture with 30 kg N/ha soluble urea fertilizer applied at 60 DARS (NF), and stylo seeded at the time of rice sowing but with the stylo being pruned (to mimic a forage cut and carry operation) to reduce its pressure on rice (D1P).

The experiment was laid out in a randomized complete block design with four replicates in each site. The individual plot size was 4.5 m × 6 m. A soil sample was taken to a depth of 0–15 cm at the time of rice sowing in 2003. A traditional glutinous cultivar 'Mak hin sung' of medium duration was dibble-sown in hills at a spacing of 0.30 m × 0.25 m on 23 May in both sites using the same sowing method as Expt. 1. Stylo was seeded in rows between the rice rows at 0.9 m intervals and separated from rice hills by 0.15 m. Hand weeding was done as necessary. In D1P, stylo was pruned at 20 cm above ground level on 30 July, 18 August and 7 September 2003. The cuttings for the whole plot were dried then weighed. All stylo cuttings were removed from the plot to simulate a forage cut and carry operation. At rice maturity, the height of rice and stylo was measured from 10 plants per plot. Rice was harvested for yield determination on 4 and 7 October 2003 in Hatkho and Pathung, respectively, from a 13.5 m^2 area in each plot. Stylo density and cover were recorded in a 2.7 m^2 area after rice harvest.

During the dry season fallow period, cattle invaded and grazed the Pathung field one time; however, stylo was able to regenerate. Before slashing fallow vegetation in 2004 (Fig. 1), each plot was split into two (individual sub-plot size was 4.5 m × 3 m) and the residues were either burned or left as a mulch. In the burning management all residues were slashed on the 7–8 April and burned on 22 April 2004 and in the mulching treatment all residues were cut and mulched on 1–2 May (Fig. 1). At slashing time, stylo biomass was measured based on 5.4 m^2, and weed biomass measured from two randomly placed frames of 0.9 m^2. In D4, stylo establishment was poor in 2003 so the treatment was changed to one that received N and P fertilizer to rice (NPF). In NF and NPF, N fertilizer (60 kg N/ha soluble urea) was applied in equal splits at 30 and 60 DARS in furrows 1–2 cm apart from rice hills and then was covered with soil to avoid fertilizer movement. P fertilizer (30 kg P/ha triple super phosphate) was placed in 3–5 cm deep holes made with a dibble stick at rice sowing but applied separately from rice. The rice was dibble-sown using the same method as the previous year on 9 May. Weed biomass was measured at the time of weeding on 27 May, 28 June and 5 August from two randomly placed frames of 0.9 m^2. Rice was harvested for yield determination on 6 October 2004 from a 5.4 m^2 area.

2.4. Laboratory analysis

Soil samples were air-dried and sieved for soil analysis. Available N content as NH_4–N was determined by the indophenol method (Hidaka, 1997) and as NO_3–N by Griess–Ilosvay method after reduction to NO_2 (Hidaka, 1997). Extractable P content was analyzed using the Bray-2 method (Nanjo, 1997). Additionally, soil pH was determined in a 1:1 soil/water mixture and total C and N contents determined with a tracer mass spectrometer (Tracer MAT, Thermo Quest Co. Ltd., Tokyo) for the 2002 soil (Expt. 1) and the 2003 soil (Expt. 2) only.

2.5. Statistical analysis

Analyses of variance (ANOVA) were conducted in each experiment. For Expt. 2, ANOVA was conducted on the combined data for both sites to determine the effect of site, treatment and residue management on each measured stylo growth parameter, rice yield, weed biomass and soil fertility properties. Simple regression analysis was conducted to identify relationship between total fallow biomass (includes stylo and weeds) at the time of slashing and upland rice yields or weed biomass.

