Agroforest Syst (2008) 74:63–72
DOI 10.1007/s10457-008-9149-y

Planted legume fallows reduce weeds and increase soil N and P contents but not upland rice yields

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Received: 19 January 2007 / Accepted: 28 April 2008 / Published online: 8 May 2008

Abstract Shortened fallows have resulted in declining upland rice yields in slash-and-burn upland rice systems in northern Laos. We studied the benefit of planted legume fallows for rice productivity, weeds, and soil nitrogen and phosphorus availability. Four systems were evaluated over a 5-year period: 1-year fallow with native species, 1-year *Cajanus cajan* fallow, 1-year *Leucaena leucocephala* fallow, and continuous annual rice cropping. Rice was grown either once each year as continuous annual cropping or in alternate years of 2001, 2003, and 2005. *C. cajan* and *L. leucocephala* were sown with rice during the 2001 growing season. In subsequent years, *L. leucocephala* regenerated from root stock and did not have to be resown, whereas *C. cajan* was resown in 2003. Establishment of either *C. cajan* or *L. leucocephala* had no significant effect on rice yield in 2001, and rice yields ranged from 2.0 to 2.3 t/ha. Rice yields declined rapidly in succeeding years, and rice yields in the four systems ranged from 0.7 to 1.1 t/ha in 2003 and from 0.3 to 0.5 t/ha in 2005. Although two planted fallow systems increased nitrogen input because of greater biomass accumulation in 2003 and 2005 and soil phosphorus availability was higher following *L. leucocephala* fallow in 2005, there were no significant differences in rice yields among the four systems in either year. Weed biomass during the rice growing season increased each year in all systems and increased more rapidly for continuous annual rice cropping, in which the dominant weed species was *Ageratum conyzoides* L. Among the other three systems, there were no significant differences in the weed biomass in 2003 and 2005. We conclude that *C. cajan* and *L. leucocephala* as 1-year fallows do not offset the negative effects of increased cropping intensity on rice yield in this region.

Keywords *Cajanus cajan* · Laos · *Leucaena leucocephala* · Nitrogen · Slash-and-burn · Upland rice · Weeds

Introduction

Upland rice (*Oryza sativa* L.) is the main crop grown in the mountainous areas of northern Laos by

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resource-poor farmers and accounts for about half of the total rice area in this region (National Statistical Center 2004). “Slash-and-burn” is the major land-use practice and traditional upland rice cultivars are grown with little to no external inputs during the rainy season (from May to October). Farmers rely on extended fallows to restore soil fertility and to reduce weed and pest pressure. Rapid population growth, however, and current government policies that give priority to reducing the area under slash-and-burn have resulted in increased cropping intensity and shorter fallows (Roder et al. 1997a; Troesch 2003). In 2002, fallow periods of only 2 or 3 years were common (Troesch 2003). Increased cropping intensity has resulted in reduced soil fertility and rice yields, and increased problems from weeds and pests in northern Laos (Roder et al. 1997a, b, 1998a; Saito et al. 2006a).

An option to offset the negative effects of reduced fallow periods between crops is to use fast-growing N-fixing legumes in a planted fallow system. Fallow systems with legumes can increase fodder availability, suppress weeds, and accelerate nutrient cycling (Fujisaka 1991; Roder 2001). *Cajanus cajan* (L.) Huth (pigeon pea) and *Leucaena leucocephala* (Lam.) De Wit (leucaena) have been suggested as promising shrubby leguminous short-term fallow species for northern Laos with potential as multipurpose crops (Roder and Maniphone 1998; Roder et al. 1998b; Roder 2001). However, information on the value of these legumes as planted fallow species in slash-and-burn upland rice systems in Laos is limited. The objectives of this study were to evaluate the potential of these legumes as 1-year planted fallows between rice crops as alternatives to slash-and-burn systems in Laos, and to evaluate the effects of these alternatives on rice productivity, weed infestation, and soil N and P availability.

Materials and methods

The experiment was conducted over 5 years at the Northern Regional Agriculture and Forestry Research Center (NAFReC) (19°44′ N, 102°09′ E, 350 m asl) in Luang Prabang Province of Laos. Luang Prabang Province has the highest proportion of upland rice cultivation in the country and about 70% of total rice area was in upland rice (National Statistical Center 2004). Total annual average rainfall is 1,300 mm, with about 80% of rainfall from May to October (Table 1). The experiment began in 2001 in a field that had been fallow for the previous 2 years. Prior to the 2-year fallow, upland rice had been grown. The native fallow comprised mainly *Chromolaena odorata* (L.) R. King & H. Robinson and *Mimosa invisa* Mart. The field had a slope of 25% and the primary soil was a Eutric Cambisol with a pH (H_2O) of 6.1 and an organic carbon content of 1.6% (Roder et al. 1998b).

