CHAPTER 16

Arthropod communities of the lowland rice ecosystems in the Lao PDR

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Rice is the most important crop in Laos, being grown on more than 80% of the cultivated area. Total annual rice production in 2004 was reported to be 2.529 million tons, with the wet-season lowland environment accounting for about 78% of national production. Dry-season irrigated rice cultivation in the 2003-04 cropping season was undertaken on about 78,000 ha, and accounted for about 13.5% of production. Approximately 74% of wet-season production comes from the lowland environment in the central and southern agricultural regions.

Unlike much of the rice-producing area in the rest of Asia, until about the mid-1990s, rice cultivation in all environments of Laos was based on relatively few inputs apart from family labor. Even fertilizer inputs were limited until the latter half of the 1990s. Planting, weeding, harvesting, and threshing were all done manually. Mechanized land preparation and the use of mechanical threshers are relatively recent innovations in the main lowland rice-growing areas in the Mekong River Valley. Production in much of the remainder of Laos remains largely based on traditional practices.

Pesticide (insecticides, fungicides, herbicides, etc.) use in most rice environments in Laos has been low, and it has only been relatively recently that pesticides have become available in local markets. In comparison with other countries in the region, in the early 2000s, insecticide use in most lowland rice areas in Laos was still at a very low level. As a result, the arthropod communities in the rice environments of Laos have remained relatively undisturbed. Reports on the diversity of the arthropod communities in the rice environments have also been rare. The first published report giving some detail of the arthropods of Laos was that of Dean (1978), who undertook a pest survey in the country in the period 1973-75, in which was included a list of some pests and natural enemies. However, this study focused on just one locality and was limited in its scope.

This chapter reports on the results of a detailed study of the arthropod community of the rainfed lowland and irrigated rice ecosystems in Laos undertaken in 1995. The study covered six provinces representing the northern, central, and southern agricultural regions of the country. The purpose was to highlight the great biodiversity that exists in the arthropod communities of rice ecosystems in Laos.

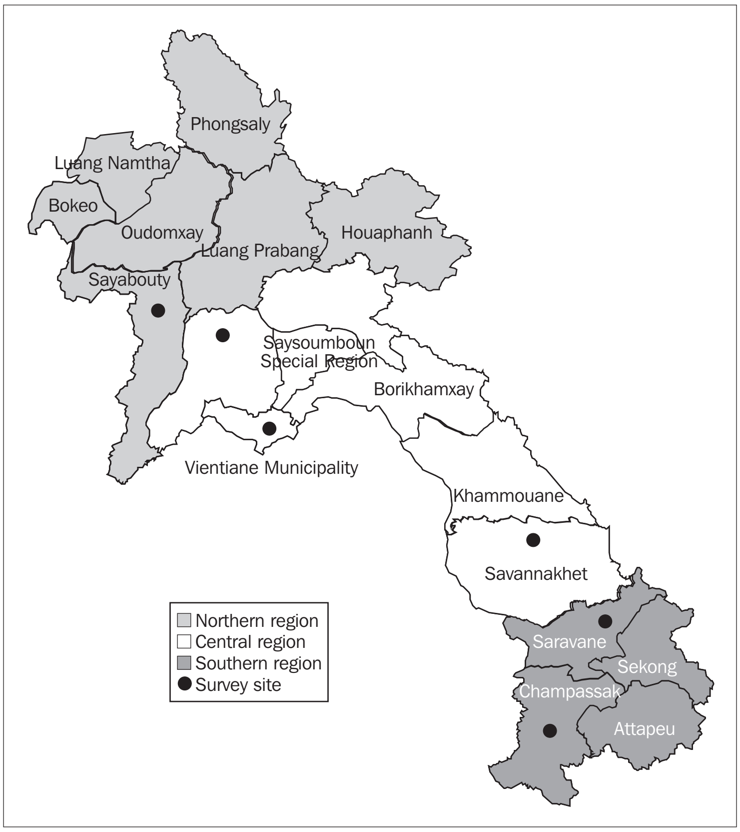

Fig. 1. Survey of arthropod communities in wet-season lowland rice environments.

Survey methodology

Survey sites

The six provinces covered by the survey were Sayabouly in the northern region, Vientiane Municipality, Vientiane Province, and Savannakhet in the central region, and Champassak and Saravane in the southern region (Fig. 1). Two districts were surveyed in Sayabouly Province, Phiang (4 villages) and Sayabouly (1 village). In Savannakhet, sampling was done in three districts—Khantabouly (3 villages), Asphangthong (1 village), and Outhomphong (1 village). Sampling in Champassak was done in four districts—Pakse (3 villages), Sanasomboune (1 village), Soukhouma (1 village), and Champassak (1 village). In Saravane, Vientiane Province, and Vientiane Municipality, sampling was done in only one district within each province. Within each village targeted by the study, three farmers' fields were chosen for the detailed surveys. Site selection was done with the help of collaborators in the Lao National

Table 1. Sampling sites and number of samples from each site, 1995 wet season.

Locality	No. of districts	No. of villages	No. of fields	No. of sampling sites
Northern region				
Sayabouly Province	2	5	15	600
Central region				
Vientiane Municipality	1	2	3	120
Vientiane Province	1	1	3	120
Savannakhet Province	3	5	15	600
Southern region				
Saravane Province	1	1	3	120
Champassak Province	4	6	18	720
Total	12	20	57	2,280

Rice Research Program Network. Farmers and farming areas were selected that did not have a history of any pesticide use at the time of the survey.

Sampling methods

Sampling was done three times during the crop cycle—30, 55, and 80 days after transplanting (DT) during the 1995 wet-season cropping cycle. The sampling sites and the number of field samples from each site are summarized in Table 1.

Arthropod samples were collected using the D-Vac and Blower-Vac suction machines and sweep net. The D-Vac machine used was an 18-kg backpack vacuum insect collector (D-Vac Model 24), powered by a Tecumesh 3-horsepower, 2-cycle engine and regular gasoline (Fig. 2). The Blower-Vac machine used was similar to that described by Arida and Heong (1992).

On each sampling date, three D-Vac, 10 Blower-Vac, and one sweep-net sample were collected from each of 57 fields. D-Vac samples were obtained from 10 hills selected at random within the selected field, with approximately 2 minutes' time of suction from each hill. In the study, one D-Vac sample constituted a total catch from 10 hills. To collect samples with the Blower-Vac, the enclosure was dropped over the rice plant (covering 4 hills at the early crop stage at 20 × 20-cm distance, but fewer hills as the crop matured). Arthropods collected from the Blower-Vac were sucked starting from a nylon net sleeve, then the air column, the plant surfaces, and finally the water surface. The time spent for the collection was approximately 2–3 minutes. Sweep-net samples were collected by making 10 sweeps of the plant canopy while walking diagonally across the field. Sweep nets were used only at 55 DT.

Sorting, counting, and identification

Samples were placed in labeled vials, preserved in 75% ethyl alcohol and brought to the Crop Protection Laboratory at the National Agricultural Research Center in Vientiane Municipality for sorting, counting, and identification. Each specimen was identified to its lowest possible taxon based on previously published keys. Each ar-

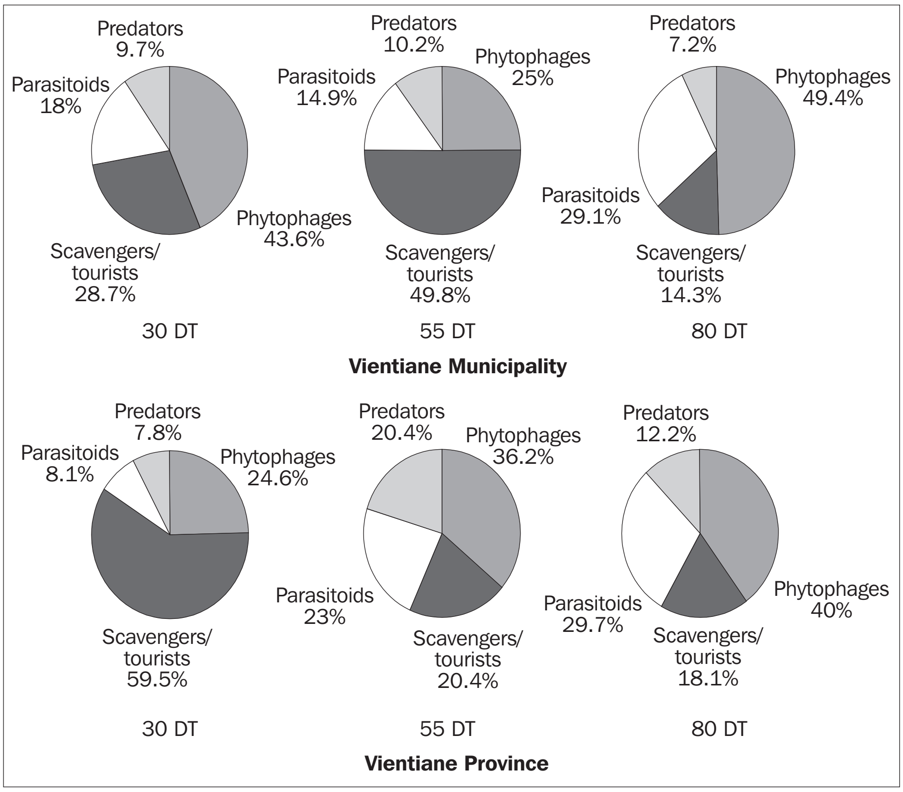

Fig. 2. Percent composition of the arthropod guilds collected in rainfed lowland rice ecosystems in Vientiane Municipality and Vientiane Province, 1995 wet season. DT = days after transplanting.

thropod species was grouped into one of four guilds: herbivores, predators, parasitoids, and detritivores (scavengers/tourists after Norman and Southwood 1982). Sorting, counting, and identification were done in Laos, with the raw data being entered into electronic form (Excel spreadsheet) for analysis and archiving.

Arthropod diversity

Taxonomic richness and abundance relations

A total of 391,713 individual organisms were collected in this study. Champassak yielded the greatest total abundance, followed by Sayabouly, Savannakhet, Saravane, Vientiane Province, and Vientiane Municipality (Table 2). Sayabouly recorded the greatest number of species, followed by Savannakhet, Champassak, Vientiane Province, Vientiane Municipality, and Saravane. Because the number of sampled fields differed among the provinces, the average data were standardized across sites as average number of individuals per field. The average number of individuals per field

Table 2. Arthropod counts by province and crop age (days after transplanting, DT) in the rainfed lowland rice ecosystem, 1995 wet season.

Locality	Crop age (DT)	Total arthropod counts	Av per field	% composition
Northern region				
Sayabouly Province	30	47,911	3,194	39.7
	55	33,045	2,203	27.9
	80	38,288	2,552	
Total		119,244		
Central region				
Vientiane Municipality	30	4,145	1,382	28.5
	55	4,732	1,577	34.2
	80	5,172	1,724	37.3
Total		14,049		
Vientiane Province	30	4,623	1,541	25.6
	55	7,642	2,547	42.5
	80	5,752	1,917	31.9
Total		18,017		
Savannakhet Province	30	15,448	1,030	22.7
	55	28,604	1,907	42.1
	80	23,936	1,596	35.2
Total		67,988		
Southern region				
Saravane Province	30	13,963	4,654	5701
	55	3,110	1,037	12.7
	80	7,391	2,457	20.3
Total		24,464		
Champassak Province	30	46,823	2,601	31.6
	55	69,962	3,860	47.0
	80	31,649	1,758	20.3
Total		148,434		

was highest in Champassak, followed in decreasing order by Saravane, Sayabouly, Vientiane Province, Vientiane Municipality, and Savannakhet (Table 2).

Across the six sites, 763 arthropod taxa belonging to 592 genera, 202 families, and 18 orders were determined. Aside from the arthropods collected, 17 species of non-arthropods (nematodes, snails, fish, and frogs) were also collected.

The herbivore group constituted 23.9% of all the arthropods collected. Predators and parasitoids represented 12.5% and 16.9%, respectively, of the samples, while the scavengers/tourists were almost one-half (46.7%) of the total individuals collected (Table 3). Predators and parasitoids, when combined, had higher total counts than the herbivores.

Arthropod abundance also varied over the growing season. The scavengers/tourists guild was the dominant guild at 30 DT for all sites except Vientiane Municipality, where this guild was highest at 55 DT. In decreasing order of abundance, they were

Table 3. Percent composition of the different arthropod guilds collected in rainfed lowland rice ecosystems by province and crop age, 1995 wet season.

Locality	Arthropod composition (%)			
	Crop age (DT)	Herbivores	Natural enemies (predators and parasitoids)	Detritivores
Northern region				
Sayabouly Province	30	25.4	27.0	47.5
	55	37.8	39.4	22.8
	80	23.7	40.0	36.3
Central region				
Vientiane Municipality	30	43.6	27.7	28.7
	55	25.0	25.1	49.8
	80	49.4	36.3	14.3
Vientiane Province	30	24.6	15.9	59.5
	55	36.2	43.4	20.4
	80	40.0	41.9	18.1
Savannakhet Province	30	18.2	24.9	56.8
	55	30.7	44.7	24.6
	80	20.5	37.6	41.9
Southern region				
Saravane Province	30	4.2	4.2	91.6
	55	23.1	33.0	43.9
	80	7.8	16.5	75.7
Champassak Province	30	10.7	15.3	74.0
	55	18.5	21.0	60.5
	80	34.9	36.4	28.7
Overall % composition		23.9	29.4	46.7

followed by herbivores, parasitoids, and predators. In Sayabouly, herbivores constituted 25.4% of the samples collected, parasitoids 17.7%, predators 9.3%, and detritivores 47.5%. At 55 DT, an increase in the number of predators, parasitoids, and herbivores was observed; however, scavengers declined to almost one-half the number at 30 DT. At 80 DT, the herbivores and predators decreased but parasitoids and detritivores increased.

Similar trends were observed in Savannakhet. Herbivores collected constituted 18.2%, predators 12.2%, parasitoids 12.7%, and detritivores 56.7% of the samples at 30 DT. At 55 DT, the number of herbivores increased to 30.7% but predators and parasitoids almost doubled their number at 30 DT, whereas detritivores decreased to 24.6%. The percentage of predators and parasitoids decreased slightly at 80 DT; herbivores also decreased while detritivores increased.

In Vientiane Municipality, 43.5% of the samples at 30 DT were herbivores. Predators and parasitoids were low (9.7% and 18%, respectively) and detritivores were 28.7%. However, this latter group constituted 49.8% of the samples at 55 DT.

Herbivores at 80 DT increased to almost double their number at 55 DT but parasitoids had a twofold increase at 80 DT over those at 30 and 55 DT. Detritivores also decreased and predators were least abundant at 80 DT.

Results obtained from Vientiane Province showed that the herbivore group increased as the crop matured, from 24.6% at 30 DT to 40% at 80 DT. Parasitoids followed the population trend of the herbivores and predators, reaching peak abundance at 80 DT (Fig. 2). Detritivores decreased with crop age.

Detritivores dominated the samples collected at 30 DT in both Champassak and Saravane. This group showed a continuous decline to 80 DT in Champassak but in Saravane the increase continued after 80 DT. The herbivore group was relatively low in both provinces at all sampling dates, with the exception of 80 DT in Champassak. In most cases, the increase in the number of predators and parasitoids coincided with the increase in the number of herbivores. Generally, the herbivores, predators, and parasitoids were more abundant at 55 DT than at either 30 or 80 DT.

Guild composition

Herbivores. Herbivores were represented by seven orders: Hemiptera, Diptera, Thysanoptera, Coleoptera, Orthoptera, Lepidoptera, and Trichoptera (Table 4). These belonged to 57 families, 180 genera, and 237 species. Hemipterans constituted 86.5% of all herbivores collected, followed by Diptera (6.1%), Thysanoptera (3.3%), Coleoptera (1.9%), Orthoptera (1.4%), Lepidoptera (0.8%), and Trichoptera (0.01%).

Hemipterans belonged to 18 families, 62 genera, and 92 species, the most abundant species being in the families Cicadellidae (30 species) and Delphacidae (18 species). Among the cicadellids, *Nephotettix virescens* (Distant), *Empoascanara* spp., *Thaia* spp., *Recilia dorsalis* (Motschulsky), and *Nephotettix nigropictus* (Stål) were the most abundant. *Sogatella furcifera* (Horvath), *S. vibix*, and *Nilaparvata lugens* Stål dominated the delphacids, with *N. lugens* only around a quarter that of *S. furcifera*.

Dipterans were found to belong to 7 families, 22 genera, and 28 species. This group was dominated by whorl maggots, *Hydrellia philippina* Ferino, *Notiphila* spp., *Psilopa* sp., and *Paralimna* sp. (Ephydridae); the rice gall midge, *Orseolia oryzae* (Wood-Mason); and *Cantarina* spp. (Cecidomyiidae).

Thrips (Thysanoptera), although more abundant than beetles (Coleoptera), were found to belong to only three families. Among the thrips, 17 species were found, dominated by *Thrips* spp., *Haplothrips* spp., and *Stenchaetothrips biformis* (Bagdall).

Ten families, 39 genera, and 42 species of beetles were identified. *Nanophyes* spp. and *Bagous* spp. (Curculionidae) were the most abundant, followed by *Chaetocnema* spp. (Chrysomellidae), *Aeloderma brachmana* (Elateridae), and *Callosobruchus* spp. (Bruchiddae).

Other orders were Orthoptera, Lepidoptera, and Trichoptera. Among the Orthoptera, *Oxya* spp. (Acrdidae) and *Eucyrtus concinnus* (Gryllidae) were the most abundant. Thirteen families in 30 genera and 37 species represented the order Lepidoptera, but they occurred only in small numbers. Only one species of Trichoptera was collected.