3. Results

3.1. Experiment 1: one-year stylo fallow

There was high variation in 2002 rice yields (Table 2), possibly resulting from soil variability. Rice yields were lowest in D1 (1.2 t/ha) where stylo was seeded at the same time as rice. When D1 rice yields are compared to the rice

Table 2
Effect of seeding date of stylo relay cropped with rice on rice yield, stylo density, height and cover at 2002 rice harvest in Expt. 1

Treatment	Stylo			Rice yield (t/ha)
	Density (plants/m^2)	Height (cm)	Cover (%)	
Rice monoculture (control)	–	–	–	1.7
Stylo 0 DARS[a] (D1)	12	121	66	1.2
Stylo 27 DARS (D2)	7	60	4	2.5
Stylo 55 DARS (D3)	4	29	1	2.1
Stylo 83 DARS (D4)	7	19	1	1.7
PR > F	0.36	<0.01	<0.01	0.12
L.S.D. (0.05)	ns	21.1	16.8	ns

[a] Days after rice sowing.

yields in all the other treatments (2.0 t/ha averaged over control, D2–D4), D1 rice yields are significantly lower.

Where stylo was seeded into rice, stylo density at the time of the 2002 rice harvest ranged from 4 to 12 plants/m^2 and was highest in D1, although differences were not significant (Table 2). However, when stylo seeding was delayed, there was a decrease in the stylo cover (from 66 to 4% or less) and stylo height (from 121 to less than 60 cm) at the time of rice harvest.

Following a one-year fallow, at slashing time in 2004, total fallow biomass (combined stylo and weeds) and stylo cover in D1 were the highest of all treatments (Table 3). When stylo was introduced at 27 DARS or later, total fallow biomass and stylo cover were approximately half of D1. In the control plots, where stylo was not seeded in 2002, there were some stylo plants at slashing time and during rice growing season in 2004, due to invasion of seeds from adjacent plots (Table 3).

Rice yields in 2004 were low, ranging from 0.4 to 1.1 t/ha (Table 3); however, the cause for the low rice yields is not known but may be related to the short fallow between rice crops or brown spot and root aphids which occurred in all plots (Gupta and O'Toole, 1986; Listinger et al., 1986; Van Keer, 2003). Rice yields in D1 and D2 were 1 t/ha or more and were significantly higher than those in the other treatments (Table 3), and the yields were correlated to total fallow biomass (weeds plus stylo) at slashing time (Fig. 2a). Weed biomass from the first weeding and total weed biomass from all weedings were lower in the treatments after a stylo fallow, although differences were not significant (Table 3). However, weed biomass from the first weeding and total weed biomass from all weedings were significantly correlated to total fallow biomass at slashing time (Fig. 2b and c).

Soil available N content in D1, where biomass accumulation during fallow period was highest, was about twice that of the control and D2 before burning and remained higher than these treatments through the rice growing season (Fig. 3). At the time of rice sowing, the treatments following a stylo fallow (D1 and D2) had higher available N content. Following this spike in available N, there was a continual decline through the rest of the season, which is consistent with the previous studies (Roder et al., 1995a). There was no difference in extractable P content among the treatments (data not shown).

3.2. Experiment 2: dry season stylo fallow

The 2003 rice yield in the control treatment in Hatkho (0.8 t/ha) was significantly lower than in Pathung (1.7 t/ha) (Table 1). The reason for this difference between sites (which was also observed in 2004) was not clear as soil nutrient status and cropping history were similar (Table 1) and these sites were within 1 km of each other and at the same elevation so climate was similar. The effects of stylo and fertilizer treatments on rice yields in 2003 were similar at both sites and there was no treatment × site interaction on rice yields; therefore, rice yields were averaged across the two sites (Table 4).

Stylo seeded at the time of rice sowing without pruning (D1) reduced rice yields by 64% relative to the control (Table 4). In the other stylo treatments, including when stylo was seeded at rice sowing but later pruned (D1P), there was no significant difference in rice yields compared to the control treatment. An application of N fertilizer had little effect on rice yields.

Delaying stylo seeding substantially decreased stylo density, height and percent stylo cover at the time of rice harvest in both sites, although there was a significant treatment × site interaction on stylo density and height (Table 4). Good establishment of stylo (as determined by stylo density and cover at rice harvest) was observed for D1, D1P and D2 in both sites, but stylo establishment was poor in D4. Where stylo was seeded with rice and later pruned (D1P), stylo biomass for the first, second and third prunings was 0.07, 0.18 and 0.36 t/ha averaged for two sites, respectively.

Following a dry season fallow, at the time of slashing in 2004, total fallow biomass (stylo plus weeds) was the highest in both sites, followed by D1P and D2 (Table 5). Delaying stylo seeding decreased the total fallow biomass at both sites. The lower fallow biomass in Pathung, especially in D1 and D1P, was probably caused by cattle grazing during fallow period. Total fallow biomass where the residues were burned was less than where they were mulched because the biomass in residue burning management treatment was measured 23 days earlier.