There were four treatments: (1) 1-year fallow with native species (NF), (2) 1-year pigeon pea fallow (PP; local variety), (3) 1-year leucaena fallow (LL), and (4) continuous annual rice cropping (CR). The cropping calendar for treatments is shown in Fig. 1. In the CR treatment, residue was burned after cutting every April, and rice was grown every year. In the NF, LL, and PP fallow treatments, rice was grown in 2001, 2003, and 2005. Four replicates were arranged in a randomized complete block design with a plot size of 7.5 m × 10 m. In May, a medium-duration traditional rice variety (Dam) was “dibble” sown (3–5 cm deep) with about 10 seeds placed in holes made with a stick at a spacing of 0.25 m × 0.25 m. Rice harvest dates ranged from 29 Sept. to 10 Oct. Weeds were controlled by hand during the rice growing period as needed and, following weeding, weeds were left in the field.

Leucaena was sown with five seeds in holes, separate from those for rice, at a spacing of 1.25 m × 1.25 m at the same time as rice was planted in 2001. Following the rice harvest, leucaena continued to grow in the field as a planted fallow species. At the end of the fallow period, the

Table 1 Rainfall (mm) as monthly and wet-season total at Northern Regional Agriculture and Forestry Research Center, Luang Prabang, Laos

Month	2001	2002	2003	2004	2005
May	109	333	87	241	174
June	141	138	168	182	129
July	340	354	162	221	276
August	236	303	274	190	261
September	166	132	350	175	327
October	174	87	5	31	12
Wet-season total	1,166	1,347	1,046	1,040	1,179

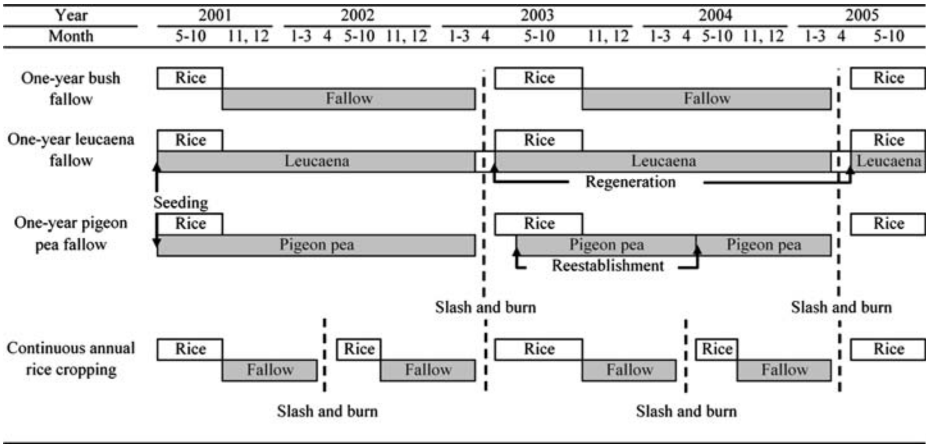

Fig. 1 Cropping calendars for each treatment from 2001 to 2005

vegetation was cut and burned in preparation for rice. Leucaena regenerated from root stock after burning and was not reseeded in 2003 or 2005. During the rice growing period in 2003 and 2005, leucaena was pruned back to a height of 20 cm until rice flowered so as not to compete with rice for light. The leucaena biomass, weighing 0.8 and 0.7 t/ha in 2003 and 2005, respectively, was left on the soil surface in each plot between the rice plants.

Pigeon pea, unlike leucaena, does not regenerate from root stock and needed to be re-established after the fallow vegetation had been cut and burned in preparation for rice. In 2001, pigeon pea was sown at the same time as rice, and at a spacing of 1.25 m × 1.25 m. In 2003, pigeon pea was sown 3 weeks after rice as it was noted that in 2001 rice yields appeared to decline slightly because of competition when pigeon pea was sown at the same time as rice. In March 2002 and 2005, pigeon pea grain yield was measured from whole plots. In the 2003 wet season, pigeon pea growth was slow and it was resown in May 2004. Weeding was undertaken around pigeon pea several times during the wet season 2004 to ensure establishment. Pigeon pea and native fallow vegetation were cut and burned at the end of the fallow period. Pigeon pea was not sown in the 2005 season.

During the rice growing period, weed biomass was measured prior to each weeding event from three randomly placed 1 m^2 quadrats in each plot. In August 2005, the number of individual weed species was counted within a randomly placed 1 m^2 quadrat in each plot. At rice maturity, rice yields were determined by harvesting all the rice within the plots except for the two outside border rows. Plant height of rice, leucaena, and pigeon pea was measured at rice harvest from 10 randomly selected hills. In 2004 and 2005, during harvest, 10 rice hills in each plot were dug out after rice harvest and inspected for root aphid (*Tetraneura nigriabdominalis*).

When the vegetation was cut following the fallow in 2003 and 2005, leucaena and pigeon pea biomass was determined from an 18.75 m^2 area. Planted fallow species biomass was separated into large (trunk and stems with a diameter >15 mm) and small fractions (leaves and branches with a diameter of <15 mm). At the same time, the native fallow vegetation biomass was determined for the whole plot and litter biomass was determined from a 3 m^2 area.