Table 4. Composition of the different arthropod guilds collected in the rainfed lowland rice ecosystem, 1995 wet season.

Guild	Order	%	No. of families	No. of genera	No. of species
Herbivores	Hemiptera	86.5	18	59	88
	Diptera	6.1	7	22	28
	Thysanoptera	3.3	3	12	17
	Coleoptera	1.9	10	39	42
	Orthoptera	1.4	5	14	20
	Lepidoptera	0.8	13	30	37
	Trichoptera	0.01	1	1	1
Predators	Aranea (spiders)	35	18	67	91
	Diptera	31	9	19	23
	Hemiptera	19	20	41	52
	Coleoptera	7.7	14	46	55
	Odonata	2.8	2	6	8
	Others	4.5	4	19	24
	Dermaptera		1	1	1
	Hymenoptera		1	1	1
	Mantodea		1	1	1
	Neoroptera		3	6	9
	Orthoptera		1	1	1
	Pseudoscorpionida				
Parasitoids	Hymenoptera	98.0	21	112	164
	Diptera	1.3	5	12	15
	Strepsiptera	0.3	2	3	4
	Acarina	0.4	2	3	3
	Nematoda		1	5	5
Detritivores	Diptera	58	19	43	49
	Collembola	39.5	4	6	6
	Acarina	1.5	2	3	3
	Others	1.3			

Predators. Aranea (spiders) constituted 35% of the predators collected (Table 4). Spiders were found in 18 families, 67 genera, and 91 species. Orb weavers (Tetragnathidae) yielded the highest count of individuals, but Araneidae had the highest count of species. Of the orb weavers, *Tetragnatha* spp. [*T. javana* (Thorell), *T. virescens* Okuma, and *T. maxillosa* Thorell] and *Dyschiriognatha* spp. were the most abundant. *Atypena formosana* Oi (Linyphiidae) was also common. Among hunting spiders, *Pardosa pseudoannulata* (Boesenberg and Strand) (Lycosidae) was the most common, followed by *Clubiona* spp. (Clubionidae) and *Oxyopes* sp. (Oxyopidae).

Nine families were represented in the order Diptera with 19 genera and 23 species. Families Ceratopogonidae (*Nillobezzia* sp., *Stillobezzia* sp., and *Culicoides* sp.), Empidae (*Drapetis* spp.), and Dolicophodidae were the most abundant.

The most common species among the Hemipteran predators were *Cyrtorhinus lividipennis* (Miridae), *Microvelia* spp. (Veliidae), *Mesovelia* spp. (Mesoveliidae), and *Limnogonus* sp. (Geridae) in order of their abundance. These predaceous species were reported to attack eggs and nymphs of all hoppers, although *N. lugens* were often preferred (Heong et al 1990, 1991). This could be one of the reasons for the low population of *N. lugens.*

Fifty-five species of predaceous beetles were found, belonging to 46 genera and 14 families (Table 4), although in all cases they were recorded in low numbers. The more common species were *Stilbus* sp., *Micraspis* spp., *Scymnus* sp. (Coccinellidae), *Paederus* spp., *Oligota* sp. (Staphylinidae), and *Ophionea* spp. (Carabidae).

Among the Odonata, *Agriocnemis* spp. (Coenagrionidae) was the most abundant, although eight species in six genera and two families were represented in the samples. The orders Hymenoptera, Orthoptera, Dermaptera, Mantoidea, and Neuroptera occurred only in small numbers.

Parasitoids. The parasitoid group was from four orders and 98% of all the individuals belonged to order Hymenoptera (Table 4). The other parasitic orders, Diptera, Strepsiptera, and Acarina, constituted 2%. A total of 164 species in 112 genera and 21 families represented the hymenopterans. The most abundant of these species were *Oligosita* spp. and *Paracentrobia* spp. (Trichogrammatidae), followed by *Gonaocerus* spp., *Anagrus* spp. (Mymaridae), *Tetrastichus* spp. (Eulophidae), *Telenomus* spp. (Scelionidae), and *Platygaster* spp. (Platygasteridae). Most of these parasitoids attack eggs of leafhoppers and planthoppers, whereas the other parasitoids listed attack eggs and larvae of stem borers and other Lepidoterans. *Platygaster* spp. parasitize larvae and pupae of the rice gall midge, *Orseolia oryzae* (Wood-Mason).

Detritivores. The most abundant in this group were the flies (Diptera) (58%) and springtails (Collembola) (39.5%). Among the flies, Chironomidae (genera *Chironomus, Cryptochironomus*, and *Tanytarsus*) were the most abundant, followed by Dolicopodidae, Culicidae, and Chloropidae. Other groups of scavengers and tourists belonged to the orders Ephemeroptera, Blattoidea, Coleoptera, and Acarina, and phyla Nematoda, Crustacea, fishes, and snails (*Pila* sp.).

Between-site comparisons

Champassak yielded the greatest total arthropod counts, followed by Sayabouly, Savannakhet, Saravane, Vientiane Province, and Vientiane Municipality. However, the largest number of species (572) was recorded in Sayabouly and then in decreasing order Savannakhet (532), Champassak (473), Vientiane Province (311), Vientiane Municipality (258), and Saravane (253) (Table 5). The fewer species found from the latter three localities might be attributed to the fewer sampling sites (3 fields in each locality). The occurrence of different species in different provinces followed similar patterns. Variations were more distinct in the number of individuals collected per species.

Sayabouly gave the highest number of species of herbivores (170), whereas Savannakhet had the most predators (200). For parasitoids, Sayabouly again yielded the highest number of species (152), followed by Savannakhet (125). Saravane had

Table 5. Herbivore (H) and natural enemy (NE) abundance ratio in the rainfed lowland ecosystem in Laos, 1995 wet season.

Locality	Crop age (DT)	H:NE ratio
Northern region		
Sayabouly Province	30	1:1.1
	55	1:1.0
	80	1:1.7
Central region		
Vientiane Province	30	1:0.6
	55	1:1.2
	80	1:1.2
Vientiane Municipality	30	1:0.6
	55	1:1.0
	80	1:0.7
Savannakhet Province	30	1:1.4
	55	1:1.6
	80	1:1.6
Southern region		
Saravane Province	30	1:1.0
	55	1:1.4
	80	1:2.1
Champassak Province	30	1:1.4
	55	1:1.4
	80	1:1.0

the fewest species of herbivores, whereas Vientiane Municipality yielded the least for parasitoids and predators.

The dominant species of phytophagous Diptera, whorl maggots (*Hydrellia* spp. and *Notiphila* spp.), were most abundant in Sayabouly and least abundant in Saravane. The rice gall midge (*Orseolia oryzae*) was also most abundant in Sayabouly. Among the Cicdellidae (Hemiptera), *N. virescens* was the most abundant in Champassak, whereas, in Sayabouly, it was *Empoascanara* sp. For delphacids, *S. furcifera* was the most abundant in Champassak and *N. lugens* in Sayabouly. Although the same species were found at the other sites, they were collected in lesser numbers.

At all the sites, the spiders *Tettragnatha* spp. were the most abundant, followed by *A. formosana* (Linyphiide), *C. japonicola* (Clubionidae), and *P. pseudoannulata* (Lycosidae). Sayabouly yielded the most abundant spiders, followed by Champassak and Savannakhet. *Cyrtorhinus lividipennis* (Miridae), *Microvelia* spp., and *Mesovelia* spp. were the most abundant among the predaceous Hemiptera at all sites, but were particularly abundant in Sayabouly, Champassak, and Savannakhet. Among the parasitoids, *Oligosita* spp. (Trichogrammatidae), *Gonatocerus* spp., and *Anagrus* spp. (Mymaridae) were the most abundant at all sites. These species attack eggs and nymphs of leafhoppers and planthoppers, but have a preference for *N. lugens*. This may be another reason for the low population of *N. lugens* at the sites surveyed. The average number of taxa for all the sampling dates was highest for predators, followed by herbivores, parasitoids, and scavengers.

Herbivore-natural enemy relationships

For each site and sampling date, herbivore (H) to natural enemy (NE) ratio was calculated (Table 5). In Sayabouly, ratios at 30 and 55 DT were similar, 1:1.1 and 1:1, respectively. However, at 80 DT, the ratio increased to 1:1.7; the average H:NE ratio for the province was 1:1.3. The H:NE ratio at 30 DT in Vientiane Province was low (1:0.6) but increased to 1:1.2 at 55 DT and 80 DT. In Vientiane Municipality, H:NE ratios were 1:0.6 at 30 DT, 1:1 at 55 DT, and 1:0.7 at 80 DT. In Savannakhet, the ratio increased with crop age from 1:1.4 at 30 DT to 1:1.6 at 55 DT and 1:1.8 at 80 DT (Table 5). Saravane had a higher ratio at 80 DT (1:2.1) than at 30 DT (1:1). Champassak showed a 1:1:3 average ratio.

In most samples, natural enemies outnumbered herbivores. The lowest ratio of natural enemies to herbivores was obtained in Savannakhet, followed by Saravane, Sayabouly, Champassak, Vientiane Province, and Vientiane Municipality. These results revealed a more favorable scenario for the pest situation when compared with the results obtained by Heong et al (1991), in which more herbivores than predators were found in Cabanatuan (9:1), Los Baños (5:1), and Banaue (2:1) in the Philippines.

Comparison of arthropod communities in irrigated and rainfed rice ecosystems

Results reported in the study for the rainfed lowland environment showed similarities to those of the dry-season irrigated ecosystem for Laos (Inthavong et al 1996). The guild composition of both ecosystems was similar. During the dry-season study, detritivores also dominated the population of arthropods, with the predominant species being chironomids and collembolans. The seasonal patterns of abundance of the herbivores were similar to those of the predators and parasitoids, with arthropods increasing with crop age. The herbivore population was generally low at the early stage of crop growth, reaching a peak at 49 and 63 DT. Predators followed the same population pattern of herbivores. Parasitoids increased at 35 DT, with a further gradual increase to 63 DT. The combined population of predators and parasitoids exceeded that of herbivores. In the dry-season study, the herbivore Hemiptera was dominated by *Thaia* spp. and *Empoascanara* spp. These two species were also abundant in the rainfed lowland study, but with *Nephotettix* spp. the most abundant. The occurrence and abundance of parasitoids and predators were found to be similar in both ecosystems.

Discussion

According to a 1994 survey, approximately 47% of Laos was under forest cover, including 19% under dense forest cover, one of the highest coverage rates in Asia (MAF 1999). This forest cover provides a diverse patchwork of natural vegetation that is a potentially rich source of natural enemies. A large proportion of the lowland rice fields have been developed for agricultural use in relatively recent times. Patches of trees and other vegetation are often observed around or within the rice paddies. These patches are important habitats that may serve to maintain populations of beneficial arthropods, especially during the 6-month fallow period. Nonrice habitats (i.e., bunds around rice paddies) are important sources of early-arriving predators such as spiders (Arida and Heong 1994) and *Cyrtorhinus lividipennis* Reuter (Bentur and Kalode 1987). Spiders are also found residing in soil crevices in the paddy or on bunds (Arida and Heong 1994) and on rice straw bundles or straw piles in the paddy or bunds (Shepard et al 1989) during the fallow period. Parasitoids taxonomically identical to species attacking eggs of rice hoppers (i.e., *N. lugens*) also parasitize hopper species on wild hosts during fallow periods (Way and Heong 1994). Lao farmers often leave piles of rice straw in the field after harvest. This practice is one way of preserving natural enemy abundance in the field during the fallow period.

Although considerable between-site variability in arthropod species richness and abundance was found in the study, proportional membership in different guilds did not vary much across sites. Herbivores yielded the highest number of species at 55 DT at all sites. Predator species found were also highest at 55 DT except in Savannakhet, for which the greatest abundance was at 80 DT. Among parasitoids, the largest number of species was observed at 55 DT except in Vientiane Province, Champassak, and Saravane, where it was highest at 80 DT.

At all sites, predators and parasitoids outnumbered herbivores. This situation could be the result of the low use of insecticides in the country and it provides a great opportunity to maximize naturally-occurring biological control.

High populations of green leafhoppers (*N. virescens* and *N. nigropictus*) were found but were not causing any problems, even though these species are important vectors of tungro disease of rice (Rivera and Ou 1985) and transitory yellowing (Hsieh et al 1970). These diseases have not been reported in Laos. Likewise, the low population of brown planthopper (BPH) is a reason for a lack of “hopperburn” and grassy stunt and ragged stunt virus diseases, both vectored by BPH. The whitebacked planthopper (*S. furcifera*) is also an important sap-sucking species, though not a disease vector.

The rice gall midge (*Orseolia oryzae*) was found at all survey sites. However, several species of known parasitoids of gall midge were also found. These included *Platygaster* spp., which are egg and larval parasitoids, *Neanastatus* spp. (pupal parasitoid), and *Propicrocystus minificus, Eurotoma* sp., *Tetrastichus* sp., *Telenomus* sp., and *Trichopria* sp. (larval and pupal parasitoids). These and other species of parasitoids attacking the rice gall midge were reported by Kobayshi (1986) and Barrion et al (1996). The presence of such beneficial species in Lao rice fields is one indicator of natural checks on gall midge infestation.

Inthavong et al (1996) reported that, for the Lao irrigated environment, detritivores dominated rice arthropod samples, especially during the early growth stage. This conforms with results of studies in Indonesia (Settle et al 1996), in the Philippines (Schoenly et al 1996a,b), and in the rainfed lowland component of this study in Laos, where populations of detritivores peaked at close to 30 DT. Most detritivores found in the Indonesian study were chironomid larvae, as was the case of this study. Other species included Collembolans (Sminthuridae and Entomobryiidae).

The early occurrence of scavengers/tourists in Laos, Indonesia, and the Philippines provided an abundant and consistent food source for the early-arriving generalist predators while predator populations grew. Some predators and parasitoids became established by 30 DT and continuously increased to 55 DT. Parasitoids increased their colonization up to 80 DT, whereas predators either declined or remained the same. Such trends are consistent with the study of Heong et al (1991), which reported peaked abundances of parasitoids and predators between 40 and 50 DT. At the Lao sites, as populations of herbivores increased, so did predators and parasitoids. This was particularly apparent for cicadellids, delphacids, and the rice gall midge and their respective predators and parasitoids. Total counts of predators and parasitoids at the sampling sites were always greater than herbivore counts. This situation of natural enemies outnumbering herbivores may contribute to the relatively infrequent occurrence of pest problems reported in Laos. A study conducted by Heong et al (1991) in the Philippines showed a reverse pattern. Herbivores were more abundant than predators, ranging from 9:1 to 2:1 ratios at three of their study sites; one site had more predators than herbivores (2:1).

The higher population of natural enemies in Lao rice fields could be attributed to the absence of chemical pesticide use. Studies conducted in the Philippines have showed that natural enemy abundance was much greater in unsprayed plots than in sprayed plots (Schoenly et al 1996a,b). Outbreaks of BPH in several tropical Asian countries have been associated with the widespread and intensive use of insecticides (Heinrichs et al 1982, Heinrichs and Mochida 1984, Kenmore et al 1984). In Laos, where few insecticides are used on rice, outbreaks of insect pests are relatively infrequently reported.

Farmers in Laos perceive the rice gall midge (*Orseolia oryzae*) and rice stem borers (yellow and striped) to be potentially significant damaging pests to their rice crop (Rapusas et al 1997). However, experiments conducted in farmers' fields from 1993 to 1996 (Lao-IRRI 1994, 1995, 1996) failed to demonstrate significant yield losses caused by these pests. Although there have been occasions when gall midge has been known to cause damage, such losses have generally occurred in relatively small areas located near forest. These areas also have high populations of wild rice (*Oryza rufipogon*), an alternate host of the rice gall midge. During the fallow period, this insect aestivates on wild rice and on ratoons of *O. sativa* Linn.

Brown and Southwood (1983) have shown that trophic diversity can increase with successional age, while proportions of species in different guilds remain unchanged. Strong et al (1977) showed that herbivore diversity and abundance are related to host-plant composition, plant architecture (Lawton 1983), geography (Hendrix et al 1988), and environmental fluctuations. In tropical rice ecosystems, however, arthropod communities may vary more with cropping patterns, varieties, and cultivation practices than with season or geography. The predominance of nonrice habitats within or around rice paddies may have contributed to the abundance and diversity of the natural enemy populations inhabiting Laos rice fields. Furthermore, as pesticide use in Laos is minimal, there were no chemical perturbations in the rice ecosystem other than those coming from fertilizer inputs. Lao farmers have, until recently, planted a wide range of rice cultivars, with individual farmers planting 3–4 varieties. This may provide a diverse array of habitat sites and preferences for rice-associated arthropods.

Summary of findings

Arthropods collected were categorized into four guilds: herbivores, predators, parasitoids, and detritivores. Samples yielded a total of 391,713 individuals. Across sites, 763 species of arthropods belonging to 592 genera, 202 families, and 18 orders were found. Detritivores were the most abundant (46.7%), followed by herbivores (23.9%), parasitoids (16.9%), and predators (12.5%). Detritivores were the most common at 30 DT, whereas predators, parasitoids, and herbivores were the most abundant at 55 DT.

The herbivores belonged to 57 families, 180 genera, and 237 species. Spiders constituted 35% of the total predators, followed by Dipterans and Hemipterans. Some 98% of the parasitoids were Hymenopterans. The other 2% belonged to Acarina, Diptera, and Strepsiptera. Hymenopteran parasitoids were dominated by species of the families Trichogrammatidae and Mymaridae (important parasitoids of hopper eggs), Eulophidae and Scelionidae (attack stem borer eggs), and Platygasteridae (attack eggs and larvae of the rice gall midge).