The 2004 rice yield in the control in Hatkho was lower than that in Pathung (Table 5), similar to 2003. Residue

Table 3
Total fallow biomass (combined stylo and weeds) and percent stylo cover at the slashing time, rice yield, weed biomass at first weeding, total weed biomass during the rice growing season and total stylo biomass (sum of all of weedings; stylo was weeded out in each weeding) for Expt. 1 in 2004

Treatment	Total fallow biomass (t/ha)	Stylo cover (%)	Rice yield (t/ha)	Weed biomass at first weeding (t/ha)	Total season weed biomass (t/ha)	Total season stylo biomass (t/ha)
Rice monoculture (control)	6.6	4	0.4	1.2	3.0	<0.1
Stylo 0 DARS[a] (D1)	19.9	93	1.0	0.2	1.2	0.3
Stylo 27 DARS (D2)	9.5	40	1.1	0.5	1.7	0.1
Stylo 55 DARS (D3)	7.9	47	0.6	0.4	2.0	0.1
Stylo 83 DARS (D4)	7.3	40	0.4	0.8	2.3	<0.1
PR > F	<0.01	<0.01	<0.01	0.12	0.21	<0.01
L.S.D. (0.05)	4.56	38.7	0.34	ns	ns	0.09

[a] Days after rice sowing.