After weighing each fraction, a representative subsample (at least 0.4 kg fresh weight) from each fraction was taken to determine moisture content; the remaining fallow vegetation was then spread uniformly over the plot and burned when dry.

Soil samples were collected when the fallow vegetation was cut (about 1 month before burning), after burning, and at rice maturity by taking a composite soil sample of 8–10 sub-samples per plot at a depth of 0–5 cm using an Oakfield core sampler (20 mm diameter) in 2003 and 2005. The soil samples were air-dried and sieved for soil analysis. Inorganic N content as NH_4–N was determined by the indophenol method (Hidaka 1997) and as NO_3–N by the Griess-Ilosvay method after reduction to NO_2 (Hidaka 1997). Extractable P content was measured using Bray No. 2 (Nanjo 1997).

Analyses of variance were conducted for data on rice yield, weeds, total fallow biomass, soil inorganic N, and extractable P. Simple regression analysis was applied to identify relationships between total fallow biomass at the time of cutting and inorganic N and extractable P contents in the soil, weed biomass during the rice growing season, or rice yield in 2003 and 2005.

Results

Growth performance of planted fallow species

At rice maturity in 2001, 81% of leucaena plants had survived and, following the subsequent fallow period, by March 2003, 71% of the leucaena plants survived and persisted until 2005 (data not shown). In 2001 and 2003, more than 90% of the pigeon pea plants were surviving at rice maturity, whereas, following the 1-year fallow period, 84% remained. Survival of pigeon pea sown in 2003 was high (about 90%), though its growth was slow. By April 2004, its biomass was only 2.0 t/ha and it was resown in May 2004.

At cutting in 2003 and 2005, the above-ground biomass of leucaena and pigeon pea was not significantly different, whereas the biomass of pigeon pea was lower than that of leucaena in 2005 (Table 2). The growth of pigeon pea reduced the component of native species in the fallow vegetation compared to the NF and LL treatments. In 2003, there was on average 31% less native fallow vegetation biomass with the PP treatment than in the NF and LL treatments, and 55% less in 2005. Visual observation suggests that this suppression of the native species may have been due to the denser canopy of PP compared with LL, although plant height of pigeon pea was less than that of leucaena. The reduced native vegetation in 2005 may also be in part due to the weeding done during the 2004 wet season to re-establish PP. The LL treatment did not reduce native fallow vegetation biomass compared with the NF treatment in either 2003 or 2005. The amount of native fallow vegetation biomass was low in the CR treatment in both years. In this system, there is little growth of vegetation after rice harvest and during the fallow period due to the low rainfall in this period.

In 2003, total fallow biomass (planted fallow species plus native fallow vegetation plus litter) was highest in PP and LL treatments, followed by NF and CR (Table 2). In 2005, at the end of the fallow, some plots were heavily infested by *Mimosa invisa*, making it difficult to separate weed biomass from litter biomass. The native fallow vegetation biomass in the plots may have included dead mimosa biomass (litter biomass). Thus, the total fallow biomass (either PP or LL plus the native fallow vegetation and litter) may have been overestimated in these plots. Despite this, a similar pattern was observed in 2005, except that the PP treatment had less total fallow biomass than the LL treatment. Pigeon pea produced 1.3, 0.1, 0.1, and 0.2 t/ha of seed yield in March 2002, 2003, 2004, and 2005, respectively.

Table 2 Above-ground biomass (t/ha) of native fallow vegetation and planted fallow species at the time of cutting in March, 2003 and 2005 ($n = 4$)

Treatment	2003				2005			
	Planted fallow species	Native fallow vegetation	Litter	Total fallow biomass[A]	Planted fallow species	Native fallow vegetation	Litter	Total fallow biomass[A]
Native fallow	–	6.0 a	2.9 a	8.9 b	–	5.2 a	3.8 a	9.0 b
Leucaena	7.9	5.4 a	1.3 b	14.6 a	6.1	5.8 a	2.7 b	14.6 a
Pigeon pea	7.9	3.9 b	3.2 a	15.1 a	4.6	2.5 b	2.9 b	10.0 b
Continuous rice	–	1.2 c	0.4 c	1.6 c	–	1.8 b	1.4 c	3.2 c
PR > *F*	0.98	<0.01	<0.01	<0.01	0.45	0.02	0.04	<0.01
LSD (0.05)	ns	1.27	0.88	3.46	ns	2.63	0.82	2.98
CV (%)	28.3	28.2	19.4	21.6	47.7	42.7	19.1	20.2

Values in a column followed by the same letter are not significantly different at 5% level based on mean separation by LSD

[A] Total fallow biomass = planted fallow species + native fallow vegetation + litter

Effect of fallow treatments on rice yield, weeds, and soil N and P availability

Throughout the 5-year experiment, rice yields declined regardless of fallow treatments. In 2001, rice yields ranged from 2.0 to 2.3 t/ha and were not significantly different from each other (Table 3). In the PP treatment, rice yields were 13% less than in the other treatments, which may be a result of competition with pigeon pea. At harvest, PP was about 100 cm higher than the rice, whereas leucaena developed slowly and was shorter than the rice by the 2001 harvest. As a result of this possible competition with rice, pigeon pea was seeded 3 weeks after rice planting in 2003. Low or no rice yields in the CR systems in 2002 and 2004 were mainly due to root aphid. In the 2004 rice crop, out of 10 hills sampled per plot, 85% of hills were infected by root aphids. Root aphids have been shown to decrease upland rice yields in northern Laos and Thailand (Saito et al. 2006a; van Keer et al. 2000).