Similar successional patterns in the populations of herbivores, predators, and parasitoids were observed across sites. High populations of predators and parasitoids coincided with high populations of herbivores at 55 DT. Generally, more natural enemies (predators and parasitoids combined) than herbivores were collected. The predominance of natural enemies coincided with the country's low insecticide inputs for rice, thus permitting maximum use of natural biological control agents. Moreover, the predominance of nonrice habitats within and around rice paddies contributed sources and sinks of natural enemy populations.

Implications for rice integrated pest management

An important principle of pest management is to maximize natural biological control. The results of studies in the rainfed and irrigated environments have demonstrated the existence of a mechanism that supports high levels of natural biological control in Laos. It is therefore important that these existing natural biological control agents be conserved by maintaining their natural habitats, especially during the seasons when rice is not cropped, and continuing the current practice of minimal insecticide use. However, as rice production targets increase, and as production is intensified with an expansion of irrigation area and increased fertilizer use, increased pesticide use might be expected to follow. These practices will inevitably change not only the rice ecosystem but also neighboring (nonrice) landscapes in the country.

A recent analysis of farmers' beliefs and practices in Laos showed that farmers beliefs and attitudes toward insects and insecticide use are similar to those in other Asian countries (Heong et al 2002). Farmers strongly believe that insects will decrease production. Lao farmers are potentially vulnerable to becoming victims of insecticide misuse as in many Asian countries that implemented rice intensification programs.

Strategic plans in research, education, extension, and policies related to pest management and pesticide use will need to be developed and implemented in order to avoid the mistakes of the Green Revolution.

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Notes

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Appendix I. Arthropod inventory.

PHYTOPHAGES

Coleoptera

- Apionidae
  - *Apion* sp.***

- Bostrichidae
  - Unidentified Bostrichidae *

- Bruchidae
  - *Callosobruchus* sp. ***
  - *Mylabris* sp. **
  - Unidentified Bruchidae **

- Buprestidae
  - Unidentified Buprestidae **

- Chrysomelidae
  - *Aulocophora* sp.***
  - *Aulocophora cf femoralis* ***
  - *Basilepta* sp. **
  - *Chaetocnema basalis* (Baly) ***
  - *Chaetocnema* spp. ***
  - *Colpodes* sp. **
  - *Dicladispa armigera* (Olivier) ***
  - Galerucinae **
  - *Hispa stygia* (Chapuis) **
  - *Hispellinus* sp. **
  - *Leptinotarsa* sp. **
  - *Luperodes* sp. **
  - *Luperomorpha* sp. **
  - *Medythia* sp. **
  - *Monocerus* sp. **
  - *Monolepta signata* Olivier ***
  - *Monolepta* sp. ***
  - *Oulema* sp. **
  - *Phylotreta* sp. **
  - *Psylliodes* sp.***
  - *Rhyparida* sp. **
  - Unidentified Chrysomelidae A **
  - Unidentified Chrysomelidae B **

- Cucujidae
  - *Cryptolestes pusillus* (Schoener) **

- Curculionidae
  - *Bagous* sp. ***
  - *Echinocnemus* sp. ***
  - *Hydronomidius* sp. **
  - *Nanphyes* sp. ***
  - *Sitophilus* sp. **
  - Sitophilinae **
  - Unidentified Curculionidae A ***
  - Unidentified Curculionidae B **

- Elateridae
  - *Aeoloderma brachmana* (Candeze) ***
  - Unidentified Elateridae ***

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* = recorded in irrigated lowland rice ecosystem (DS) only,
** = recorded in rainfed lowland rice ecosystem (WS) only,
*** = recorded in both rainfed and irrigated rice ecosystems.

Languridae
    Langura sp. **

Pselaphidae
    Unidentified Pselaphidae **

Tenebrionidae
    Unidentified Tenebrionidae **

Diptera
Agromyzidae
    Agromyza sp. **
    Pseudonapomyza sp. *
    Unidentified Agromyzidae ***

Cecidomyiidae
    Cantarina sp. **
    Cantarina nom. rev. *sorghicola* (Coquillet) **
    Orseolia oryzae (Wood-Mason) ***
    Orseolia sp. **

Chloropidae
    Chlorops sp. **

Ephydridiae
    Brachydeutera sp. *
    Ephydra sp. ***
    Hydrellia griseola (Fallen) ***
    H. philippina Ferino ***
    Hydrellia sp. nov. ***
    Notiphila sp. **
    N. dorsopunctata Wiedemann***
    N. similis de Meijere ***
    Paralimna sp. ***
    Psilopa spp. ***
    Psilopinae **
    Unidentified Ephydridae A **

Muscidae
    Atherigona sp. ***
    Unidentified Muscidae **

Tephritidae
    Spathulina sp. ***
    Unidentified Tephritidae **

Tipulidae
    Tipula sp. ***
    Unidentified Tipulidae A ***
    Unidentified Tipulidae B **
    Unidentified Tipulidae C **

Hemiptera
Aleyrodidae
    Unidentified Aleyrodidae ***

Alydidae
    Leptocorisa sp. ***
    L. acuta (Thunberg) ***
    L. oratorious (Fabricius) ***
    Riptortus sp. **

Berytidae
    Unidentified Berytidae **

Cercopidae
    Clovia sp. ***
    Unidentified Cercopidae **

Cicadellidae
    Amrasca sp. **
    Balclutha spp. ***
    Cicadulina bipunctata (Melichar) **
    Cicadulina sp. 1 **
    Cicadulina sp. 2 **
    Cofana spectra (Distant) ***
    Cofana inimaculata (Signoret) ***
    Deltacephalus sp. ***
    Deltacephalus samuelsoni Knight ***
    Empoascacini sp. **
    Empoascanara sp. ***
    E. nana Dworakowska & Pawar **
    Exitianus sp. **
    E. indicus (Distant) **
    Hecalus morrisoni (Thomson) **
    Macrosteles sp. ***
    M. striifrons (Anufriev) ***
    Nephotettix sp. **
    N. malayanus Ishihara & Kawase ***
    N. nigropictus (Stål)***
    N. parvus Ishira & Kawase ***
    N. virescens (Distant) ***
    Recilia dorsalis (Motschulsky)***
    R. distincta (Motschulsky) ***

Scaphoideus morosus Melichar **
Thaia ghauri Dworakowska ***
T. oryzivora Ghauri **
Ugyops sp. *
Unidentified Cicadellidae. **

Cixiidae
Oliarus sp. **
Unidentified Cixiidae **

Delphacidae
Harmalia sp. ***
H. anacharsis Ghauri **
Nilaparvata bakeri Muir **
N. lugens (Stål) ***
Opinconsiva sp. ***
O. dodona (Fennah) ***
Perigrinus maidis (Ashmead)**
Perkinsiella sp. **
Sardia rostrata (Melichar) **
Sogatella furcifera (Horvath) ***
S. kolophon (Kirkaldt)**
S. vibix (Haupt) **
Sogatella sp. **
Stenocranus sp. **
Tarophagus sp. **
Tagosodes pusanus (Distant) ***
Toya propinqua (Fieber) ***
Toya sp. ***

Derbidae
Proutista moesta (Westwood) **
Unidentified Derbidae **

Dictyoparidae
Dictyophara sp. **

Lygaeidae
Cletus sp. **
Cymmoninus sp. **
C. turaensis (Paiva) ***
C. basicornis (Motschulsky) ***
Cymodema sp. **
Horridipamera sp. ***
Nysius nr. vinitor Bergroth ***
Pachybrachius sp. **
P. nietneri (Dohnn) ***
Pachygrontha sp. **
Paromius piratoides Costa **
Unidentified Lygaeidae A ***
Unidentified Lygaeidae B **

Meenoplidae
Nisia nervosa (Mutschulsky) **
Nisia sp. ***

Miridae
Campylomma sp. **
Halticus minutus Reuter **
Halticus sp. **

Pentatomidae
Eysarcoris sp. **
E. ventralis Distant ***
Pygomenida sp. **
Unidentfied Pentatomidae **

Plataspidae
Unidentified Plataspidae **

Pseudococcidae
Unidentified Pseudococcidae A **
Unidentified Pseudococcidae B **

Psyllidae
Unidentified Psyllidae **

Tingidae
Belenus sp. ***
Unidentified Tingidae **

Lepidoptera
Arctiidae
Utethesia sp. **
Unidentified Arctiidae **

Gelechiidae
Sitotroga sp. **

Geometriidae
Geometrid larva **
Unidentified Geometriidae **

Hesperidae
Parnara sp. ***
P. gutatta Bremer & Gray *

Pelopidas mathias (Fabricius) ***
Pelopidas sp. **

Lasiocampidae
Unidentified Lasiocampidae **

Lymantriidae
Lymantria sp. **
Unidentified Lymantriidae **

Noctuidae
Chrysodexis chalcites Esper **
Mocis frugalis (Fabricius) **
Mocis sp. **
Mythimna rosilinea (Walker) **
M. separata (Walker) ***
Naranga aenescens (Moore) ***
Rivula atimeta (Swinhoe) **
Rivula sp. **
Sesamia inferens (Walker) **
Spodoptera mauritia acronyctoides (Guenee)***
Unidentified Noctuidae **

Pieridae
Pieres rapae crucivora Boisduval **

Psychidae
Clania sp. **

Pterophoridae
Unidentified Pterophoridae ***

Pyralidae
Bradina sp. **
Chilo auricillus Dudgeon **
C. suppressalis (Walker) ***
Cnaphalocrocis/Marasmia spp. ***
Nymphula sp. **
N. depunctalis (Guenee) ***
Scirpophaga incertulas (Walker) ***

Satyridae
Melanitis leda leda Cramer **
Pothanthus sp. **
Unidentified Satyridae **

Ypomomeutidae
Unidentified sp. **

Orthoptera
Acrididae
Acrida sp. ***
Acrida willemsie Dirsh **
Ailophus sp. **
Oxya hyla intricata (Stal) ***
O. japonica japonica (Thunberg) ***
Oxya spp, ***
Patanga succinata (Linn) **
Unidentified Acrididae **

Gryllidae
Ducetia sp. **
Eucyrtus cuncinnus (de Haan) ***
Oecanthus sp. **
Plebeiogryllus sp. ***
Teleogryllus sp. ***

Pyrgomorphidae
Atractomorpha sp. ***
A. crenulata (Fabricius) ***
A. psittacina (de Haan) **

Tettigoniidae
Phaneroptera sp. **

Tetrigiidae
Euparatettix sp. **
Paratettix sp. **
Unidentified Tetrigiidae ***

Thysanoptera
Aelothripidae
Unidentified Aelothripidae **

Phaeothripidae
Unidentified Phaeothripidae A ***
Unidentified Phaeothripidae B ***

Thripidae
Caliothrips sp. **
Chirothrips sp. ***
C. manicatus (Haliday) **
Chleothrips sp. **
Eliothrips sp. **

Frankiniella sp. ***
Haplothrips sp. ***
H. aculeatus (Fabricius) ***
H. ganglbaueri Schmutz ***
Scirtothrips sp. ***
Stenchaetothrips sp. **
S. biformis (Bagnall) ***
Thrips palmi Kamy **
Thrips tabaci **
Thrips sp. ***
Unidentified Thripidae A **
Unidentified Thripidae B ***

Trichoptera
Unidentifed Trichoptera **

PREDATORS
Araneae

Orb weavers
Araneidae
Araneus inustus (C.L. Koch) ***
Araneus sp. **
Argiope sp. ***
A. bruenichii **
A. catenulate (Doleschall) ***
Cyclosa sp. **
Cyrtophora sp. ***
Gea subarmata Thorell **
Gea sp. **
Laninia sp. **
Neoscona theisi (Walckenaer) **
Singa harmata (Clerck)**
Singa sp. **
Unidentified Araneidae **

Lyniphiidae
Atypena formosana (Oi) ***
Erigona sp. ***
Linyphia sp. **
Unidentified Lyniphiidae A **
Unidentified Lyniphiidae B **

Metidae
Leucauge decorata (Blackwall) ***
Metinae sp. **
Taylorida striata Thorell **
Tylorida sp. **
Unidentified Metidae **

Philodromidae
Thanatus sp. **
Tibellus sp. **

Tetragnathidae
Dyschiriognatha sp. ***
Tetragnatha sp. ***
T. ceylonica Cambridge **
T. javana (Thorell) ***
T. mandibulata Walckenaer ***
T. maxillosa Thorell ***
T. nitens (Audouin) ***
T. virescens Okuma ***
Unidentified Tetragnathidae **

Theridiosomatidae
Wendilgardia sp. **
Unidentified Theridiosomatidae **

Uloboridae
Uloborus sp. **

Hunters
Clubionidae
Castianera sp, **
Chiracanthium sp. **
Clubiona drassodes O.P.Cambridge **
C. japonica Boesenberg & Strand ***

Gnaphosidae
Zelotes sp. **
Unidentified Gnaphosidae **

Lycosidae
Arctosa sp. **
Hippasa sp. **
H. holmerae Thorell **
Pardosa bimanica Simon **
P. pseudoannulata (Boesenberg & Strand) ***
P. sumatrana (Thorell) **
Pardosa sp. **
Pirata sp. ***
Trochosa sp. ***

Oonopidae
  Oonops sp. **
  Unidentified Oonopidae **

Oxyopidae
  Oxyopes sp. **
  O. javanus thorell ***
  O. lineatipes (C.L. Kock) ***
  O. macilentus C.L. Kock **

Pisauridae
  Dolomedes sp. ***
  Perenethis sp. **
  Unidentified Pisauridae A **
  Unidentified Pisauridae B **

Salticidae
  Bianor hotengchiehi Schenkel ***
  Bianor sp. ***
  Harmochirus sp. **
  H. brachiatus (Thorell) **
  Marpissa sp. **
  Mymarachne sp. ***
  Rhene sp. **
  Plesippus sp. **
  P. paykulli (Audouin) ***
  Salticus sp. **
  Salticus sp. (tiger-like) **
  Unidentified Salticidae ***

Scytodidae
  Scytodes thoracica (Latreille) **

Sparrasidae
  Heteropoda sp. **
  Olios sp. **
  Unidentified Sparrasidae**

Theridiidae
  Chrysso sp. **
  Coleosoma blandum Cambridge **
  C. flavidanum **
  Conopistha sp. **
  Dipoena sp. ***
  Rhompea sagana (Doenitz) **
  Theridion sp. ***
  T. octomaculatum Boesenberg & Strand **
  Unidentified Theridiidae ***

Thomisidae
  Camaricus sp. *
  Runcinia sp. ***
  Thomisus sp. **
  Xysticus sp. **
  Unidentified Thomisidae ***

Acarina
Cunaxidae
  Cunaxa sp. **
  Unidentified Cunaxidae ***

Hydrachnidae
  Hydrachna sp. **
  Unidentified Hydrachnidae ***

Mesostigmatidae
  Unidentified sp. **

Phytoseidae
  Unidentified sp. **

Trombiculidae
  Unidentified Trombiculidae **

Coleoptera
Anthicidae
  Anthicus sp. ***
  Formicomus sp. ***
  F. braminus (La Ferte Senectere) ***
  Unidentified Anthicidae A ***
  Unidentified Anthicidae B **

Carabidae
  Anoplogenius sp. ***
  Batoscelis sp. **
  Chlaenius sp. **
  Cicindella sp. **
  Drypta sp. **
  D. japonica (Bates) **
  Egadroma sp. **
  Ophionea sp. ***
  O. indica (Thunberg) **
  O. interstitialis Schymidt-Goebel **
  O. ishii Habu **
  Selena sp. **

- *Stenius* sp. **
- Unidentified Carabidae A ***
- Unidentified Carabidae B **

Cleridae
- Unidentified Cleridae ***

Coccinellidae
- *Brumoides* sp. ***
- *Coccinella repanda* Thunberg ***
- *Harmonia octomaculata* (Fabr.) *
- *Micraspis discolor* (Fabr.) ***
- *M. vincta* (Gorham) ***
- *Paracymnus* sp. **
- *Scymnus* sp. ***
- Unidentified Coccinelidae **

Dysticidae
- *Agabus* sp. **
- *Cybister* sp. ***
- *Laccophilus* sp. **
- *Rhantus* sp. **
- Unidentifed Dysticidae ***

Gryinidae
- Unidentified Gryinidae **

Halyplidae
- *Peltodytes* sp. **

Hydraenidae
- *Hydraena* sp. ***
- Unidentified Hydraenidae ***

Hydrophilidae
- *Berosus* sp. **
- *Stemolophus* sp. **
- Unidentified Hydrophilidae ***

Melyridae
- *Apalochrus* sp. ***
- *A. rufofasciatus* Pic ***

Mordellidae
- Unidentified Mordellidae **

Phalacridae
- *Stilbus* sp. ***

Spercheidae
- *Sphercus* sp. **

Staphylinidae
- *Oligota* sp. **
- *Paederus* sp. **
- *P. fuscipes* Curtis **
- *P. tamulus* Erichson ***
- *Philonthus* sp. ***
- *Stenus* sp. ***
- *Stilcopsis* sp. ***
- Unidentified Staphylinidae A ***
- Unidentified Staphylinidae B **

Diptera

Asilidae
- Unidentified Asilidae **

Ceratopogonidae
- *Culicoides* sp. **
- *Dasyhelea* sp. **
- *Nilobezia* sp. ***
- *Nilobezia*-like, red-brown
- *Nilobezia*-like, light brown
- *Stilobezia* sp. **
- Unidentified Ceratopogonidae ***