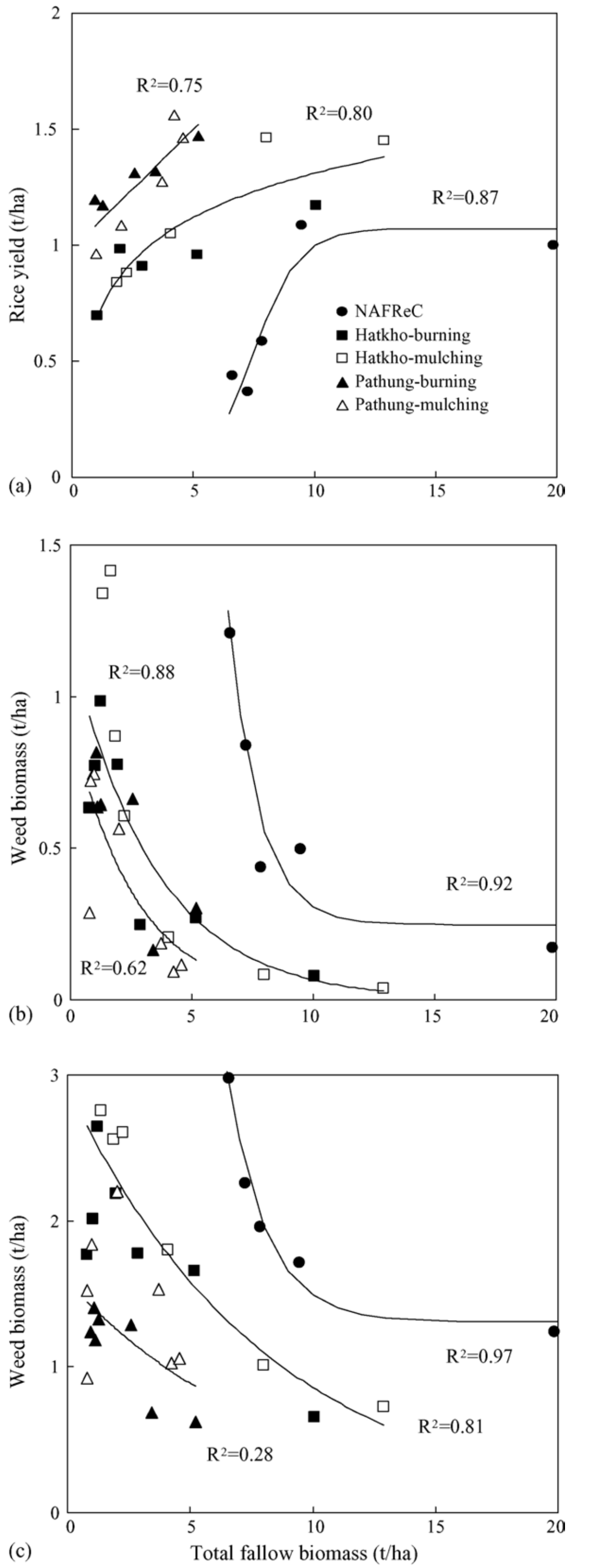

Fig. 2. The effect of total fallow biomass (stylo plus weeds) at the time of slashing on: (a) rice yield; (b) weed biomass at first weeding; (c) total weed biomass during rice growing season. The burning and mulching residue management treatments for Hatkho and Pathung were combined for the regression lines in (a–c).

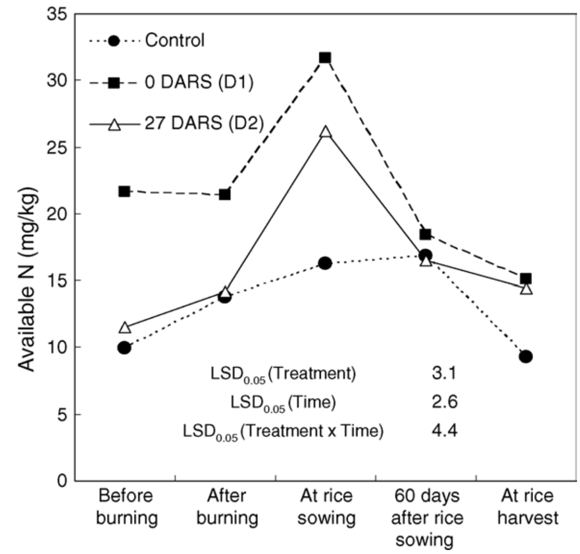

Fig. 3. Available N content of soils collected before and during the 2004 rice growing season following a one-year fallow (Expt. 1). The different treatments are a one-year natural fallow (control), and stylo seeded with rice (0 DARS; D1) and 27 days after rice planting (27 DARS; D2) in the previous rice crop in 2002. Available N as NH_4–N was determined by the indophenol method (Hidaka, 1997) and as NO_3–N by Griess–Ilosvay method after reduction to NO_2 (Hidaka, 1997).

management treatments (burning or mulching) did not have a significant effect on rice yields and there was not a significant treatment × residue management interaction on rice yields at either site; therefore, average rice yield over the two residue management treatments is used in the following discussion. The effect of stylo fallow on rice yields followed a similar pattern at both sites (Table 5). In Pathung, the treatment differences were significant but not at Hatkho ($P = 0.15$). However, when Hatkho rice yields in the control were compared to the rice yields in D1 and D1P, there was significant difference in the yields ($P < 0.05$). Rice yields were higher than the control following a stylo fallow when stylo was seeded early into rice and accumulated more biomass during fallow period (D1, D1P and D2). Rice yields were correlated with total fallow biomass at both sites (Fig. 2a—NF and NPF treatments not shown).

When Hatkho rice yields in the control and NF are compared to the rice yields in NPF, there was significant difference in yield ($P < 0.05$), suggesting that P might be limiting in Hatkho as yields did not respond to N alone but there was a 0.4 t/ha increase in yields when both N and P were applied. In Pathung, N increased rice yields by 76% and applying P did not increase rice yields once N was already applied, indicating that P was not limiting in this field.

There was significant treatment effect on weed biomass from the first weeding and total weed biomass from all weedings at both sites (Tables 6 and 7). The average weed biomass over both residue management treatments in D1, D1P and D2 was lower than the control and fertilizer treatments at both sites. While there was a significant

Table 4
Effect of seeding date of stylo relay cropped with rice on rice yield, density, height and cover of stylo at the time of 2003 rice harvest in Expt. 2