Rice yields in 2003 were relatively low and ranged from 0.7 to 1.1 t/ha (Table 3) due to the effects of cropping intensity or the relatively low total rainfall. Total rainfall from May to July in 2003 was only 417 mm (Table 1), whereas rainfall in the other years ranged from 579 to 825 mm. Root aphids were not observed in any treatments in 2003.

Rice yields in 2005 ranged from 0.3 to 0.5 t/ha with no significant differences among the four fallow treatments. Rainfall was not a factor in the low yields. Root aphids, however, infested 33% of rice hills but with no significant differences between the treatments (data not shown). The percentage of infestation, however, was lower than observed in the 2004 CR. Among four treatments, there was no significant difference in 2003–2005 total rice yields, which summed up those from 2003 to 2005 (Table 3).

In 2001, there was no effect of fallow treatments on weed biomass during the rice growing season (Table 4). Total weed biomass tended to increase over years in all treatments and almost tripled between 2001 and 2005 in all treatments. Total weed biomass was significantly greater in the CR treatment than in the fallow treatments in 2003. Although there were no significant differences in weed biomass among NF, LL, and PP treatments in each year, there was an indication for fewer weeds following leucaena and pigeon pea in 2005. Total weed biomass during the rice growing season in 2003 and 2005 was negatively correlated ($P < 0.05$) with total fallow biomass at cutting time (Fig. 2). Toward the end of the 5-year experiment, during the growing season of the last crop, *Ageratum conyzoides* density was higher in CR than in the other treatments (Table 5). This supports earlier observations that there is a shift in weed populations toward *A. conyzoides* as cropping systems intensify (Roder et al. 1998a).

Table 3 Mean rice yields (t/ha) in the four fallow treatments ($n = 4$)

Treatment	2001	2002	2003	2004	2005	2003–2005^A
Native fallow	2.3	–	0.9	–	0.5	1.4
Leucaena	2.3	–	0.8	–	0.5	1.3
Pigeon pea	2.0	–	1.1	–	0.4	1.5
Continuous rice	2.3	nd^B	0.7	0.2	0.3	1.3
PR > *F*	0.06	–	0.10	–	0.25	0.39
LSD (0.05)	ns	–	ns	–	ns	ns
CV (%)	7.0	–	21.2	–	30.6	15.5

^{A} Data from 2003 to 2005 were summed up

^{B} Not determined due to severe root aphid damage resulting in negligible yields

Table 4 Total accumulative weed biomass (t/ha) during the rice growing season in four fallow treatments (averaged over four replications)

Treatment	2001	2002	2003	2004	2005	2003–2005^A
Native fallow	0.6	–	1.1 b	–	1.7	2.7 a
Leucaena	0.5	–	1.0 b	–	1.2	2.3 a
Pigeon pea	0.4	–	1.1 b	–	1.3	2.4 a
Continuous rice	0.6	nd^B	1.8 a	2.1	2.0	5.9 b
PR > *F*	0.57	–	0.03	–	0.17	<0.01
LSD (0.05)	ns	–	0.549	–	ns	1.15
CV (%)	41.2	–	27.2	–	32.3	21.8

Values in a column followed by the same letter are not significantly different at 5% level based on mean separation by LSD

^{A} Data from 2003 to 2005 were summed up

^{B} Not determined

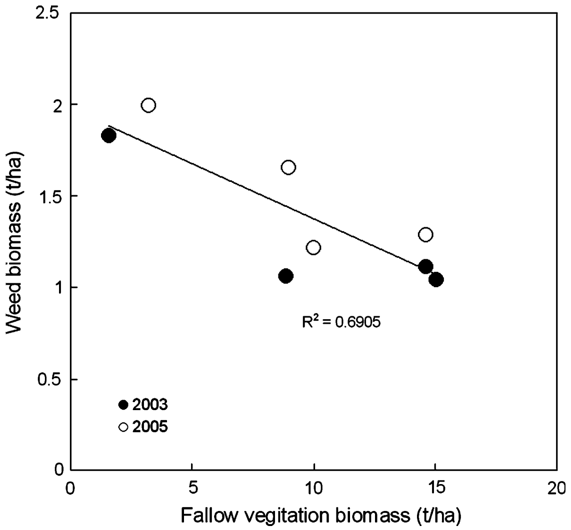

Fig. 2 The relationship between total fallow biomass (planted fallow species + native fallow vegetation + litter) and weed biomass during the rice growing season in 2003 and 2005. The data from 2003 and 2005 were combined for the regression line