Chloropidae
- *Anatrichus pygmaeus* (Loew) ***
- *Anatrichus* sp. **
- Unidentified Choloripidae **

Dolicopodidae
- *Syntretus* sp. **
- Unidentified Dolicopodidae A (blue) **
- Unidentified Dolicopodidae B (yellow) **
- Unidentified Dolicopodidae C **

Empidae
- *Drapetis* sp. 1 ***
- *Drapetis* sp. 2 ***

Ephydridae
- *Ochthera brevitibialis* de Mejere ***

Platystomatidae
  Poecilotraphera taeniata (Macquart) ***

Stratiomyidae
  Microchryza sp. *

Syrphidae
  Epistrophe sp. ***
  Vulbocela sp. **
  Unidentified Syrphidae ***

Hemiptera
Anthocoridae
  Orius sp. ***
  O. tantillus (Motschulsky) ***
  Unidentified Anthocoridae **

Belostomatidae
  Diplonychus rusticus (Fabr.) **

Corixidae
  Micronecta sp. **
  M. quadristrigata Breddin**

Dipsocoridae
  Unidentified Dipsocoridae **

Gerridae
  Gerris sp. ***
  G. adelaides Dohrn **
  Limnogonus sp. ***

Hebridae
  Hebrus sp. ***

Hydrometridae
  Hydrometra spp. ***

Leptopodidae
  Unidentified Leptopodidae **

Lygaeidae
  Geocoris sp. **
  Graphotesthus sp. ***

Mesoveliidae
  Mesovelia vittigera (Horvath) ***

Miridae
  Creontiades sp. ***
  C. pallidifer **
  Cyrtorhinus lividipennis Reuter ***
  Deraecoris sp. **
  Proboscidocoris sp. ***
  Tytthus chinensis (Stål) ***
  Unidentified Miridae A ***
  Unidentified Miridae B **

Nabidae
  Nabis sp. **
  Stenonabis sp. ***
  S. tagalicus (Stål) ***
  Unidentified Nabidae **

Nepidae
  Ranatra sp. **
  R. diminuta Montadon **

Notonectidae
  Anisops spp. ***
  Enithares sp. **
  Unidentified Notonectidae **

Ochteridae
  Ochterus sp. **
  O. marginatus (Latreille) **

Pentatomidae
  Eurydema sp. **
  Zincrona caerulea (Linne) **

Plataspidae
  Coptosoma sp. **

Pleidae
  Paraplea sp. **
  Plea sp. **
  P. liturata **
  Unidentified Pleidae **

Reduviidae
  Polytoxus sp. ***
  Scipinia sp. **
  S. horrida Stål **
  Staccia sp. **
  Unidentified Reduviidae **

Veliidae
Microvelia sp. ***
M. douglasi atrolineata Bergroth ***
M. douglasi Scott **
Unidentified Veliidae A **
Unidentified Veliidae B **

Hymenoptera
Formicidae
Anoplolepis sp. ***
Camponotus sp. **
Diacamma sp. ***
Monomorium sp. **
M. floricola **
Oecophylla smarginata (Fabr.) **
Pheidole sp. **
Plagiolepis sp. **
Polyrachis sp. **
Solenopsis sp. A ***
Solenopsis sp. B **
Tapinoma sp. ***
Tetramorium ninatum (Nylander) **
Tetramorium sp. A **
Tetramorium sp. B **
Technomyrmex sp. **
Unidentified Formicidae **

Mutillidae
Unidentified Mutillidae **

Sphecidae
Unidentified Sphecidae **

Vespidae
Ropalida sp. ***
R. cyathiformis (Fabricius) ***
Vespa sp. **
Unidentified Vespidae **

Mantodea
Mantidae
Unidentified Mantidae **

Neuroptera
Chrysopidae
Unidentified Chrysopidae **

Odonata
Coenagrionidae
Agriocnemis spp. ***
Coenagrion sp. ***
Ischnura senegalensis (Brauer) ***

Libelludidae
Diplacodes sp. **
D. trivialis Fabr. ***
Neurothemis sp. **
N. tullia tullia (Drury) ***
Orthethrum sp. ***

Orthoptera
Gryllidae
Anaxipha sp. ***
Metioche sp. **
M. vittaticolis (Stål) ***

Tettigoniidae
Conocephalus longipennis (de Haan) ***
C. maculatus (de Guillou) ***
Euconocephalus sp. **
Euconocephalus varius (Walker) **
Unidentified sp. *

Tridactylidae
Tridactylus sp. **

Pseudoscorpionida
Pseudoscorpionidae
Unidentified Pseudoscorpionidae **

PARASITOIDS

Acarina
Hydrachnidae
Hydrachna sp. **
Unidentified Hydrachnidae **

Tarsonemidae
Unidentified Tarsonemidae ***

Diptera
Phoridae
Megaselia spp. ***
Unidentified Phoridae **

- Pipunculidae
  - *Pipunculus* sp. ***
  - *P. mutillatus* Loew **
  - *Tomosvaryella* sp. ***
  - *T. inazumae* (Koizumi) **
  - *T. oryzaetora* (Koizumi) **
  - Unidentified Pipunculidae *

- Sarcophidae
  - Unidentified Sarcophidae **

- Sciomyzidae
  - *Sepedon* sp. ***

- Tachnidae
  - *Argyrophylax* sp. **
  - *Halidaya luteicornis* (Walker) **
  - *Siphona* sp. ***
    - Unidentified Tachinidae A ***
    - Unidentified Tachinidae B **

Hymenoptera

- Aphelinidae
  - *Aphelinus* sp. **
  - *Aphytis* sp. **
  - *Encarsia* sp. ***
  - Unidentified Aphelinidae **

- Bethyliida
  - *Goniozus* sp. **
  - *G.* nom. rev. *triangulifer* Kieffer **

- Braconidae
  - *Aphidius* sp. **
  - *Aspilota* sp. ***
  - *Bracon chinensis* (Szepligeti) ***
  - *B. onuki* Watanabe ***
  - *Bracon* sp. ***
  - *Cotesia* spp. ***
  - *Cubochelonus* sp. **
  - *Diatrella* sp. **
  - *Euopius* sp. ***
  - *Exoryza schoenobii* (Wilkinson) ***
  - *Hygroplitis russatus* (Haliday) **
  - *Macrocentrus* sp. **
  - *M. philippinensis* Ashmead **
  - *Opius barrioni* Fisher **
  - *Opius* sp. ***
  - *Rogas* sp. ***
  - *R. narangae* Rohwer **
  - *Tropobracon* sp. ***
  - *T. schoenobii* (Viereck) ***
  - Unidentified Braconidae A ***
  - Unidentified Braconidae B ***

- Ceraphronidae
  - *Aphanogmus* sp. ***
  - *A. fijiensis* (Ferriere) ***
  - *Ceraphron* sp. ***
  - *Ceraphron* sp. A **
  - *Ceraphron* sp. B **

- Chalcididae
  - *Antrocephalus* sp. **
  - *Brachymeria* sp. **
  - *B. excarinata* Gahan ***
  - *B. lasus* (Walker)**
  - Unidentified Chalcididae **

- Cypinidae
  - *Eucoilidea* sp. ***
  - Unidentified Cypinidae *

- Diapriidae
  - *Spilomicrus* sp. **
  - *Trichopria* sp. ***
  - *Trichropia* sp. 1 ***
  - *Trichropia* sp. 2 **
  - Unidentified Diapriidae *

- Dryinidae
  - *Echthrodelphax* sp. **
  - *E. fairchildii* Perkins **
  - *Haplogonatopus* sp. ***
  - *Neogonatopus* sp. **
  - *Pseudogonatopus* sp. ***
  - *Tetrodontochelys* sp. **
  - Unidentified Dryinidae ***

- Elasmidae
  - *Elasmus* sp. A***
  - *Elasmus* sp. B **
  - *Elasmus* sp. C **

- Encyrtidae
  - *Anagyrus* sp. ***

Copidosoma sp. **
Copidosomopsis sp. ***
C. nacoleiae (Eady) ***
Encyrtus sp. **
Unidentified Encyrtidae A ***
Unidentified Encyrtidae B **

Eulophidae
Diglyphus sp. **
Eotetrastichus sp. **
E. beatus **
E. formosanus ***
Euplectus sp. **
E. chapadae (Ashmead) ***
Hemiptarsenus sp. **
H. cf. semialbiclavus Girault ***
Norbanus sp. ***
Pediobius sp. **
Stenomesius sp. **
Sympiesis sp. ***
Tetrastichus sp. ***
T. howardii (Olliff) **
T. schoenobii Ferriere ***
Unidentified Eulophidae ***
Unidentified Tetrastichinae **

Eupelmidae
Eupelmus sp. **
Neanastatus sp. ***
Neanastatus sp. A **
Neanastatus sp. B **

Eurytomidae
Eurytoma sp. ***
E. braconidia (Wilkinson) ***

Ichneumonidae
Amauromorpha sp. ***
A. accepta metathoracica (Ashmead) **
Astomaspis sp. **
A. metathoracica **
Casinaria sp. **
Charops sp. **
Coccygomimus sp. **
Goryphus sp. ***
Itoplectis narangae (Ashmead) **
Leptbatopsis sp. **
Linella sp. ***
Metopius rufus (Ashmead) **
Metopius sp. **
Paraphylax spp. **
Stenobracon sp. **
Strepsimallus sp. **
Temelucha stangli (Ashmead) ***
Temelucha sp. **
Temelucha-like **
Theronia sp.**
Vulgichneumon leucaniae Uchida **
Xanthopimpla punctata (Fabr.) *
X. flavolineata (Cameron) ***
X. stemmator (Thunberg) **

Mymaridae
Acmopolynema sp. **
Anagrus spp. ***
Anaphes sp. **
Arescon sp. **
Gonatocerus spp. ***
Mymar sp. **
M. taprobanicum Ward ***
Polynema sp. **
Stephanodes sp. **
Unidentified Mymaridae **

Platygasteridae
Inostema sp. **
Platygaster sp. ***
P. foersteri (Gahan) **
P. oryzae (Cameron)**

Pteromalidae
Obtusiclava sp. **
Panstenon nom. rev. *collaris* Boucek **
Panstenon sp. ***
Propicrcystus sp. **
P. minificus (Girault) **
Trichomalopsis spp. ***
Unidentified Pteromalidae **

Scelionidae
Baeus spp. ***
Ceratobaeus sp. ***
Fusicornia sp. **
Gryon sp. **
G. nixoni Masner ***
Idris spp. ***

Macrotelia sp. **
Platyscelio sp. ***
Psix sp. **
Scelio sp. **
Telenomus sp. ***
T. dignoides Nixon ***
T. rowani (gahan) ***
Trimorus sp. **
Unidentified Scelionidae A ***
Unidentified Scelionidae B ***
Unidentified Scelionidae C **

Tiphiidae
Unidentified Tiphiidae **

Torymidae
Podagrion sp. **
Unidentified Torymidae ***

Trichogrammatidae
Epoligosita sp. **
Megaphragma sp. **
Oligosita sp. nov. A **
Oligosita sp. nov. B **
Oligosita spp. ***
O. aesopi Girault **
O. consanguinea Girault **
O. naias Girault **
Paracentrobia sp. ***
P. andoi (Ishii) ***
Trichogramma sp. ***
T. chilonis Ishii ***
T. japonicum Ashmead ***
Trichogrammatoidea sp. **
Unidentified Trichogrammatidae ***

Strepsiptera
Elenchidae
Elenchus sp. **
E.yasumatsui Kifune & Hirashima **

Halictophagidae
Halictophagus sp. **
Unidentified Strepsiptera **

Nematoda
Mermithidae
Hydromermis sp. **
Unidentified Mermithidae **
Unidentified nematode **
Nematode on BPH **
Unidentified Nematoda **

SCAVENGERS (Detritivores) and TOURISTS

Acarina
Oribatidae
Oribatid mites **
Unidentified Oribatidae **

Uropididae
Unidentified Uropididae **

Blattodea
Blatellidae
Blatella sp. **
Unidentified Blatellidae **

Coleoptera
Chrysomellidae
Altica cyanea (Weber) ***

Inoplepidae
Unidenified Inoplepidae **

Ptinidae
Unidentified Ptinidae ***

Collembola
Entomobryiidae
Entomobrya sp. **
Unidentified Entomobryiidae **

Isotomidae
Isotoma sp. **
Unidentified Isotomidae **

Poduridae
Unidentified Poduridae **

Sminthuridae
Sminthurus sp. ***

Diptera

Anthomyiidae
- Unidentified Anthomyiidae **

Calliphoridae
- *Calliphora* sp. **
- Unidentified Calliphoridae

Celyphidae
- Unidentified Celyphidae

Chironomidae
- *Chironomus* spp. ***
- *Cryptochironomus* spp. ***
- *Smittia* sp. **
- *Tanytarsus* sp. **
- Unidentified Chironomidae A ***
- Unidentified Chironomidae B **

Chloropidae
- *Conioscinella* sp. **
- *C. griseicollis* (Becker)**
- *C. inequalis* Becker **
- *Stelescerulus ensifer* (Thomson) **
- Unidentified Chloropidae **

Culicidae
- *Aedes* sp. **
- *Anopheles* sp. **
- *Culex* sp. **
- Unidentified Culicidae **

Diopsidae
- Unidentified Diopsidae **

Drosophilidae
- Banded Drosophilidae **
- Yellow Drosophilidae **
- *Drosophila* sp. **
- Unidentified larva **
- Unidentified Drosophilidae **

Ephydridae
- *Discomyza* sp. **
- *Scatella* sp. ***
- Unidentified Ephydridae A **
- Unidentified Ephydridae B **

Heliomyzidae
- Unidentified Heliomyzidae **

Mycetophilidae
- Unidentified Mycetophilidae ***

Muscidae
- *Musca domestica* **
- *Musca* sp. **
- Unidentified Muscidae **

Psychodidae
- *Psychoda* sp. **
- Unidentified pupa **
- Unidentified Psychodidae **

Pergotidae
- Unidentified Pergotidae

Scatopsidae
- Unidentified Scatopsidae **

Simuliidae
- Unidentified Simuliidae **

Stratiomyidae
- *Hemetia illucens* (L.) **
- *Odontomyia* sp. **
- Unidentified Stratiomyidae **

Tabanidae
- *Chrysops* sp. **
- *Tabanus* sp. **
- Unidentified Tabanidae **

Tephritidae
- *Rhabdochaeta* sp. **
- Unidentified pupa **
- Unidentified Diptera **

Ephemeroptera
- *Baetis* sp. **

Hymenoptera

Apidae
- *Apis* sp. **

Others

- Crustacea
    - *Cypris* sp. **
    - *Cypris*-like **
    - *Cyclops* **
    - *Eucyclops* **
    - *Daphnia*-like **
    - Species A-H **
- Crab **
- Fish **
- Snails **
    - *Pila* sp. **
- Tadpoles **
- Earthworms **

CHAPTER 17

Pests and diseases of the rice production systems of Laos

B. Douangboupha, K. Khamphoukeo, S. Inthavong, J. Schiller, and G. Jahn

Until the early 1990s, rice production in Lao PDR (Laos) was based on traditional production systems with minimum inputs apart from labor. Because of the relative isolation of the country, the Green Revolution of the late 1960s and 1970s had relatively little impact on rice production systems in Laos. Until the mid-1990s, there was little use of chemical pesticides in most areas of agricultural production. Studies by Rapusas et al (1995, 1997) (refer also to Chapter 16) about this time showed a much greater diversity in the communities of insects in the rice environments of Laos than was found in other countries of the region where insecticide use had become routine in rice production systems. Some of the insect species found in Laos are pests, but most are harmless or beneficial species (Shepard et al 1995).

Pests and diseases, although present in Lao rice production systems, are generally not regarded as major constraints to yield, although some pests, such as the rice gall midge (RGM) (*Orseolia oryzae* (Wood-Mason)), can significantly affect yields on a year-to-year and area-specific basis (Inthavong 1999). However, some recent changes in traditional rice production practices are believed to have brought about increased pest and disease problems, with the greatest changes and greatest impact taking place in the lowland environment. This chapter reviews the importance and recent changes in the status of the major pests and diseases of rice in Laos.

The lowland rice environment

Changes in agricultural systems in lowlands

Before the 1960s, rainfed rice cultivation was the single most important rice production system in the country, with 100% of varieties grown being traditional cultivars, which were cultivated using traditional methods. Little information is available on rice pest and disease problems during that period. It has only been since 1990 that systematic studies have been undertaken on insect pests and diseases (and other production constraints) in the rice environments of Laos. The most recent plant protection research has concentrated on the rainfed lowland environment, as this has been, and remains, the dominant rice ecosystem in Laos.

Improved high-yielding varieties were first used on a limited scale in intensified rice systems in the late 1970s, making their impact mainly in areas where irrigation facilities were available. Changes in agricultural practices can sometimes result in increased pest and disease problems. Several examples can be cited from Laos. Some of the higher-yielding improved rice varieties are more susceptible to insect pests and diseases than traditional cultivars. The release of the high-yielding variety Thadokham-1 (TDK-1) in 1993 was associated with an epidemic of bakanae disease (caused by *Gibberella fujikuroi*). The variety RD10, first introduced from Thailand in the late 1970s, was susceptible to stem borer. Since 1986, brown planthopper (BPH) (*Nilaparvata lugens* (Stål)) and rice bug (*Leptocorisa oratorius*) (Fabricius) have caused serious damage to dry-season irrigated rice crops in several provinces in the central and southern agricultural areas (particularly in the provinces of Vientiane (and Vientiane Municipality), Borikhamxay, Khammouane, and Saravane). In contrast, maturity time rather than susceptibility is often the determining factor in rice bug outbreaks. The adoption of improved early-maturing varieties in some areas of lowland rice cultivation has sometimes been associated with increased rice bug damage (Lao-IRRI 2000). The significant expansion in the area of irrigated rice cultivation since the mid-1990s in the central and southern agricultural regions, allowing both wet-season and dry-season rice cropping, has provided conditions favorable for the carryover of pests from season to season.