	Stylo					Rice yield (t/ha) (average over two sites)
	Density(plants/m^2)		Height (cm)		Cover (%) (average over two sites)	
	Hatkho	Pathung	Hatkho	Pathung		
Treatment						
Rice monoculture (control)	–	–	–	–	–	1.2
Rice monoculture with N (NF)	–	–	–	–	–	1.3
Stylo 0 DARS[a] (D1)	115	47	109	130	77	0.4
Stylo 0 DARS with pruning (D1P)	130	54	74	76	46	0.9
Stylo 15 DARS (D2)	29	44	79	102	41	1.1
Stylo 30 DARS (D3)	6	13	59	69	10	1.1
Stylo 45 DARS (D4)	0	1	0	42	1	1.0
ANOVA summary						
Treatment	<0.01		<0.01		<0.01	<0.01
Site	<0.01		<0.01		0.61	<0.01
Treatment × site	<0.01		<0.01		0.29	0.81
L.S.D. (0.05, treatment main effect)	13.8		9.7		8.8	0.40
L.S.D. (0.05, treatment × site interaction effect)	19.5		13.8		ns	ns

[a] Days after rice sowing.

treatment × residue management interaction for total weed biomass from all weedings in Hatkho (Table 6), average total weed biomass over seven treatments when the residues were burned tended to be lower than when they were mulched at both sites.

Weed biomass from the first weeding and total weed biomass from all weedings at each site were affected by the total fallow biomass (Fig. 2b and c). As the total fallow biomass increased, weed biomass from the first weeding and total weed biomass from all weedings decreased in both residue management treatments at both sites. Stylo was present in all plots due to seed germination (and migration of seeds into rice monoculture plots) and regrowth from cut stylo where stylo residues were mulched. Stylo was weeded out during the rice growing season and at both sites total stylo biomass was higher when fallow residues were burned (Tables 6 and 7).

4. Discussion

The best approach to replace the natural fallow vegetation with nitrogen-fixing legumes is to establish the species during the rice growing season and then allow the species to

Table 5
Total fallow biomass (includes stylo and weeds) and rice yields in Expt. 2 (dry season fallow) 2004

	Total fallow biomass (t/ha)		Rice yield (t/ha)	
	Hatkho	Pathung	Hatkho	Pathung
Treatment (T)				
Rice monoculture (control)	1.5	1.0	0.8	1.1
Rice monoculture with N (NF)	1.3	1.0	0.9	1.9
Rice monoculture with N and P (NPF)	1.2	0.9	1.3	2.0
Stylo 0 DARS[a] (D1)	11.5	4.7	1.4	1.5
Stylo 0 DARS with pruning (D1P)	6.6	3.1	1.2	1.3
Stylo 15 DARS (D2)	3.5	4.0	1.0	1.4
Stylo 30 DARS (D3)	2.1	1.6	0.9	1.1
Residue management (R)				
Burning	3.3	2.2	1.0	1.4
Mulching	4.6	2.5	1.1	1.5
ANOVA summary				
T	<0.01	<0.01	0.15	0.02
R	<0.01	0.26	0.49	0.56
T × R	0.07	0.06	0.63	0.55
L.S.D. (0.05, treatment main effect)	1.09	0.76	ns	0.54

[a] Days after rice sowing.

Table 6
Weed biomass at first weeding, and total season weed biomass (sum of all weedings) and total season stylo biomass (sum of all of weedings; stylo was weeded out in each weeding) in Hatkho in Expt. 2, 2004

	Weed biomass at first weeding (t/ha)		Total season weed biomass (t/ha)		Total season stylo biomass (t/ha)	
	Burning	Mulching	Burning	Mulching	Burning	Mulching
Treatment (T)						
Rice monoculture (control)	0.8	0.9	2.0	2.6	<0.1	<0.1
Rice monoculture with N (NF)	1.0	1.3	2.6	2.8	<0.1	<0.1
Rice monoculture with N and P (NPF)	0.6	1.4	1.8	4.0	<0.1	<0.1
Stylo 0 DARS[a] (D1)	0.1	<0.1	0.7	0.7	0.3	<0.1
Stylo 0 DARS with pruning (D1P)	0.3	0.1	1.7	1.0	0.4	<0.1
Stylo 15 DARS (D2)	0.2	0.2	1.8	1.8	0.2	<0.1
Stylo 30 DARS (D3)	0.8	0.6	2.2	2.6	0.1	0.1
Mean	0.5	0.7	1.8	2.2	0.1	<0.1
ANOVA summary						
T	<0.01		<0.01		<0.01	
Residue management (R)	0.24		0.02		<0.01	
T × R	0.12		0.01		0.02	
L.S.D. (0.05, treatment main effect)	0.46		0.74		0.11	
L.S.D. (0.05, residue management main effect)	ns		0.34		0.06	
L.S.D. (0.05, T × R interaction)	ns		0.89		0.16	

[a] Days after rice sowing.

grow during the subsequent fallow period. When the fallow species are planted into rice is crucial so as not to reduce yields of upland rice, the staple crop, and yet allow for good establishment of the fallow species. Planting times of fallow species, relative to when rice is sown, will depend on the competitiveness and growth rate of the introduced fallow species. In this study, stylo was chosen as it has potential to also be used as a forage crop.