There were no differences between the treatments in soil inorganic N content at cutting time in 2003 and 2005 (Table 6). Following burning, soil inorganic N content increased in all treatments. During the growing season, inorganic N content in four fallow treatments declined as a result of plant uptake and losses from the system and at rice maturity there were no differences in inorganic N among the treatments. Such substantial fluctuation in inorganic N content over the rice growing season is consistent with other studies (i.e., Kyuma and Pairintra 1983; Roder et al. 1995; Saito et al. 2006a, b). Inorganic N, averaged over treatments at maturity in 2003, tended to be smaller than in 2005, which may reflect the smaller rice yield in 2005. Although not always significant, inorganic N content after burning was higher in the LL, PP, and NF treatments than in the CR treatment. Soil inorganic N content in NF, LL, and CR after burning in 2003 was similar to that in 2005. But, in the PP treatment, it was higher in 2003 (42 mg/kg) than in 2005 (26 mg/kg). Total fallow biomass at cutting time in PP in 2005 was much lower than in 2003, possibly as a result of the lower inorganic N content in 2005.

Total fallow biomass at the time of cutting was correlated with differences in inorganic N between soils collected before and after burning in 2003 and 2005 (Fig. 3), suggesting that the N input due to burning was affected by biomass accumulation during the fallow period. Combined data from 2003 and 2005 showed that rice yield was weakly related to soil inorganic N content after burning ($P = 0.051$); however, the relationship was affected by differences in rice yield in 2003 and 2005 (Tables 3 and 6).

Soil extractable P content varied considerably within a given season and across seasons (Table 7). Soil extractable P, averaged over treatments between cutting in 2003 and 2005, declined from an average of 14 to 10 mg/kg. Burning increased soil extractable P in all treatments in 2003 and 2005 by 13 and 19 mg/kg, respectively. Although there is little effect of fallow treatment, the LL treatment had consistently higher soil extractable P content following burning in both years relative to the NF treatment. There were no relationships among total fallow biomass at the time of cutting, the difference in extractable P between soils collected before and after burning, and rice yield in combined data from 2003 and 2005 (Tables 2, 3, and 7).

Table 5 Density of weed species (number per m^2) measured on 30 August 2005 in four fallow systems (averaged over four replications)

Treatment	*Ageratum conyzoides*	*Chromolaena odorata*	*Mimosa invisa*	*Saxifraga paniculata*	Others	Total
Native fallow	37 b	9	4 b	43	50	143 b
Leucaena	18 b	8	1 b	24	45	95 b
Pigeon pea	48 b	38	3 b	19	63	171 b
Continuous rice	203 a	2	8 a	54	41	309 a
PR > *F*	<0.01	0.47	<0.01	0.27	0.68	0.03
LSD (0.05)	100.8	ns	3.0	ns	ns	130.2
CV (%)	82.7	238.5	45.5	76.9	53.7	45.4

Values in a column followed by the same letter are not significantly different at 5% level based on mean separation by LSD

Table 6 Soil inorganic nitrogen content (mg/kg, soil extractable NH_4–N plus NO_3–N) at a depth of 0–5 cm at cutting, after burning, and at rice maturity in 2003 and 2005 in four fallow treatments (averaged over four replications)

Treatment	2003				2005			
	At cutting (a)	After burning (b)	Burn effect (b)−(a)	At maturity	At cutting (a)	After burning (b)	Burn effect (b)−(a)	At maturity
Native fallow	17	30	13	12	17	28 b	11 b	17
Leucaena	15	34	19	14	16	36 a	20 a	21
Pigeon pea	18	42	24	16	14	26 bc	12 b	15
Continuous rice	17	28	11	9	14	22 c	8 b	24
Mean	17	34	17	13	15	28	13	19
PR > *F*	0.54	0.07	0.10	0.28	0.12	<0.01	0.01	0.66
LSD (0.05)	ns	ns	ns	ns	ns	5.6	5.9	ns
CV (%)	17.9	21.0	44.3	37.6	10.9	12.5	28.5	59.6

Values in a column followed by the same letter are not significantly different at 5% level based on mean separation by LSD

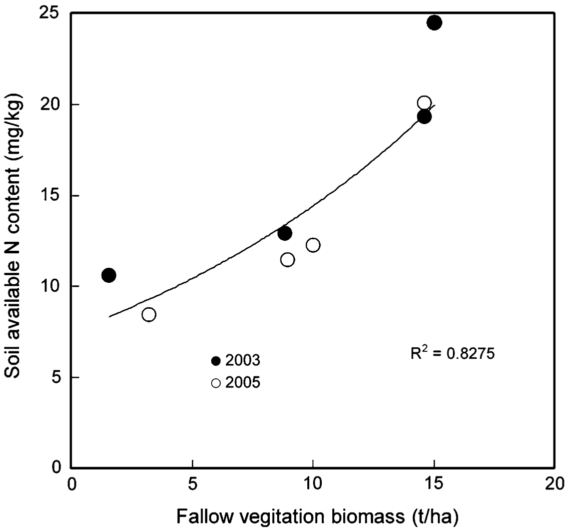

Fig. 3 The relationship between total fallow biomass (planted fallow species + native fallow vegetation + litter) and the increase in soil inorganic N content due to burning in 2003 and 2005. The data from 2003 and 2005 were combined for the regression line

Discussion

The lack of significant differences in rice grain yield, weeds, and soil N and P availability in some cases of this study may be attributed, in part, to soil heterogeneity together with relatively low replication ($n = 4$). As far as possible, areas with termite mounds and tree stumps were excluded from the experiment. Nevertheless, soil conditions and weed growth were highly heterogeneous as seen by the high coefficient of variation (Tables 3–7). These results are consistent with previous studies in upland fields in northern Laos (Roder 2001; Saito et al. 2006b, 2007).