Pests and diseases in the lowland rice environment

The lowland rice environment in Laos consists of a combination of wet-season rainfed and dry-season irrigated rice cultivation. More than 80% of the lowland rice-growing area in the wet season is located in the central and southern agricultural regions of the country. Farmers have generally cited drought and poor soil fertility as the major constraints to production and yields in wet-season rice cultivation in these areas (Schiller et al 2001). Until relatively recently, insect pests and diseases have generally not been regarded as major production constraints in the wet-season rainfed lowland environment. Insect pests probably cause more damage to lowland rice crops than diseases (Rapusas et al 1995). Serious pest and disease outbreaks that have periodically caused significant declines in yields and total production have included outbreaks of BPH in parts of Vientiane Province and Vientiane Municipality in dry-season irrigated areas in 1998; rice bug (*L. oratorius*) damage in Saravane Province in 1998; RGM damage in Atsaphangthong District of Savannakhet Province in the 1992 wet season, and in several districts of the same province in 2005; rice blast in Hadsayphong District of Vientiane Municipality in 1995; and neck blast in parts of Khammouane Province in 2005.

The occurrence of significant pest and disease problems is often related to the prevailing weather conditions. Outbreaks of RGM and armyworms are generally associated with high rainfall in the wet season. Drought conditions during the period of seeding the rice crop at the beginning of the wet season can often be associated with a higher than usual incidence of rice thrips. Very warm weather in the period of dry-season irrigated rice cultivation can lead to BPH and stem borer outbreaks. Sheath blight is often a problem if rain is received during the maturation phase of dry-season irrigated rice crops.

Some recent pest problems of Laos have been the result of intentional or accidental introductions of exotic species. The rapid spread of golden apple snail (*Pomacea canaliculata*) since 1992 and the outbreak of bakanae disease in 1993 are examples of exotic species that, following their introduction, have subsequently achieved pest status in Laos. Among significant weed species currently found in Laos are two that were also relatively recently introduced: the water hyacinth (*Eichhornia crassipes* Martius) and the giant sensitive plant (*Mimosa pigra* L.), both of which originated from South America (Napomphet 1992, Miller and Pickering 1980) and became major weeds in Laos, following their introduction and establishment in neighboring countries, from where they then spread to Laos.

The insect pests and diseases that have been recorded in the lowland environments of Laos, and their relative importance, are listed in Table 1. The major pests of lowland rice environments are described in the following sections.

Rice gall midge (*Orseolia oryzae*) (Wood-Mason)

With the exception of the Philippines and Malaysia, the Asian rice gall midge is a serious rice pest of all rice-producing countries in South and Southeast Asia (Gagne 1985). It is the most consistently reported cause of yield loss due to insects in the wet-season rainfed lowland environment of Laos (Lao-IRRI 1997). However, in areas of double cropping it has not been reported to be an important pest.

RGM damage has been recorded in many parts of Laos, but particularly in the provinces in the central and southern agricultural regions, including Vientiane, Borikhamxay, Khammouane, Savannakhet, Saravane, and Champassak. It has also been reported in the more northern provinces of Sayabouly and Xieng Khouang (Inthavong 1999, Inthavong et al 2004). Gall midge damage can reduce grain yield of wet-season lowland crops in Laos by 30–60% (Inthavong et al 2004). Detailed studies on the gall midge problem in the rainfed lowland environment have been undertaken in Savannakhet Province in the lower part of the central agricultural region of Laos. The RGM breeds on host plants in May, migrates to the seedbeds of wet-season crops in May or June, and is transferred during transplanting to paddy fields in June or July. Generally, RGM infestations become apparent between July and September, with peak damage toward the end of August and early September (Fig. 1). In recent times, particularly high RGM incidence and damage were recorded in areas of rainfed lowland cropping in Laos in the wet seasons of 1999, 2000, and 2005. The degree of RGM damage in any year is closely related to rainfall distribution and time of planting (Hikada et al 1994, 1996, Lao-IRRI 1996, 2001). Early wet-season plantings (May) are generally associated with low levels of infestation. Later plantings (in June and July) often enter the tillering stage of crop development when weather conditions are favorable to the buildup of gall midge populations; when combined with higher than average rainfall in September and October, RGM damage and yield loss can be very severe (Lao-IRRI 1999).

Table 1. Insect pests and diseases found in the lowland rice production systems of Laos.

Region	Common name	Scientific name	Period of crop growth	Ranking^a	
				Wet-season crops	Dry-season crops
Northern					
	Pests				
	Ants	*Solenopsis geminate*	Sowing	+	+
	Golden apple snail	*Canaliculata incertulas*	Seedling	+++	+++
	Asian rice gall midge	*Orseolia oryzae*	Tillering	+++	++
	Black bugs	*Scotinophara* spp.	Tillering	+	+
	Brown planthopper	*Nilaparvata lugens*	Tillering-harvest	+++	+++
	Grasshopper	*Oxya* spp. and *Acrida* spp.	Seedling-ripening	++	+
	Hispa	*Dicladispa armigera*	Tillering	+	+
	Rats	*Rattus* sp. *and Mus* sp.	Sowing, reproductive	+++	+++
	Rice bug	*Leptocorisa oratorius*	Reproductive	++	++
	Stem borers	*Chilo suppressalis*	Tillering	++	++
		Scirpophaga incertulas	Tillering	++	++
	Thrips	*Balothrips biformis*	Seedling	++	++
	Diseases				
	Bakanae disease	*Fusarium moniliforme*	Tillering	++	++
	Brown spot	*Helminthosporium oryzae*	Tillering-reproductive	++	++
Central					
	Pests				
	Golden apple snail	*Canaliculata incertulas*	Seedling	+++	+++
	Armyworm	*Spodoptera mauritia*	Seedling-panicle	++	+
	Asian rice gall midge	*Orseolia oryzae*	Tillering	+++	++
	Brown planthopper	*Nilaparvata lugens*	Tillering-harvest	+++	+++
	Caseworm	*Nymphula litura*	Tillering	+	+
	Cutworm	*Spodoptera litura*	Seedling-tillering	+	+
	Leaffolder	*Cnaphalocrocis medinalis*	Tillering	+	+
	Rice bug	*Leptocorisa oratorius*	Reproductive stage	+++	+++
	Stem borers	*Chilo suppressalis*	Tillering	++	++
		Scirpophaga incertulas	Tillering	+	+
		S. innotata, Sesamia inferens	Tillering	+	+
	Thrips	*Balothrips biformis*	Seedling	++	++
	Whitebacked planthopper	*Sogatella furcifera*	Tillering	++	+
	Whorl maggot	*Hydrellia philippina*	Tillering	+	+
	Zigzag leafhopper	*Recilia dorsalis*	Tillering	++	++
	Diseases				
	Bacterial leaf blight	*Xanthomonas campestris*	Maximum tillering-reproductive stage	++	++
	Bakanae disease	*Fusarium moniliforme*	Tillering	++	++
		Gibberella fujikuroi	Tillering	++	++

Continued on next page

Table 1 continued.

Region	Common name	Scientific name	Period of crop growth	Ranking* Wet-season crops	 Dry-season crops
	Blast	*Pyricularia oryzae*	Seedling-reproductive stage	++	++
	Brown spot	*Helminthosporium oryzae*	Tillering-reproductive stage	++	++
	False smut	*Ustilaginoidea virens*	Flowering-maturing	+	+
	Foot rot	*Erwinia chrysanthemi*	Maximum tillering-reproductive stage	+	+
	Leaf streak	*Xanthomonas campestris*	Tillering-reproductive stage	+	+
	Narrow brown leaf spot	*Cercospora oryzae*	Tillering-reproductive stage	++	++
	Sheath blight	*Rhizoctonia solani*	Maturing	+	+
	Sheath rot	*Sarocladium oryzae*	Booting	++	++
	Stem rot	*Helminthosporium sigmoideum*	Reproductive stage	++	++
Southern					
	Pests				
	Golden apple snail	*Canaliculata incertulas*	Seedling	+++	+++
	Armyworm	*Spodoptera mauritia*	Seedling-panicle	++	+
	Asian rice gall midge	*Orseolia oryzae*	Tillering	+++	++
	Brown planthopper	*Nilaparvata lugens*	Tillering-harvest	+++	+++
	Caseworm	*Nymphula litura*	Tillering	+	+
	Cutworm	*Spodoptera litura*	Seedling-tillering	++	++
	Leaffolder	*Cnaphalocrocis medinalis*	Tillering	+	+
	Rice bug	*Leptocorisa oratorius*	Reproductive stage	+++	++
	Stem borers	*Chilo suppressalis*	Tillering	++	++
	Thrips	*Balothrips biformis*	Seedling	++	++
	Whitebacked planthopper	*Sogatella furcifera*	Tillering	++	+
	Whorl maggot	*Hydrellia philippina*	Tillering	+	+
	Zigzag leafhopper	*Recilia dorsalis*	Tillering	++	++
	Diseases				
	Bacterial leaf blight	*Xanthomonas campestris*	Maximum tillering-reproductive stage	++	++
	Bakanae disease	*Fusarium moniliforme*	Tillering	++	++
		Gibberella fujikuroi	Tillering	++	++
	Blast	*Pyricularia oryzae*	Seedling-reproductive stage	++	++
	Brown spot	*Helminthosporium oryzae*	Tillering-reproductive stage	++	++

Continued on next page

Table 1 continued.

Region	Common name	Scientific name	Period of crop growth	Ranking*	
				Wet-season crops	Dry-season crops
	False smut	*Ustilaginoidea virens*	Flowering-maturation	+	+
	Foot rot	*Erwinia chrysanthemi*	Maximum tillering-reproductive stage	+	+
	Leaf streak	*Xanthomonas campestris*	Tillering-reproductive stage	+	+
	Narrow brown leaf spot	*Cercospora oryzae*	Tillering-reproductive stage	++	++
	Sheath blight	*Rhizoctonia solani*	Maturation	+	+
	Sheath rot	*Sarocladium oryzae*	Booting	++	++
	Stem rot	*Helminthosporium sigmoideum*	Reproductive stage	++	++

[a]+++ = very important, ++ = important, + = relatively unimportant.
Source: Modified from Sounthone et al (1995).

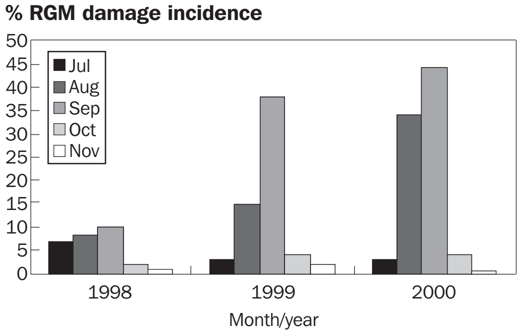

Fig. 1. Damage incidence of RGM in the 1998, 1999, and 2000 wet-season lowland rice crops of Savannakhet Province of Laos (Source: Lao-IRRI 2001).

Studies on levels of varietal susceptibility to RGM undertaken in an area with chronic levels of RGM infestation in Savannakhet Province in central Laos in the wet seasons of 1999, 2000, and 2001 have shown a wide range in susceptibility of both recommended improved and traditional varieties (Table 2). Traditional variety *Muangna* (originating from northern Laos) has shown a high level of resistance, with less than 5% of damaged tillers, relative to more than 50% of tillers being damaged in susceptible varieties in the same growing seasons. A further 17 entries were classified as having moderate levels of resistance, with 6% to 15% of tillers damaged; included among these are varieties RD6, CR203, CR23, IR66, NGS19, and the traditional

Table 2. Classification of recommended and promising varieties for rice gall midge resistance in the rainfed lowland environment of Savannakhet Province, 1999-2001.

Varieties and promising lines	WS 1999	WS 2000	WS 2001
1. TDK1	MS[a]	MS	MS
2. TDK2	MS	MS	MS
3. TDK3	MS	MS	MS
4. TDK4	MS	MS	MS
5. TSN1	MR	MS	MS
6. PNG1	MR	MR	MS
7. RD10	MS	MS	MS
8. RD6	MR	MR	MR
9. RD8	MR	MR	MR
10. RD23	MR	MR	MR
11. NSG19	MR	MS	MR
12. NTN1	MS	MS	MS
13. CR203	MR	MR	MR
14. IR66	MR	MR	MR
15. KDML105	MS	MS	MS
16. Muangna	R	R	RM
17. Ise	MS	MR	R
18. Phuamalai	MS	MS	MS
19. Dokmai	MS	MS	S
20. Dokphao	MS	MS	MS
21. Luakhat	MS	S	MS
22. Takhet	MS	MS	MS
23. Naiteng	MS	MS	MS
24. Iphon	MS	S	S
25. Hom Nangnuan	MR	MS	MS
26. IR70220-UBN-3-TDK-4-1	R	MR	MS
27. IR57514-SPN-299-2-1-1	R	MS	MR
28. IR68101-TDK-1-B-1-1	R	MR	MR
29. IR70824-TDK-44-B-B-1-2	MR	MR	MR
30. LNT-1	MR	MR	MR
31. IR68101-TDK-B-B-33-1	MR	MS	MR
32. IR66396-APA-51-3R-0	MR	MS	MS
33. IR68105-TDK-B-B-22-1	MR	MS	MR
34. IR71514-TDK-6-1-3	MR	MS	MS
35. IR71514-TDK-9-1-2	MR	MR	MR
36. IR57514-PMI-5-B-1-2	MR	MS	MR
37. IR68105-TDK-B-B-27-1	MS	MS	MS
38. IR68101-TDK-B-B-33-3	MS	MS	MS
39. IR-UBN8-4-TDK-B-B-7-1	MS	MS	MR
40. IR68102-TDK-B-B-7-1	MS	MS	MS
41. IR46346-KKN-1-2-1-3	MS	MR	MR
42. SPT84276-PAN-33	MS	MS	MS
43. IR253-100	S	MS	MS
44. TDK-5	S	MS	S
45. TDK94017-60-1	MS	MS	MS

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Table 2 continued.

Varieties and promising lines	WS 1999	WS 2000	WS 2001
46. TDK94017-1-1	MS	MS	MS
47. TDK94018-21-3	MS	MS	MS
48. TDK94018-21-4	MS	MS	S
49. TDK94018-38-2-2	MS	MS	MS
50. TDK94018-50-1	MS	MS	MS
51. TDK94019-1-2	MR	MS	MR

[a]WS = wet season, R = resistant (1–5% damaged tillers), MR = moderately resistant (6–15% damaged tillers), MS = moderately susceptible (16–50% damaged tillers), S = susceptible (>51% damaged tillers) (Standard evaluation system, IRRI 1985).
Source: Lao-IRRI (1999, 2000, and 2001).

varieties *Ise* and *Hom-Nangnuan*. Two lines, IR253-100 and SK12-117-2-2, were classified as being susceptible, with levels of tiller damage exceeding 50%. Among the Lao improved varieties, the greatest level of RGM tolerance was shown by Phone Ngam-1 (PNG1) (moderate resistance) and Thasano-1 (TSN1). The improved Lao varieties in the Thadokham (TDK) series—TDK1, TDK2, TDK3, and TDK4—all showed moderate levels of susceptibility and their planting should be avoided in areas where RGM infestation and damage are a chronic problem.

Natural enemies of RGM have been reported in several countries. The hymenopterous parasitoids are Plastygasterids, Eupelmids, Preromalids, Eurytomyts, Eulophids, Scelionids, Ichneumonids, and Braconids. They have been reported to be the most important parasitoids of RGM in South and Southeast Asia (Kobayashi et al 1990, 1991, 1994, Hikada et al 1996, Jahn and Bunnarith 2004). In Laos, three species of hymenopterous parasitoids are important natural enemies of RGM: *Plastygaster oryzae* (Cameron), *Plastygaster foresteri* (Gahan), and *Neanastatus grallarius* (Masi). *Ophionia indica* (Thumberg) (Carabidae), a predator of RGM, also occurs in Laos (Lao-IRRI 1999, 2001).

Several weed species have been reported as alternate hosts of RGM in Laos, including the wild rice *Oryza rufipogon* and the weeds *Cynodon dactylon* and *Leersia hexandra* (Lao-IRRI 2001) (Fig. 2). These alternate hosts are similar to those found in Thailand and Cambodia (Hikada et al 1996, Jahn and Bunnarith 2004). As forest and wild rice habitats decline with agricultural development, the incidence of RGM might also be expected to decline.

Rice stem borers

Four different species of rice stem borer are associated with rice cultivation in Laos: *Chilo suppressalis, Scirpophaga incertulas, S. innotata,* and *Sesamia inferens.* However, of these, only two, *C. suppressalis* and *S. incertulas*, appear to be economically important. Field observations suggest that, under Lao conditions, stem borer infestations are greater in improved varieties relative to traditional varieties, and that the level of infestation is greatest under conditions of high nitrogen fertilizer application

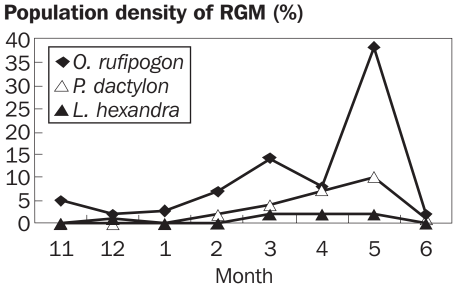

Fig. 2. Alternative host plants of RGM in the 1999 and 2000 dry season in Savannakhet Province of Laos (Source: Lao-IRRI 2001).