To successfully establish stylo into an upland rice crop, stylo needs to be seeded around 15 DARS or seeded with rice and pruned. Seeding stylo and rice at the same time without pruning stylo resulted in a 55% reduction in rice yields (averaged across sites and years). Seeding stylo after 15 DARS had no effect on rice yields but resulted in poor stylo establishment and low biomass accumulation during the fallow period. Shelton and Humphreys (1972, 1975) also found that broadcasting stylo at 10, 31 or 60 DARS had no effect on rice yields in central Laos and northeast Thailand. However, Akanvou et al. (2002; *Stylosanthes hamata*) in West Africa reported that rice yields were reduced when stylo was seeded between 0 and 28 DARS. The reason for this may be due to the higher stylo density in their study (160 plants/m^2 compared to less than 130 plants/m^2 in this study), the stylo species (they used *S. hamata*,

Table 7
Weed biomass at first weeding, total season weed biomass (sum of all weedings) and total season stylo biomass in Pathung in Expt. 2, 2004

	Weed biomass at first weeding (t/ha)	Total season weed biomass (t/ha)	Total season stylo biomass (t/ha)
Treatment (T)			
Rice monoculture (control)	0.7	1.5	0.2
Rice monoculture with N (NF)	0.5	1.1	<0.1
Rice monoculture with N and P (NPF)	0.8	1.5	<0.1
Stylo 0 DARS[a] (D1)	0.2	0.8	0.4
Stylo 0 DARS with pruning (D1P)	0.4	1.4	0.3
Stylo 15 DARS (D2)	0.1	0.9	0.4
Stylo 30 DARS (D2)	0.6	1.8	0.4
Residue management (R)			
Burning	0.6	1.1	0.4
Mulching	0.4	1.4	0.1
ANOVA summary			
T	<0.01	0.01	0.02
R	0.04	0.02	<0.01
T × R	0.69	0.42	0.23
L.S.D. (0.05, treatment main effect)	0.30	0.52	0.30
L.S.D. (0.05, residue management main effect)	0.17	0.27	0.17

[a] Days after rice sowing.

while this study used *S. guianensis*) or upland rice cultivars used.

Roder and Maniphone (1995) suggested that planting a mixture of legume and rice seed was probably the best approach for the establishment of slow-growing shrubby or tree species, and Roder and Maniphone (1998) demonstrated good establishment of some selected shrubby species by this method. Establishment using this method is also appealing to farmers as little additional labor is required to plant and it is easy to weed around the rice hills. However, our results suggest that stylo is too competitive when seeded in this way and rice yields are reduced (Table 2). When stylo is seeded in rows at the same time as rice sowing and the stylo is pruned occasionally to reduce its competitiveness, stylo establishment is good and rice yields are not reduced (Table 4).

Planting stylo by broadcasting after rice sowing has been shown to result in good establishment (Roder and Maniphone, 1995; Shelton and Humphreys, 1972). However, in this study, establishment by this method was poor (Table 2). Furthermore, broadcasting made weeding difficult. Since weeding already requires over 150 person days/(ha year) (half of the total labor demand) (Roder et al., 1997) it is unlikely that farmers would adopt this method of establishment.

When stylo seeding was delayed, its height and cover at the time of rice harvest, and biomass accumulation during fallow period, were significantly reduced compared to when stylo was seeded with rice, similar to reports of others (Shelton and Humphreys, 1972; Roder and Maniphone, 1995; Akanvou et al., 2002). However, seeding stylo with rice and pruning or seeding stylo at 15 DARS resulted in increased fallow biomass relative to the control where no stylo was seeded.