An efficient approach to replace the native fallow vegetation with N-fixing legumes is to establish the legumes during the rice growing season and then allow the legumes to grow during the subsequent fallow period. A challenge is to achieve high establishment of the legumes without reducing yields of upland rice and with a minimum effort and cost to farmers. Seeding time and density of the planted fallow species can affect rice growth. In this experiment, establishment of leucaena and pigeon pea into rice was successful and did not reduce rice yield. Other studies have also shown that establishing leucaena by seeding it at the same time as rice is planted has not reduced rice yields in the initial year of establishment (Roder and Maniphone 1995, 1998). This is likely due to the initial slow growth of leucaena. Our results on pigeon pea are neither consistent with those of Roder and Maniphone (1995), who reported that pigeon pea sown with rice resulted in a 55% reduction in rice yields, nor those of Akanvou et al. (2002), who found that the optimum seeding time of pigeon pea, so as not to reduce rice yield, was between 30 and 35 days after rice seeding. These inconsistencies are likely due to the higher seeding densities used by Roder and Maniphone (1995), who used 5 hills/m^2 (seeding rate is 4–6 seeds per hill), or by Akanvou et al. (2002) with 20 plants/m^2. In this

Table 7 Soil extractable P content (mg/kg, Bray No. 2) at a depth of 0–5 cm at cutting, after burning, and at rice maturity in 2003 and 2005 in four fallow treatments (averaged over four replications)

Treatment	2003				2005			
	At cutting (a)	After burning (b)	Burn effect (b)−(a)	At maturity	At cutting (a)	After burning (b)	Burn effect (b)−(a)	At maturity
Native fallow	12	19	7	12	10	28 b	17 b	10 b
Leucaena	14	29	15	15	10	47 a	38 a	18 a
Pigeon pea	16	31	14	12	10	19 b	9 b	9 b
Continuous rice	13	27	15	10	11	23 b	12 b	8 b
Mean	14	26	13	12	10	29	19	11
PR > *F*	0.27	0.11	0.13	0.20	0.86	0.01	<0.01	0.03
LSD (0.05)	ns	ns	ns	ns	ns	14.0	12.8	6.0
CV (%)	23.6	25.2	40.3	26.8	16.6	29.8	41.6	32.8

Values in a column followed by the same letter are not significantly different at 5% level based on mean separation by LSD

study, we used 0.64 hills/m^2 (with 5 seeds per hill). Furthermore, in 2003, we delayed the seeding date of pigeon pea by 3 weeks to reduce the effects of competition on rice. Seeding pigeon pea at a lower density and after rice planting requires less labor and may be more attractive to farmers.

Pigeon pea biomass and yields declined over years. Pigeon pea sown in 2001 had greater biomass accumulation, weed suppression, and grain yield than pigeon pea sown in 2003 and 2004. This performance of pigeon pea in 2001 is consistent with other reports (e.g., Akanvou et al. 2002; Becker and Johnson 1998; Boehringer and Caldwell 1989; Daniel and Ong 1990). Roder and Maniphone (1998) reported that pigeon pea died after 1 year due to overgrowth by weeds. In another experiment, only 9% of the pigeon pea plants were still alive 15 months after seeding (Roder et al. 1998b), leading the authors to conclude that pigeon pea was not suitable for fallow periods of more than 1 year and that it was inferior to leucaena in terms of persistence, biomass production, and weed suppression. In their study, pigeon pea was pruned twice during the rice growing season so its competitiveness and vigor were reduced. The reasons for the decline in pigeon pea growth and yield during the course of this experiment are not known but may be due to several factors. First, delaying the seeding of pigeon pea in 2003 by 3 weeks resulted in pigeon pea plants being smaller at the beginning of the dry season, which may have affected pigeon pea growth and yield. Second, soil P availability may have been a limiting factor for pigeon pea growth. Although pigeon pea is able to fix N, N fixation is dependent on P availability (Cassman et al. 1993). Compared with the other treatments, more P could have been removed from the soil in the PP treatment because of harvesting of pigeon pea seeds. In this experiment, some evidence suggests that soil P availability declined in the PP treatment (Table 7). Third, soil-borne pests may have had an impact, as they did on rice productivity; however, this was not investigated.