(Lao-IRRI 1993, 2002). Nitrogen application rates are known to affect the body size, population size, survival, and intrinsic rate of increase of several rice pests (Jahn et al 2001, 2005, Preap et al 2001, Jahn 2004, Lu et al 2004).

The glutinous variety RD10, which originated from Thailand, is known to be susceptible to stem borer damage in all areas of Laos where it has been grown. In contrast, the nonglutinous variety CR203, which originated from Vietnam, has shown resistance to stem borer damage. Since 1998, the incidence of stem borer damage has increased in both irrigated and rainfed conditions (Lao-IRRI 1999, 2004). However, no evidence has shown that stem borer is a consistent cause of significant yield loss. Deadheart and whitehead incidence have generally been recorded at less than 3% at 30 DAT and less than 7% before harvest in studies; these rates are regarded as being too low to cause any real economic loss. Although yield losses of 50% due to deadheart have occasionally been reported by farmers, such losses remain unverified ((Lao-IRRI 1993 1994, 1995, 1996, 1997, 2002, 2003). Most improved varieties currently being distributed in Laos appear to have reasonable tolerance of stem borer damage, and can generally compensate for it.

Rice bug (*Leptocorisa oratorius*) (Fabricius)

Until recently, Lao farmers have not considered rice bug, *L. oratorius*, as a major pest. It appears to have developed pest status in both the irrigated and rainfed lowland environments since 1995, in association with the intensification of rice cultivation as a result of an expansion of the irrigable rice area available for double cropping. Rice bugs have been reported in areas of lowland rice cultivation in many provinces, but particularly in the central and southern agricultural regions in the Mekong River Valley (Vientiane Municipality and the provinces of Vientiane, Borikhamxay, Khammouane, Savannakhet, Saravane, Champassak, and Attapeu, Lao-IRRI 1999). Rice bug infestations and damage have also been reported in the northern provinces of Luang Prabang and Sayabouly. Rice bug damage occurs during the milky stage of rice development and damaged panicles produce unfilled grains and an increased percentage of small

Average no. of bugs per hill

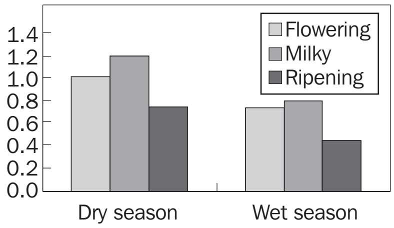

Fig. 3. Rice bug density at flowering, milky, and ripening stages of rice in the wet and dry seasons of 2000, Vientiane Province.

and broken grain during milling (Dale 1994, Lao-IRRI 1999). Rice bugs reduce yield, grain quality, and seed germination rates (Jahn et al 2004).

Rice bug is generally a more important pest in areas of irrigated cropping than in areas of wet-season rainfed cultivation. Their population (and associated damage) is generally higher in dry-season cropping environments than in the wet season (Fig. 3). Reliable quantitative information on the rice bug problem in Laos is limited. Some studies began in 1999 and 2000 to quantify the importance and economic impact of the problem. Early-flowering (and therefore earlier-maturing) varieties are generally more susceptible to rice bug damage; medium-maturity and later-maturity varieties generally have lower levels of infestation and damage. Generally, the medium- and later-maturity types are more widely grown (Douangboupha et al 2000).

During the early part of the wet season, rice bugs survive on a large range of host plants that are usually found as weeds in areas adjacent to rice fields or in nearby forests. They then migrate from these host plants to the rice paddies in late August, feeding on the rice plants to produce the first generation of insects that attack early-flowering rice varieties in August and September. These insects then produce a second generation, which continues to cause damage until November, after which the population usually shows a marked decline, reflecting a lack of food after harvest of the rice crop. The remaining survivors then once again move to alternate host plants. The population increases once again where a second (dry-season irrigated) rice crop is grown. Mature rice bugs are observed in the rice paddies only during March; they breed there and attack the rice in April. No varieties with resistance to rice bug damage have been identified in Laos. It is generally acknowledged that the ecology and biology of the rice bug must be better understood before it can be effectively managed under Lao conditions.

Brown planthopper (*Nilaparvata lugens*) (Stål)

The brown planthopper (BPH) (*N. lugens*) has long been recognized as an economically important rice pest in Laos. The first report of BPH in rice crops in Laos was in 1956 from Phiang District of Sayabouly Province, where dry-season rice cultivation under irrigated conditions was first attempted in the country. Subsequently, there were few reports of outbreaks until the 1980s, when there was a further expansion of dry-season irrigated rice cultivation in other provinces in the Mekong River Valley. The most significant BPH outbreaks were recorded in areas of dry-season rice cultivation in the early 1990s in the Vientiane Plain. These outbreaks were associated with the widespread use of the BPH-susceptible variety RD10 from Thailand, in association with increased nitrogen fertilizer use. The more serious outbreaks have been associated with areas of "hopper burn" in the period before harvest. It has been difficult to correlate the frequency of outbreaks to specific environmental parameters. The greatest damage has been recorded under generally high-temperature conditions during April, when dry-season irrigated crops are approaching maturity. The most recent significant outbreaks were recorded in dry-season crops in 1998, in Vientiane Municipality and Borikhamxay Province. The Lao improved glutinous variety *Thadokkham 1* (TDK1), which was first released in 1993, initially showed a reasonably high level of BPH resistance under farmers' field conditions. However, more recently, it has shown susceptibility to what are believed to be new BPH biotypes. A later improved Lao variety, TDK3, released in 1997, has also shown a high level of BPH tolerance.

Golden apple snail (*Pomacea canaliculata*) (Lamarck)

In Laos, the golden apple snail, *Pomacea canaliculata* (Gastropoda: Ampullariidae Lamarck), is a well-known invasive alien species. It was first introduced to Asia through Taiwan in 1980 from South America (Halwart 1994) for human consumption (Naylor 1996), and then subsequently introduced to many other countries in the Southeast Asian region (Jahn et al 1998, Carlsson 2004). It was first introduced to Laos from Thailand in 1991 by a Lao farmer in Sikhotabong District of Vientiane Municipality. As a result of flooding in the 1992 wet season, the snail escaped from fish ponds and quickly established itself in four additional districts. Farmers in Xaythany District of Vientiane Municipality also independently reported the presence of the snail in areas of irrigated and rainfed rice cultivation in 1991. It would therefore appear that there was a simultaneous introduction of the snail to more than one locality of Vientiane Municipality. By 2000, it had become established in 10 provinces. In northern Laos, the snail was first recorded in areas of irrigated rice cultivation of La District of Oudomxay Province and Sing District of Luang Namtha Province in 1994; the source of the snail in these areas is believed to have been China.

The golden apple snail, locally known as "*the big mouth snail"* on account of its appetite and capacity to cause damage, is regarded as potentially constituting one of the greatest economic threats to the agricultural wetlands of Laos. Both juveniles and adults defoliate the rice plant from the young seedling until the maximum tillering stage; they also damage other aquatic vegetation.

Lao farmers have developed some botanical pesticides that have proven to be reasonably effective for the control of the golden apple snail. Included among these is the use of papaya leaf and pineapple bard (Douangboupha et al 2002). In experimental plots of the National Agricultural Research Center in Saythany District of Vientiane Municipality in 2002-03, it was demonstrated that an application of bitter nut and ebony fruit (*dios piros mollis*) at 90 kg ha^{-1} gave effective control of the golden apple snail (Lao IRRI 2004). Farmers in Vientiane Municipality have also reported that the application of bitter nut (locally known as *mak khe*w) after transplanting in both the wet and dry seasons reduced the population of golden apple snail and minimized damage. In areas of heavy infestation, the raising of ducks is often used to assist with the control of infestations of, and damage by, the snail.

The upland rainfed environment

Slash-and-burn agriculture has traditionally been the major production system used in the upland environment. Rice is the major upland crop, followed by maize. In recent years, an increasing diversification of cropping activities has developed in the upland environment, including the planting and cultivation of nontimber forest crops. All are grown under rainfed conditions. Although official government policy is to reduce and eventually stop slash-and-burn agriculture in the uplands, and to move to more sustainable forms of agricultural production, most crop production still takes place in the slash-and-burn system, and is concentrated on slopes with altitudes ranging from 300 to 800 m. The upper limit for rice cultivation is around 1,500 m. Despite the recent rapid adoption of improved rice varieties in lowland rice environments, upland rainfed rice cultivation is still almost exclusively based on the use of traditional varieties. In the traditional rainfed upland rice cultivation systems, farmers rate their most important production constraints (in decreasing order of importance) as being weeds, rodents, insufficient rainfall, lack of available land, insect pests, insufficient labor, poor soil fertility, erosion, wild animals, and diseases (Roder 2001). *Chromolaena odorata*, an American weed species introduced to Lao PDR in the 1930s, and *Mimosa invisa* dominate the weed population during the cropping and first fallow phase. Another introduced weed species, *Ageratum conyzoides,* although less dominant, has shown a strong association with root-knot nematode *Meloidogyne graminicola* (Roder et al 1992).

Many insect pests and diseases in uplands are considered to be economically important (Table 3). The following pest species are also found in the lowland rice environment: the rice bug (*L. oratorius*), grasshoppers (*Oxya* spp. and *Acrida* sp.), cutworm (*Spodoptera litura*), leaffolder (*Cnaphalocrocis medinalis*), and rodents (*Rattus* and *Mus* spp.). Others such as white grub (Scarabaeidae: *Leucophilolis* sp. and *Heteronychus* sp.) and root aphids (Aphididae: *Tetraneura nigriabdominalis* Sasaki) affect only upland rice cultivation.

In some areas of upland rice cultivation of Laos, farmers rate white grub as their most important pest problem. Arraudeau and Vergara (1988) reported many species of white grubs or scarab beetles, which feed on living roots as larvae but not as adults. In the tropics, they have a 1-year life cycle. Adults start to emerge from the soil after the first heavy rains of the rainy season. They lay eggs at the same time as farmers sow upland rice. Rice passes its most susceptible stage and damage is mostly avoided when white grubs are small. After several months, the long-lived larvae of white grubs become large enough so that two or three larvae can denude the root system of mature

Table 3. Occurrence of insect pests and diseases in rainfed upland rice production systems in Laos.

Common name	Scientific name	Crop growth period	Ranking[a]
Pests			
Ants	*Solenopsis geminata*	Sowing	++
Root aphid		Tillering	++
Armyworm	*Spodoptera mauritia,*	Seedling-panicle	++
	Mytthimna separate	Seedling-panicle	++
Grasshopper	*Oxya* spp. and *Acrida* spp.	Seedling-ripening	+++
Greenhorn caterpillar	*Melanitis ledaissmene*	Seedling-maximum tillering	+
Green semilooper	*Naranga aenescens*	Seedling-maximum tillering	+
Crickets	*Euscyrtus concinnus*	Seedling-tillering	+
Cutworm	*Spodoptera litura*	Seedling-tillering	++
Leaffolder	*Cnaphalocrocis medinalis*	Tillering	++
Mealy bugs	*Brevenia rehi*	Tillering	+
Mole cricket	*Grillotalpa africana*	Seedling-tillering	+
Planthopper		Tillering	+
Rats	*Rattus* sp. and *Mus* sp.	Sowing, reproductive	+++
Rice bug	*Leptocorisa oratorius*	Reproductive	++
Rice skipper	*Pelopidas mathias*	Seedling-maximum tillering	+
Small brown planthopper	*Laodelphax striatellus*	Maximum tillering-reproductive	++
Stem borers	*Chilo suppressalis,* *C. polichrisus,*	Tillering	+
	Scirpophaga incertulas,	Tillering	++
	S. innotata, Sesamia inferens	Tillering	++
Stink bugs	*Nezara viridula*	Milky	+
Termites		Tillering-reproductive stage	+++
White grubs		Tillering	+++
Diseases			
Bacterial leaf blight	*Xanthomonas campestris*	Maximum tillering-reproductive stage	+++
Blast	*Pyricularia oryzae* Cav.	Seedling-reproductive stage	+++
Brown spot	*Helminthosporium oryzae*	Tillering-reproductive stage	+++
Leaf streak	*Xanthomonas campestris*	Tillering-reproductive stage	+
Narrow brown leaf spot	*Cercospora oryzae*	Tillering-reproductive stage	++
Sheath blight	*Rhizoctonia solani*	Maturation	+
Sheath rot	*Sarocladium oryzae*	Booting	++
Stem rot	*Helminthosporium sigmoideum*	Reproductive stage	++

[a] +++ = very important, ++ = important, + = relatively unimportant.

Sources: Modified from Rapusas et al (n.d.), Arraudeau and Vergara (1988).

rice. This intensity of damage is rare, but wilting occurs when root loss is combined with water stress. White grubs need damp soil to survive and they pass the unfavorable dry season 1–2 m underground. The first heavy rains of the season (20–30 mm d^{-1}) stimulate the grubs to resume activity. After several weeks, they develop into pupae and adults, eventually digging their way to the surface and flying to nearby trees to seek food and mates. Grasslands may support large populations; therefore, white grubs can be more abundant in newly planted upland rice fields that were previously fallow. White grub incidence was monitored in upland areas of northern Laos in the 1990s (in Luang Prabang Province in 1992 and 1993, and in Oudomxay Province in 1992). Damage was observed as early as 3 weeks after seeding (WAS) in Luang Prabang. Damaged hills were recorded as increasing from 26% m^{-2} at 3 WAS to 52% at 7 WAS; however, thereafter, the level of damage declined as the crop matured. In Oudomxay, the level of white grub damage decreased steadily as the crop matured (Roder 2001).

The buildup of root aphids (along with nematodes) is considered a major cause of the significant decline in rice grain yield observed in upland rice, when grown on the same land for more than 3 years. Like many homopterans, root aphids are tended by ants. The recent practice of intercropping pineapple with upland rice in some areas of northern Laos is regarded as potentially able to cause increased root aphid infestations, as well as mealy bug infestations in pineapple crops, as it is generally well known that ants tend both mealybugs and aphids (Jahn et al 2003).

Rodents have always been a chronic problem in upland rice production, with varying levels of damage being common in most years in most upland areas of Laos. The severity of the problem varies with locality and between seasons. Singleton and Petch (1994) documented some perceptions and data on rodent problems in the upland rice environment of Laos. In recent years, there has been increasing use of rodenticides by upland farmers in their effort to reduce the potential impact of rodents on crop production and postharvest rodent-related losses. Many of these rodenticides present a major health risk to nontarget animals and to humans. Recent research funded by the Australian Center for International Agricultural Research (ACIAR) and undertaken on a collaborative basis between NAFRI and CSIRO has provided a better understanding of the different rodent species in Laos, the ecology of some of the major rodent pests, and the history of outbreaks (see Aplin et al, Chapter 19 in this volume). A total of 53 species of rodents have been identified in Laos, 14 of which are regarded as potential agricultural pests, with 4 to 8 spcies causing significant damage to agricultural crops. Management strategies being tested are concentrating on community actions based on a basic understanding of the ecology of the major pest species. Although good progress has been reported in protecting grain stores and in reducing the impact of rodents in and around villages, the most severe impact on farmer livelihoods occurs during the occasional eruptions of rodent populations. These outbreaks often lead to individual farmers losing more than 50% of their crop (Singleton and Petch 1994). An analysis of the patterns of these rodent outbreaks indicates that many may occur in response to bamboo flowering rather than major climatic events such as El Niño Southern Oscillation cycles (Douangboupha et al 2000). The rodent-related studies are ongoing. It is recognized that, for the development of effective control strategies, further studies and information are required on the seasonal dynamics of the breeding of the main pest species, their habitat use, and the development of improved community-based control strategies.

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CHAPTER 18

Determinants of insecticide-use decisions of lowland rice farmers in Laos

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In Lao rice production, pests and diseases are minor constraints compared to other agronomic factors such as infertile soils, unavailability of water, floods, and general lack of farmers' crop management knowledge (Schiller et al 2001). Yields in farming areas of the lowland environment in much of Laos, even under irrigated conditions, have remained relatively low for improved Lao varieties, despite their demonstrated yield potential in appropriate management conditions. Although insect pests are not perceived as a significant yield constraint in many areas of Laos, there are suggestions that farmers are prepared to rapidly adopt the use of insecticides if they become more readily available at reasonable prices. Current attitudes of farmers toward insects and pesticides seem to favor this adoption (Heong et al 2002) and thus Lao farmers can potentially fall victim to insecticide misuse just like farmers elsewhere in Asia, such as Indonesia, the Philippines, Vietnam, and Thailand. Integrated pest management (IPM) programs in these countries have thus concentrated on pesticide reduction through training (Matteson 2000) and media campaigns (Escalada et al 1999).

An earlier study on farmers' insect management beliefs and practices (Heong et al 2002) examined the qualitative elements of farmers' beliefs and how they can influence practices. This study was conducted in two irrigated areas, Vientiane Municipality (n = 101) and Vientiane Province (n = 99), and two rainfed areas, Savanneket Province (n = 150) and Champassak Province (n = 150). The results of the study indicated that most Lao farmers strongly believe that insects will decrease yields and about 56% were using insecticides; the main chemicals used were methyl parathion, diazinon, and monocrotophos, which are highly hazardous to human health. There was also strong local social pressure favoring pesticide use. In this chapter, we revisited the data set and applied a psychometric model, the theory of reasoned action (TRA, Ajzen and Fishbein 1980), to understand farmers' insecticide-use decisions and to explain such behavior.