Yields of the subsequent rice crop were significantly and positively correlated with total biomass accumulation during fallow period (Fig. 2a). Furthermore, rice yields were similar whether the fallow residues were burned or mulched, similar to reports of others (Becker and Johnson, 1999; Roder and Maniphone, 1998; Roder et al., 1998b). Rice yields after stylo fallows were up to 0.6 t/ha higher than the control (Tables 3 and 5), supporting reports of others (Becker and Johnson, 1998; Akanvou et al., 2000). Becker and Johnson (1998) reported that rice yields after legume fallows, including stylo, were on average 0.2 t/ha greater than those after natural weedy fallow. Benefits from legume fallows are at least in part due to increased N input to the system (Fig. 3). Both Becker and Johnson (1998) and Akanvou et al. (2000) reported that rice yield increases were related to amounts of fallow N input. Previous studies in northern Laos have reported that increasing N availability increases upland rice yields (Roder et al., 1995a; Saito et al., 2006). In this study, a stylo fallow was shown to increase soil N and where soil N was high rice yields were also higher (Table 3; Fig. 3). However, in Expt. 2, there is distinct difference in response of rice yield to N and P fertilizer applications between the two sites (yields did not respond to N alone in Hatkho and applying P did not increase rice yields in Pathung) and rice yields after stylo fallows tended to be higher than when N was applied alone (NF) in Hatkho (Table 5). Thus, in Hatkho, yields following a stylo fallow were similar to when both N and P fertilizer were applied, suggesting that stylo may have enhanced P availability as well.

Lower weed pressure following a stylo fallow may also have contributed to higher rice yields. Weed biomass in upland rice crop was significantly lower following stylo fallows and was correlated to total fallow biomass (Tables 3, 6 and 7; Fig. 2b and c). Similarly, Roder et al. (1998a) found that weed biomass after a stylo fallow was 33% lower than that after a natural fallow in northern Laos. Akanvou et al. (2000) also reported similar results when fallow residues were burned or mulched. In this study, it appeared that high stylo cover and biomass was able to suppress the establishment of weeds during the fallow. However, Roder and Maniphone (1995) argued that the heavy seed production of stylo might become a serious problem. Although stylo plants were observed in the field in the subsequent rice growing season, stylo biomass was much lower than weed biomass in both experiments (Tables 3, 6 and 7) and is relatively easy to control with hand weeding.

Higher rice yields following a stylo fallow could also be due to root pests which can be problematic in intensively cropped upland rice in northern Laos. Roder et al. (1998b) reported that root knot nematodes (*Meloidogyne graminicola*) increased under continuous rice cropping and may be partly responsible for low rice yields. The recent studies reported that in intensively upland rice cropping systems root aphids (*Tetraneura nigriabdominalis*) could result in rice yield declines (Van Keer, 2003; Van Keer et al., 2000; Saito, unpublished data). In this study, we did not observe severe nematode damage. Root aphids were present in all Expt. 1 treatments, so the stylo fallow had no effect on them.

This study focused on a single crop cycle and identified suitable seeding times and management strategies for stylo to optimize rice productivity and stylo growth during the fallow period. We did not study the long-term management of a rice-stylo system; however, once stylo is seeded into upland rice, stylo does not need to be replanted because stylo can grow after slashing (in preparation for upland rice cropping), either from the stylo stumps (stylo can grow for two to three years) or seeds, but the stylo would need to be pruned. The long-term management of such systems requires not only further studies but also its sustainability. Increasing rice yields will increase the amount of nutrients being removed from the soil and, over time, yields could decline if nutrients are not replenished. Furthermore, nutrient depletion will be accelerated if stylo is cut and removed as forage.

5. Conclusions

Stylo can be established as a relay crop with upland rice to replace the natural fallow vegetation for fallow improvement under slash-and-burn systems. This study shows that either of the two establishment methods: pruning stylo after seeding it at the time of rice sowing or seeding stylo 15 days after rice sowing, minimizes competition with the accompanied upland rice while optimizing stylo establishment and biomass accumulation during fallow period.

Replacing the natural fallow vegetation with stylo in the short-term fallow systems increased the yields of upland rice and reduced weed growth in the subsequent rice growing season. Yield increases were related to biomass accumulation during fallow period, which affected soil N availability and weeds. While stylo fallows appear to offer the potential to improve upland rice yields in the short-term, further research is required for evaluating the long-term sustainability of this system.

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