Weeds are the major constraint faced by farmers in upland rice systems in Laos, particularly as cropping intensifies. Technologies, such as planted fallows, that are able to reduce the labor required for weeding could result in improved returns on labor input for farmers. After 2 years of the experiment, in 2003, weed biomass during the rice growing period in the CR treatment was 70% higher than in rice grown after the legume fallows. This may have been caused by a “cool” burn due to the small amounts of biomass generated during the short dry-season fallow in the CR treatment that failed to destroy weed seeds, as found by de Rouw (1994), or due to reduced weed seed production in the fallow systems. Neither leucaena nor pigeon pea resulted in significantly less weed biomass in rice compared with the NF treatment, although there was an indication of less weed biomass following these fallows and there was a significant negative relationship between total fallow biomass and weed biomass in the subsequent rice crop (Fig. 2). Similarly, Roder and Maniphone (1998) found that increased fallow biomass resulted in less total weed biomass during the subsequent rice growing season. Saito et al. (2006b) also reported that, when stylo (*Stylosanthes guianesis*) was grown during the fallow period, high biomass was associated with fewer weeds in the rice crop in the following season. Although there seemed to be fewer weeds in the LL treatment, leucaena produced approximately 0.8 t/ha of dry weight during the rice growing season in 2003 and 2005. Total weed biomass plus leucanea biomass in the LL treatment was similar to the total weed biomass in the CR treatment in the 2003 and 2005 rice growing seasons. Although the labor requirement for cutting leucaena was not measured, if we assume that the labor required for weeding in CR and cutting leucaena in LL is similar, there is a suggestion that the labor requirement for LL may be similar to that for CR.

Planted fallow systems increased inorganic soil N because of higher biomass (Fig. 3). Although burning is expected to result in the volatilization of much of the N into the atmosphere (Kyuma and Pairintra 1983), increased soil N may be the result of legume root systems and the litter fall (and subsequent mineralization of N) from the legume trees during the fallow period.

A primary reason farmers may adopt a planted fallow system would be to maintain or increase rice yields in these systems. None of the planted fallow systems tested, however, achieved this and rice yields declined substantially over time consistent with the findings of others (Roder and Maniphone 1998; Roder et al. 1998b; Roder 2001). Rice yields in all systems were 0.5 t/ha or less by the fifth year and such systems were unlikely to be sustainable. Although weed growth was reduced and the planted fallow systems had higher N and P relative to the CR, the yield decline suggests that other factors may have been responsible. One possibility is soil-borne pests (e.g., root aphids) that tend to increase with intensive cropping and cause yield loss and indeed these have been shown to decrease upland rice yields in northern Laos and Thailand (Saito et al. 2006a; van Keer et al. 2000). Another possibility, especially for the LL treatment, is competition for nutrients and water. Roder (2001) found that alley cropping using leucaena resulted in lower rice yields and attributed the yield loss to competition for limited available soil water in these rainfed systems. Once established, therefore, leucaena may compete with rice for nutrients and water, which may offset any benefit that these species impart to the system.

Even though rice yields are not improved in planted fallow systems as shown in this study, farmers may adopt them if they provide benefits such as reduced labor requirement, pigeon pea grain, and a feed source for the insect *Laccifer lacca* in the production of sticklac (Linquist et al. 2006; Roder et al. 1998b). Labor inputs in the CR and LL treatments are considerably higher than in the other two systems since additional labor was required for rice production in the CR treatment for 2002 and 2004, and weed biomass (plus leucaena biomass for LL only) in the CR and LL treatments tended to be higher than in the other systems, requiring high labor input for weeding. These higher labor inputs may render these systems unviable. Where there is a market for pigeon pea, the pigeon pea fallow may be attractive to farmers. Linquist et al. (2006) indicate that, assuming a yield of 0.5 t/ha pigeon pea in the first year (at US$0.16 per kg), farmers would receive $80 from the pigeon pea, which equates to more than a 25% increase in average household income. From the labor standpoint, planting pigeon pea at a wide spacing requires little labor (about one person-day per ha), and no additional labor for weeding is required until its harvest (when pigeon pea is grown with rice). Although the harvest requires a significant amount of labor (not measured), demands on labor are low during March and April when pigeon pea is harvested. The benefits of planted fallow systems would be better if fodder availability were accounted for in the calculation. However, the use of planted fallows as fodder will increase the amount of nutrients being removed from the soil and, over time, rice yields might decline if nutrients are not replenished. Future research will be needed to quantify the profitability of a pigeon pea fallow system and to examine whether planted fallow systems are acceptable for farmers.

Conclusions

Leucaena and pigeon pea can be established and grown as planted fallows as alternatives to the native fallow vegetation under slash-and-burn systems for rice. Planting these legumes at wide spacing minimized competition with the accompanying rice crop. Replacing the native fallow vegetation with them in

1-year fallow systems increased biomass accumulation during the fallow period. The biomass accumulation affected soil N availability and weeds during the rice growing season. Planted fallow systems, however, do not offset the negative effects of increased cropping intensity on rice yield. The reasons for the rapid yield decline need to be understood because, until these problems are solved, planted fallow systems to maintain soil fertility and suppress weed ingression are unlikely to provide a viable alternative for sustainable intensified upland rice cropping for small farmers in this region.