Explaining farmers' decisions using a psychometric model

Farmers' insecticide use is the result of conscious decisions to respond to an insect attack that is perceived to be causing loss. Rice farmers are often described as irrational and lacking sufficient knowledge to make good judgments. Studies on human judgment and choices have, however, shown that economic models have been unable to account for how people actually make decisions (Slovic et al 1977, Simon 1978). Most violate prescriptive principles because decision making is behavioral in nature. A group of sciences concerned with understanding and improving decision-making, called decision sciences (Kleindorfer et al 1993), has recently emerged and begun to explore the behavioral aspects of decisions. To better understand the determinants of farmers' insecticide-use decisions, models from psychology have been adopted.

The psychometric model used in the study reported in this chapter is the theory of reasoned action (TRA), developed by Fishbein and Ajzen (1975) and Ajzen and Fishbein (1980). It provides a theoretical framework to explain a person's behavior. This model was adopted to understand the components of farmers' insecticide spray decisions. The TRA assumes that attitudes toward spraying and perceived social pressures are important determinants of farmers' decisions to spray. Attitudes toward spraying are, in turn, affected by spraying beliefs and their outcome evaluations. Perceived social pressures, termed subjective norms (SN), are influenced by the individual farmer's normative beliefs and his/her motivation to comply.

Methodology

Focus group discussions

Two focus group discussions (FGD) were undertaken to develop survey questions. These FGDs were conducted in farmers' homes using an inquiry format, which involved discussions on how farmers perceive and respond to insects in their crops. The approach sought to avoid leading questions and prompting for responses, with questions asked in no fixed order.

Questionnaire development

Independent variables were measured using five-point semantic differential scales. All points on these scales were described with a corresponding statement and presented to farmers using a prompt chart. The number of insecticide sprays individual farmers applied in a season was also measured and used as the independent variable. Seven belief statements (b_i) related to insect pest control were used to measure attitude toward spraying. These were "All insects can cause loss in yields," "There is a need to kill all insects in the crop," "Applying insecticides will increase yields," "Insecticides will kill natural enemies," "Some insects are beneficial to rice yields," "Insecticides are harmful to health," and "Insecticides can cause more pest problems." Farmers were then asked to evaluate the importance of each item (e_i) using another five-point semantic differential scale from "completely unimportant" to "very important." The measure for attitude toward spraying (SP) was computed as the sum of the products of belief and evaluation, $SP = \sum b_i e_i$.

The subjective norm (SN) attitude was measured using four reference groups, neighbors, village head, spouse, and agricultural technician. Farmers were asked what each of the reference groups expected of them with regard to insecticide spraying

(nb_i). Responses were scored as (1) "Never spray," (2) "Spray rarely," (3) "Spray once every 2 years," (4) "Spray once a year at least," and (5) "Spray every season." Another assessment of the SN component was motivation to comply (mc_i) and this was determined by another five-point semantic differential scale going from "I don't care at all" to "What they think I should do is very important." The subjective norm attitude was computed as the sum of the product of normative beliefs (nb) and motivation to comply (mc), $SN = \sum nb_i mc_i$.

Statistical analyses

Cronbach's alpha available in SPSS version 11.5 (SPSS 2001) was used to assess the reliability of the two independent determinants of spray behavior, SP and SN. Categorical regression (CATREG) was used to analyze the relationship between the determinants of behavior and the dependent variable, insecticide spray behavior. Correlation analysis (two-tailed) was used to analyze between the subcomponents.

When a variable is generated from a set of questions, its reliability can be assessed by Cronbach's alpha, the index of reliability ranging from 0 to 1. The higher the alpha, the more reliable the generated scale is. As a general guide, alpha > 0.7 is commonly an acceptable reliability coefficient (Nunnaly 1978, Santos 1999). The use of categorical regression is appropriate for predicting a categorical dependent variable from a set of categorical independent variables. The spray behavior of farmers was grouped into four categories: 1 = none, 2 = 1 spray, 3 = 2 sprays, and 4 = > 3 sprays, representing farmers whose sprays are none, low, medium, and high.

Results

Reliability analyses

The spray attitude scale with all six belief subcomponents was computed and subjected to reliability analysis. The initial Cronbach's alpha was 0.43 and, after removing three of the subcomponents, the scale reliability index increased to 0.73. Subsequent analyses were conducted using the spray attitude scale with the three subcomponents, "All insects can cause loss in yields," "There is a need to kill all insects in the crop," and "Applying insecticides will increase yields." The subjective norm attitude scale using all four subcomponents had a reliability index of 0.90 and thus all four subcomponents were used.

Regression analyses

The theory of reasoned action describes farmers' spray behavior based on the two predictor components. Since the data are nonparametric, categorical regression analysis was used to evaluate the contributions of the predictors to spray behavior. The intercorrelation among the two predictors was extremely low (Spearman's rho = 0.08), implying that the regression was reliable. Farmers' spray behavior was directly correlated with subjective norm attitudes. The ANOVA of the regression was significant (F = 57.6, $P < 0.001$) but yielded a coefficient of determination (R^2) of 0.374, indicating that only 37.4% of the variance was explained by the regression. Table 1 shows the

Table 1. Regression coefficients of spray categories as dependent variable and subjective norm and spray behavior attitudes as independent variables.

Item	Standardized coefficients		Correlations		Importance
	Beta	Std. error	Zero-order	Partial	
Subjective norm (SN)	0.63	0.06	0.583	0.611	0.982
Spray behavior (SP)	–0.19	0.06	–0.035	–0.228	0.018

Table 2. Mean scores of subcomponents in subjective norm (SN) attitudes in the different spray behavior categories.[a]

Spray behavior category	Referent groups			
	Neighbors	Village heads	Spouses	Technicians
Did not spray at all	6.63 a	6.05 a	6.71 a	9.37 a
Sprayed once a season	11.02 ab	13.18 b	14.06 b	15.33 b
Sprayed twice a season	13.65 bc	13.12 b	13.53 b	16.06 b
Sprayed more than three times	16.08 c	16.46 b	10.43 b	17.38 b
F	15.04	21.47	19.06	16.13
P	<0.001	<0.001	<0.001	<0.001

[a]Scores vary from 5 to 25, with high scores indicating strong attitudes. The letters after the means indicate groups of homogeneous subsets from Tukey's honestly significant difference.

standardized regression coefficients. The subjective norm attitude was higher (0.63) than spray attitudes (–0.19). The subjective norm attitude is an important component determining decision-making. Besides seeking to satisfy personal beliefs, objectives, and gains, most people are also influenced by their perceptions of what referent groups (such as peers, neighbors, friends, village officials, and relatives) would think of them. The high subjective norm implies that the influence of referent groups on farmers' spray behavior is stronger than beliefs. This is relevant to designing change interventions. Since influence from beliefs is small, increased farmer training might not result in behavioral change. A better strategy might be to implement change at the communal level.

Since spray attitudes played only a small role in predicting farmers' spray behavior, a further investigation was made of the relationships of the subcomponents in subjective norm and spray behavior. Table 2 shows the mean scores of the subcomponents of farmers in different spray behavior categories. The scores of farmers who did not spray in all four subcomponents were significantly lower than for those who did. The intercorrelations among the subcomponents were high (Table 3). The regression with each subcomponent as independent variables was highly significant (F = 35.1, $P < 0.001$, d.f. 4, 84) and R^2 was 0.424. The regression coefficients are presented in

Table 3. Correlations (Spearman's rho) between spray categories and subcomponents of subjective norm (SN) attitudes.

Item	Subcomponents				
	1	2	3	4	5
1. Spray behavior category	–				
2. Neighbor subcomponent	0.45**	–			
3. Village head subcomponent	0.72**	–			
4. Spouse subcomponent	0.45**	0.67**	0.86**	–	
5. Technician subcomponent	0.39**	0.51**	0.67**	0.75**	–

**Indicates correlation significant at $P = 0.01$ (2-tailed).

Table 4. Regression coefficients of spray categories as dependent variable and subcomponents of subjective norm (SN) attitudes.

Group	Standardized coefficients		Correlations		Importance
	Beta	Std. error	Zero-order	Partial	
Neighbors	0.23	0.07	0.458	0.246	0.252
Village heads	0.54	0.09	0.506	0.411	0.643
Spouses	–0.45	0.08	0.185	–0.375	–0.196
Technicians	0.28	0.07	0.451	0.281	0.301

Table 4. Spouses seemed to have a negative influence over spray behavior, whereas village heads, neighbors, and technicians had a positive influence. Among these, the groups most influential on farmers' spray behavior in order of importance were village heads (importance = 0.643), technicians (0.301), neighbors (0.252), and spouses (negative 0.196).

Discussion

Many insecticide sprays that rice farmers in Asia apply are unnecessary, targeting leaf-feeding insects in the early crop stages (Heong and Escalada 1997). In Laos, 30% of the sprays are done at these stages and another 37% in late stages targeting the rice bug (Heong et al 2002). The rice bug is another one of those pests that are highly visible but that cause negligible loss (Van Den Berg and Soehardi 2000). Spray decisions can subject farmers to pesticide health hazards (Rola and Pingali 1993) and compromise a vital ecosystem service, natural biological control, and this can lead to the development of secondary pests (Way and Heong 1994, Heong and Schoenly 1998). Despite the negative effects, pesticide use tends to increase because farmers are often "locked" into continuing such unsustainable practices (Wilson and Tisdell

2001). Some of these factors are ignorance, lack of information about side effects, aggressive advertising and promotion by chemical companies, and loss aversion attitudes of farmers. Research and extension will need to go beyond developing technologies and focus on ensuring that the technologies are implemented to help farmers improve their practices.

The TRA provided a useful framework to explore farmers' spray decisions. Understanding the primary reasons why farmers spray is important in order to develop strategies to overcome misuse problems. In many cases, farmers' spray decisions are influenced by noneconomic factors such as perceptions and social factors. Subjective norm (or peer pressure) attitudes seem to have a big influence over Lao farmers' spray behavior. Since village heads and technicians are the two most influential referent groups in farmers' spray decisions, a strategy to train village heads and technicians on principles of integrated pest management (IPM) might pay more dividend than just training farmers. In addition, once village heads and technicians have acquired IPM knowledge, they can also provide *in situ* training to farmers besides functioning as influence groups. Establishing local village-level IPM clubs to initiate local participation and discussions about pest management and pesticides might also be useful.

In the Philippines, extension technicians were also found to play significant roles in onion farmers' pesticide misuse (Tjornhom et al 1997). In this case, the technicians were the main source for pesticide information and were also motivated to promote pesticide use. In countries such as China, where the government promotes a pesticide-first policy, overuse had been a direct consequence (Widawsky et al 1998). Extension technicians often supplement their incomes from pesticide sales, thus increasing their influence over farmers' spray decisions. Where extension plays both advisory and marketing roles in pest management, pesticide overuse often results (Norton et al 1991). Similarly, in Thailand, weak government policies had promoted pesticide misuse (Jungbluth 1996, Oudejans 1999).

There is a high potential for Lao farmers to become pesticide-dependent as several of its neighboring countries produce pesticides. Many old pesticides such as methyl parathion, monocrotophos, and metamidophos, banned in many developed countries, are still actively sold in local markets. Our brief visits to local general stores in villages revealed large quantities of pesticides from neighboring countries, with foreign language labels, sold among other household products. The availability of spray equipment can be another limiting factor, but, with the abundance of inexpensive plastic sprayers, this is likely to diminish. However, these sprayers are often poorly manufactured, have poor spray delivery, and often leak, posing a big health hazard to the operators. The poor pump and nozzle systems of sprayers provide delivery of pesticide active ingredients in large droplets, which results in contaminating soil and water systems and killing more natural enemies than pests. Besides pesticide control, agricultural authorities will need to develop mechanisms to control the quality of spray equipment manufactured locally or imported, to ensure that it adheres to minimum standards established by the FAO.

For Laos, the strong influence of village heads and technicians may in fact be used for improving farmers' decisions since current insecticide use is still low. Much of the insecticide misuse in rice production today has been attributed to the "unwelcome harvest" of the Green Revolution (Conway and Pretty 1991). The lessons learned from the implementation of the Green Revolution in the Philippines, Indonesia, and Vietnam could come to bear in initiating the "Doubly Green Revolution" (Conway 1997). A re-engineering of local village leaders and research and extension officials' knowledge and attitudes focusing on the new paradigms in IPM that place emphasis on ecological principles and enhancing naturally occurring biodiversity of biological control (Heong 1999) is urgently needed in Laos. In addition, pesticide policies need to be revisited and modified in order to control the import and sale of pesticide to avoid abuse. Programs such as the implementation of farmer training, such as the farmer field schools (Matteson 2000), the use of media to communicate (Escalada et al 1999), and entertainment education (EE) through radio and television (Singhal and Rogers 1999), will be useful in initiating social change in pesticide use.

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CHAPTER 19

Rodents in the rice environments of Laos

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Laos has a diverse rodent fauna, with 53 described species and several others known but not yet scientifically named (Francis 1999, Aplin, unpublished data). As for much of Southeast Asia, there is a need to balance the management of a few pest species with the conservation of many harmless or even beneficial species (Aplin and Singleton 2003). The role that rodents play in ecosystems is not well recognized. They are important prey species for many native snakes, birds of prey, and carnivorous mammals. In turn, rodents can limit the growth of invertebrate populations, some of which are important pests in agricultural systems (Joshi et al 2004). Rodents also provide important ecosystem services as ecological engineers through influencing water infiltration and the flow of nutrients (Dickman 2003) and through their role as seed dispersers (Lu and Zhang 2004).

In Laos, the importance of balancing pest management and conservation is particularly acute. Of the 53 species of rodents found in the country, only 14 appear to have any effect on agricultural production, with only four to eight causing significant damage. From a conservation perspective, four rodent species found in Laos have been listed by the International Union for the Conservation of Nature (IUCN) as being at risk of extinction, while the biology and distribution of some 14 other species of rodent are so poorly known that IUCN has not been able to determine their conservation status.

The upland farming systems of Laos are changing rapidly in response to a range of factors, including the rapid increase in human population, government pressure to restrict shifting cultivation, and new economic opportunities. The population of Laos is approximately 5 million, and is increasing at a rate of 2.5% per annum, one of the highest growth rates in Southeast Asia. More than 80% of the population is living in agricultural households, and about 40% of the population is fully or partially involved in shifting cultivation in the upland environment. Sixty-five percent of these families depend on shifting agriculture for their livelihoods. With mounting pressure on the agricultural systems of Laos, it is likely that the effects of pests, weeds, and diseases will increase in the future.

Few rigorous estimates exist of the impact of rodent pests in rice-based agroecosystems in Asia, and estimates of a 5–10% loss to production preharvest are probably conservative (Singleton 2003). In many areas, losses have risen dramatically over the last decade, most noticeably in places where cropping frequency has increased from one to two or three crops per year (Singleton 1997). However, even a conservative estimate of an annual loss of 5% of rice production in Asia equates to approximately 30 million t, enough rice to feed 180 million people for 12 months. Postharvest losses are probably of a similar magnitude as preharvest losses, but there are less quantitative data on which to base any estimates of postharvest losses.

In Laos, farmers commonly report chronic annual grain losses caused by rodents in the upland environment of up to 30%. In addition, many areas have episodic outbreaks of rodent populations that can lead to losses by individual farmers of 50% to 100% (Schiller et al 1999, Douangboupha et al 2003). Because of these impacts, Lao farmers generally have a good knowledge of their local rodent communities and often distinguish ten or more different kinds of rodents with which they are familiar. This familiarity often extends to forest rodent species, which are actively hunted and trapped for consumption or sale. Table 1 gives a list of Lao "rat" names along with the equivalent scientific name or names (some names are applied to several species). Unless otherwise indicated, these names were obtained from farmers in Luang Prabang Province in the north of the country.

Collaborative research on rodent biology and management between scientists from Australia and Laos began in 1999. The research focus has been in the upland rainfed environment, with the aim of quantifying the impacts of rodents on agricultural production, identifying the key pest species, recognizing those that need to be conserved, and developing strategies of ecologically based rodent management (EBRM) (Singleton et al 1999). This chapter reports on some of the findings from these studies.

Rodent communities of rice-growing environments in Laos

The major pest species and their distribution

The small mammal fauna of Laos is perhaps the least known of the entire Asian region. This is particularly true of the rodents, which are generally understudied relative to other groups of mammals. Francis (1999) listed a total of 34 rats and mice (Muridae), three bamboo rats (Rhizomyidae), 12 ground squirrels (Sciuridae), and eight flying squirrels (Pteromyidae) as either known or likely to occur in Laos. Khamphoukeo et al (2003) tabulated the murid and rhizomyid species under four categories according to their pest status and degree of scarcity. Their listing is updated in Table 2, with the addition of two recently discovered species and some reattribution of particular species based on new information. This chapter focuses on the species listed as definite or probable agricultural pests. The major pest species belong to three genera, *Rattus, Bandicota*, and *Mus*. Another three genera include minor or more localized pests (*Berylmys*, *Cannomys*, and *Rhizomys*).