Acknowledgements The research was partly funded by the Swiss Agency for Development and Cooperation (SDC) and the "Global Environment Research Fund," The Ministry of the Environment, Government of Japan (Project S2-3b). The authors would like to gratefully acknowledge the support and help they received from the staff at the Northern Regional Agriculture and Forestry Research Center. We are also grateful for the identification of weed species of Mr. Joel Janiya, the editorial advice of Mr. Bill Hardy, and the comments of the two anonymous reviewers.

References

Akanvou R, Kropff MJ, Basitaans L et al (2002) Evaluating the use of two contrasting legume species as relay intercrop in upland rice cropping systems. Field Crops Res 76:23–36

Becker M, Johnson DE (1998) Legumes as dry season fallow in upland rice-based systems of West Africa. Biol Fertil Soils 27:358–367

Boehringer A, Caldwell R (1989) *Cajanus cajan* (L.) Millsp. as a potential agroforestry component in the Eastern Province of Zambia. Agroforest Syst 9:127–140

Cassman KG, Singleton PW, Linquist BA (1993) Input/output analysis of the cumulative soybean response to phosphorus on an Ultisol. Field Crops Res 34:23–36

Daniel JN, Ong CK (1990) Perennial pigeon pea; a multipurpose species for agroforestry systems. Agroforest Syst 10:113–129

de Rouw A (1994) Effect of fire on soil, rice, weeds and forest regrowth in a rain forest zone (Côte d'Ivoire). CATENA 22:133–152

Fujisaka S (1991) A diagnostic survey of shifting cultivation in northern Laos: targeting research to improve sustainability and productivity. Agroforest Syst 13:95–109

Hidaka S (1997) Nitrogen. In: Committee for Standard Methods of Soil Analysis, Japanese Society of Soil Science and Plant Nutrition (eds) Standard method of soil environment analyses. Hakuyusha, Tokyo (in Japanese)

Kyuma K, Pairintra C (eds) (1983) Shifting cultivation. An experiment at Nam Phrom, northeast Thailand, its implications for upland farming in the monsoon tropics. Faculty of Agriculture, Kyoto University, Japan

Linquist B, Saito K, Keoboualapha B et al (2006) Improving upland rice-based cropping systems in Laos. In: Schiller JM, Chanphengxay MB, Linquist B, Appa Rao S (eds) Rice in Laos. International Rice Research Institute, Los Banõs, Philippines, pp 391–407

Nanjo M (1997) Available phosphate. In: Committee for Standard Methods of Soil Analysis, Japanese Society of Soil Science and Plant Nutrition (eds) Standard method of soil environment analyses. Hakuyusha, Tokyo (in Japanese)

National Statistical Center (2004) Statistical yearbook 2003. Vientiane

Roder W (2001) Slash-and-burn rice systems in the hills of northern Laos PDR: description, challenges, and opportunities. International Rice Research Institute, Los Baños

Roder W, Maniphone S (1995) Forage legume establishment in rice slash-and-burn systems. Trop Grasslands 29:81–87

Roder W, Maniphone S (1998) Shrubby legumes for fallow improvement in northern Laos: establishment, fallow biomass, weeds, rice yield, and soil properties. Agroforest Syst 39:291–303

Roder W, Phengchanh S, Keoboulapha B (1995) Relationships between soil, fallow period, weeds and rice yield in slash-and-burn systems of Laos. Plant Soil 176:27–36

Roder W, Phengchanh S, Keoboulapha B (1997a) Weeds in slash-and-burn rice fields in northern Laos. Weed Res 37:111–119

Roder W, Phengchanh S, Maniphone S (1997b) Dynamics of soil and vegetation during crop and fallow period in slash-and-burn fields of northern Laos. Geoderma 76:131–144

Roder W, Keoboulapha B, Phengchanh S et al (1998a) Effect of residue management and fallow length on weeds and rice yield. Weed Res 38:167–174

Roder W, Maniphone S, Keoboulapha B (1998b) Pigeon pea for fallow improvement in slash-and-burn systems in the hills of Laos. Agroforest Syst 39:45–57

Saito K, Linquist B, Keobualapha B et al (2006a) Cropping intensity and rainfall effects on upland rice yields in northern Laos. Plant Soil 284:175–185

Saito K, Linquist B, Keobualapha B et al (2006b) *Stylosanthes guianensis* as relay intercrop for improving the productivity of upland rice cropping systems in northern Laos. Field Crops Res 96:438–447

Saito K, Atlin GN, Linquist B et al (2007) Performance of traditional and improved upland rice cultivars under nonfertilized and fertilized conditions in northern Laos. Crop Sci 47:2473–2481

Troesch K (2003) Highland rice paddy development in mountainous regions of northern Lao PDR. Draft report. Swiss College of Agriculture

van Keer K, Trébuil G, Gozé E (2000) Identifying and grading limiting factors of upland rice yields in farmers' fields of northern Thailand. Int Rice Res Notes 25:31–33