Members of the *Rattus rattus* complex are the dominant agricultural and village pests in almost all parts of Laos (Khamphoukeo et al 2003). This group of rodents is taxonomically complex (Aplin et al 2003a, 2004), with as many as 6–7 distinct

Table 1. Lao rodent names collected during fieldwork in 1999-2005, with equivalent scientific names.[a]

Lao name	Scientific name	Comments
Dtun	*Cannomys* and *Rhizomys* species	
Nuu american	*Bandicota indica*	Literally, "American rat" (so named on account of its large size), also called *nuu puk* in Sayabouly Province in the west of Laos
Nuu ban	*Rattus rattus group*	Literally, "house" rat
Nuu ghi	*Mus cookii?*	Identified as a small mouse of upland fields and forest
Nuu khii	"Rat of bamboo flower"	See text for discussion of this name
Nuu mon	*Berylmys* species	
Nuu na	*Rattus rattus* group	Literally, "field" rat
Nuu ta-suat	*Rattus exulans*	Literally, "big-eyed field rat"
Nuu na thong-khaw	*Rattus rattus* group	Literally, "white-bellied field rat"
Nuu noi	*Mus* species (probably *M. caroli*)	Literally, "small mouse" (identified as a long-tailed rice field mouse
Nuu puk	*Bandicota* species	Used for *B. indica* in Sayabouly Province but probably for *B. savilei* in Luang Namtha Province in the northwest of Laos
Nuu si	*Mus* species (probably *M. cervicolor*)	Identified as a short-tailed rice field mouse
Nuu sing	*Crocidura* spp.	Not rodents; small long-nosed shrews found in upland fields and forest
Nuu thammadaa	*Rattus rattus* group	Literally, "ordinary mouse," an alternative name for *nuu ban* (house rat), used in Luang Prabang
Nuu waay	*Leopoldamys* species	Literally, "rattan rat"

[a] Most of the names were recorded in Luang Prabang Province and verified using live or freshly killed specimens. Although most are in widespread use in other provinces, a few names appear to be used only on a local basis.

species involved across the wider Asian region. Because the correct scientific names for several of these species is not yet certain, they are identified by common names, pending completion of taxonomic studies. Within Laos, three members of the group have been recorded, each being found in a different geographic area. In the northern and northeastern provinces, and at least as far south as Vientiane Municipality in the central agricultural region, the local form is the North Asian house rat. The same species occurs broadly across Asia, from Japan in the east to Bangladesh (and probably eastern India) in the west. In general appearance, this species has a reddish brown back and its belly is variably pure white or buff to gray. The tail is usually longer than the body, sometimes much longer. In Sekong Province in the south of Laos, there is a similar looking but genetically distinct species known as the Mekong house rat;

Table 2. Summary of the murid and rhizomyid rodents of Laos, divided into four categories according to probable pest and conservation status.[a]

Definite or probable pests	Possible pests	Nonpests but thought to be common	Nonpests and thought to be rare
Murinae	**Murinae**	**Murinae**	**Murinae**
Bandicota indica	*Leopoldamys edwardsi*	*Berylmys bowersi*	*Berylmys mackenziei**
*B. savilei**	*L. sabanus*	*Chiropodomys gliroides*	*Chiromyscus chiropus*
Berylmys berdmorei	*Rattus nitidus*	*Maxomys surifer*	*Dacnomys millardi* (V)
Mus caroli		*Mus pahari*	*Hapalomys delacouri**
M. cervicolor		*M. shortridgei*	*Maxomys moi*
M. cookii		*Niviventer confuscianus**	*Maxomys* sp.
M. fragilicauda		*Niviventer fulvescens*	*Niviventer* sp. cf. *N. tenaster*
Rattus argentiventer		*N. langbianis*	
R. exulans		*Rattus sikkimensis*	**Arvicolinae**
R. "rattus" (short-tailed rat)		*Vandeleuria oleracea*	*Eothenomys melanogaster**
R. "rattus" (north Asian house rat)			*E. miletus**
R. "rattus" (Mekong house rat)		**Rhizomyidae**	
		Rhizomys sumatrensis	**Placanthomyinae**
Rhizomyidae			*Typhlomys cinereus**
Cannomys badius			
Rhizomys pruinosus			

[a] Information on the degree of scarcity are "guesstimates" based on the number of records and studies in surrounding countries. Species marked with an asterisk are recorded only provisionally from Laos. The two taxa listed as sp. in column 4 were mentioned as possible new species by Francis (1999). Species listed as possible pests or nonpests might qualify as temporary pest species during *nuu khii* outbreaks where these originate in forest habitats.

this species is also found in Cambodia and southern Vietnam. The distribution of this species in Laos is not well known. The North Asian and Mekong house rats are both ecological generalists and occur in villages, upland and valley-floor cropping areas, and around forest margins.

The third member of the *Rattus rattus* complex found in Laos was previously listed under the name *Rattus losea* (Khamphoukeo et al 2003), this classification being based on its similarity to Chinese and Vietnamese populations of this species (Marshall 1977). However, genetic studies have now shown that the Laotian (and most Thai) *R. losea* populations do not belong to this species, but represent a distinctive member of the *Rattus rattus* complex. In Laos, this species is currently recorded from localities in Vientiane Municipality and the provinces of Vientiane and Sekong. It is probably restricted to the lowland habitat bordering the Mekong River and its major tributaries. Unlike the other members of this group, it appears to be strictly a field rat. The correct scientific name for this species is still uncertain; until further clarification, it is called the "short-tailed rat." It is smaller than the other members of the *Rattus rattus* complex and, as its name suggests, it has a proportionally shorter tail. The belly fur is always a grayish color, never pure white.

The rice-field rat, *R. argentiventer*, is the major field pest in lowland rice-growing areas of Cambodia, Vietnam, Malaysia, and Indonesia (Aplin et al 2003c). In Laos, it has been recorded only from Khammouane Province (Francis 1999) in the central agricultural region. Further geographic sampling is needed to map the current range of *R. argentiventer* in Laos to provide a baseline against which to chart any future range expansion by this potentially significant pest species.

Two other *Rattus* species are probably minor pests of rice in Laos. The Pacific rat, *R. exulans*, has been collected in several localities on the Vientiane Plain. However, it does not seem to be present in any provinces with significant areas of upland agriculture although it extends to high elevations in other parts of its range and is perfectly at home in both village and garden habitats. The Himalayan rat, *Rattus nitidus*, is an important agricultural pest in parts of southern China (Aplin et al 2003c). In northeastern India and Thailand, it seems to be more closely associated with upland village habitats (Marshall 1977, Aplin, personal observations) but in Laos it seems to be absent or rare in villages—the few specimens collected in the provinces of Luang Prabang and Houaphanh came from trapping activities in rice fields adjacent to forest and in heavily disturbed forest remnants. It is possible that both *R. exulans* and *R. nitidus* have been excluded from upland village habitats in Laos by the spread of the two larger-bodied members of the *R. rattus* complex.

Two *Bandicota* species are listed as potential pest species (Table 2). The giant bandicoot, *Bandicota indica*, has been trapped on a regular basis in the provinces of Luang Prabang in the north and Sekong in the south of Laos. It does not appear to be particularly abundant anywhere in the country and may not be responsible for much damage to crops. In contrast, in parts of Cambodia and Myanmar, *B. indica* is a significant pest of lowland rice-cropping systems. The lesser bandicoot, *B. savilei*, is recorded only from photographs taken in Savannaket Province in central Laos (Aplin et al 2003b). The closest confirmed record is from the Ubon Ratchathani region of northeast Thailand, immediately west of Champassak Province in southern Laos (Musser and Brothers 1994).

The role of mice (*Mus* species) in damaging rice and other crops is almost always underestimated. This is probably because they are difficult to observe in the field and require special trapping methods for scientific study. In addition, they may cause a different kind of damage than other rodents, being able to climb the rice plant to feed directly on the panicle rather than cutting through the tillers. Farmers in Sayabouly Province in the west of Laos claim that mice in the fields mainly clean up any cut tillers and panicles left behind by *R. rattus*. However, in other parts of Laos, such as Luang Namtha Province in the northwest, farmers believe that mice cause substantial damage to lowland rice crops; this is supported by very high numbers of mouse burrows around the margins of fields in this area (Aplin, personal observations).

At least four species of mice are found in and around rice crops in Laos. The two most widespread species are *Mus caroli* and *M. cervicolor.* Both species dig their burrows in narrow bunds around paddy rice fields. A third species, *M. fragilicauda,* was described only recently from northeastern Thailand (Auffray et al 2003); the only other known occurrence is in paddy field areas in Sekong Province in southern Laos. A fourth species, *M. cookii*, appears to be restricted to upland rice fields; few specimens have been collected and little is known about its habit.

Various other species of rats are occasionally trapped in rice-cropping areas, especially where these abut areas of remnant forest. These captures may reflect low-level crop damage by these species; however, they might equally reflect foraging in fields for insects or other prey. The long-tailed arboreal rats *Berylmys bowersi* and *Leopoldamys* spp. account for most of these "occasional" captures, with fewer examples of the terrestrial rats *Maxomys surifer* and *Niviventer* spp. The rarely collected arboreal rat, *Chiromyscus chiropus,* has also been trapped in this situation. Only one of these species, *Berylmys berdmorei*, might sometimes achieve true "pest" status. This species appears to be uncommon across most of its geographic range (Marshall 1977), but in Luang Prabang Province it can be locally abundant, living in deep burrows excavated in steep banks around the margins of rice fields. One individual of this species was observed making extensive nightly movements of several hundred meters across valley-floor rice fields, while other individuals were trapped inside flooded rice fields (Aplin, unpublished data). Luang Prabang farmers hold this species responsible for damage to vegetable crops, especially sweet potato and other root crops. In Thailand, *B. berdmorei* is said to inhabit "swampy forests and marshy grass" (Marshall 1977) and this might explain its willingness to use the paddy field habitat.

Bamboo rats (members of the family Rhizomyidae) are most often associated with extensive stands of bamboo, where they feed mainly on the rhizomes and young shoots. All members of the group dig extensive burrow systems with numerous mounded exits and complexly branching tunnels many meters in length. Elsewhere in Southeast Asia, bamboo rats are reported to cause damage to tapioca, sugarcane, and rubber trees (Marshall 1977, Aplin, personal observations). In Luang Prabang, burrows of *Cannomys badius*, the smallest of the bamboo rat species, are often found in and around active upland rice fields. Several kinds of crop damage have been observed, including consumption of entire rice plants that are pulled downward by the roots into a tunnel. Vine fruits that rest on the ground, such as cucumbers and melons, are sometimes also eaten out from underneath. In Houaphanh Province in northeastern Laos, the same kind of damage is caused by a slightly larger species of bamboo rat, *Rhizomys pruinosus* (Mouan Muang Seum, personal communication).

Seasonal patterns in habitat use and abundance of upland rodents

Recent knowledge of rodent ecology in Laos comes from regular systematic trapping activities conducted in various habitats in four provinces (Luang Prabang, Oudomxay, and Houaphanh in northern Laos and Sekong in the south) between 1999 and 2002 (Khamphoukeo et al 2003), combined with extensive farmer interviews, excavation of burrow systems, observations made while participating in "rat hunts," and a limited

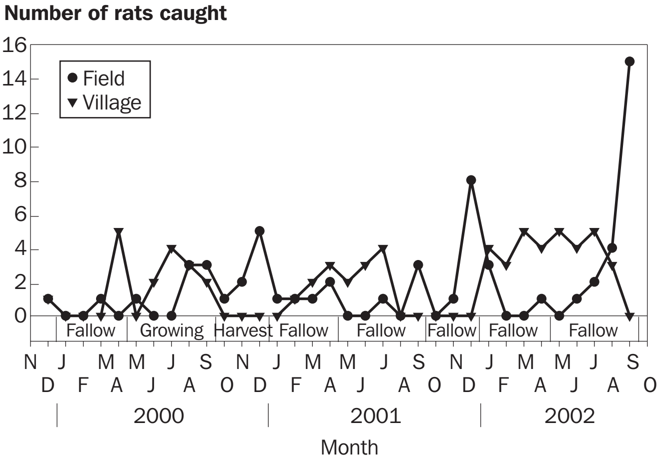

Fig. 1. Trapping results for a 3-year period at Hatsua village in Luang Prabang Province. The graph shows the number of rats caught in each of field and village habitats. With the exception of October 2003, the same number of traps were set each month. Village captures are high during the periods when grain stores are full (January to August/September) but low at other times. Field captures increase during the growing and harvest periods of each year.

study of rodent movement in Luang Prabang, using the techniques of radiotracking and line-spooling (see Aplin et al 2003c for an explanation of these methods).

The house rat is the most abundant rodent in all habitats within the upland agricultural landscape of Laos. In the village habitat, it is probably the only resident rodent, with other species (e.g., *B. indica*) encountered only as occasional visitors. In field areas, the house rat is likewise dominant, although in these habitats it occurs alongside several other resident species. In lowland rice fields, along valley floors, house rats are found together with *B. indica*, *B. berdmorei*, and two or more species of *Mus*. In upland fields, whether under crop or weedy fallow vegetation, house rats occur together with resident populations of *B. berdmorei* (mainly in moister gully habitats), *M. cookii*, and *C. badius*. House rats also occur in forest habitats but they appear to be less abundant in such contexts. Other resident species in forests include *R. nitidus*, *R. sikkimensis*, *B. berdmorei, B. bowersi*, *C. chiropus*, *Leopoldamys* spp., *Maxomys surifer*, *Mus pahari, Niviventer* spp., and the bamboo rats *C. badius* and *Rhizomys pruinosus*. How far the house rat penetrates away from the forest edge into progressively less disturbed habitats is not yet known. However, it is clear that it becomes less abundant away from field habitats.

The results of three years of trapping in and around Hatsua village in Pak Ou District of Luang Prabang are summarized in Figure 1. The results are simplified into two categories: village captures and field captures, with the latter combining results from shifting cultivation fields and a small rainfed lowland rice area within a valley.

Virtually all of the captures have been of a single species—the north Asian house rat, known locally as *nuu ban* or *nuu thammadaa*. Each year, the number of rats captured in the village habitat went through a dramatic increase, starting in December after harvest and refilling of village rice stores. Captures remained high until August or September, by which time all of the stored rice has been eaten (by people and rats). From then through until after the next harvest, few rats were captured in the village habitat.

The increase in rat numbers from December onward is probably due to a combination of migration from fields and intensive breeding in the village habitat. Farmers claim that many rats move from fields to the village following harvest and removal of their food resource. In support of this view, there is one record of the capture in a grain store in January 2003 of an adult rat that was radio-collared the previous November in an upland field, several kilometers away. There is also strong evidence of breeding within the village. Six out of seven adult female rats (84.5%) captured in Hatsua village in January to April were pregnant. This fell to 43.2% (16 pregnant out of 37 adult females) for May to September, but many of the nonpregnant females showed signs of recent breeding. Large numbers of small, recently weaned young were also captured at this time.

From August to December, when the rice stores are empty, rats are difficult to catch inside the village. Radiotracking of a small number of rats caught in August 2003 in a near-empty grain store showed that they were spending the days inside clumps of giant bamboo growing close to the village. On some nights they entered the village but on other nights they moved into nearby fields or riverside forest patches. Only 3 of 14 adult females caught over this period were pregnant (21.4%).

The number of rats captured in field habitats shows a pattern opposite to that of the village. Very few rats were captured in the fields from January to July of each year. These months include the fallow period and the early months of the growing season, times when there is little or no food available for rats in fields. Starting around July to August each year, the number of field captures increased to a maximum in December at the end of the harvest. Only 25% of the adult females captured during this period were pregnant but there was a high proportion of juveniles and young adults. This suggests that the majority of the new residents in upland fields are immigrants, with animals perhaps drawn from both the forest and village habitats. However, local breeding activity clearly also contributes to the population increase in field habitats. Harvesting presumably causes extensive disruption among the resident rats. Radiotracking of house rats during the harvest period found evidence of extensive, seemingly erratic nightly movements, often covering many hundreds of meters. Many rats spent the days sheltering inside piles of rice straw and Job's tear stalks, while others were using burrows in dense bamboo and weedy vegetation in gullies. Although many young rats are present at this time, survival of these late-season young rats is probably not very high as little food remains in fields and most likely a surfeit of adults already occupy patches of forest and fallow vegetation, including many individuals that have fled field areas. As suggested above, at least some of these refugees from the fields presumably make their way down to the village to continue the cycle of breeding and movement.

Impact of rodents in rice ecosystems in Laos

Lao farmers living in the upland environment generally draw a clear distinction between rodent damage suffered each and every year (chronic damage) and that suffered during rodent outbreaks. The damage suffered during outbreaks is sometimes so severe as to entail the rapid and complete destruction of all standing crops.

Chronic preharvest impact

In the upland environment, rodents are considered the most important pest of rice and many other crops (Schiller et al 1999). Upland rice farmers generally rate rodents as being second only to weeds as the overall most important constraint to upland rice cultivation. However, while farmers are able to control weeds through regular weeding, they currently lack any effective means of controlling rodents. As such, rodents are the production constraint over which farmers have least control (Schiller et al 1999).

Preharvest grain losses have not been properly quantified, but have been estimated to be 15% of the rice harvest annually (Schiller et al 1999). Since there is a chronic shortage of rice for upland farmers, this loss can further impair the livelihood of the chronically poor.

In a study of rodent damage in six villages in Luang Prabang Province, Harman (2003) reported that rodent damage to crops occurred mainly at planting and at harvest (Table 3) but with some differences between villages. Such information can be used to refine the timing of rodent management strategies so that control is conducted before damage occurs. Farmers reported that stored rice was the commodity most damaged by rodents, but rodent damage to upland rice was considered the biggest problem in some villages. In terms of highest losses, upland rice, maize, and stored rice were identified, whereas other stored crops, including sesame, suffered less damage (Harman 2003).

Rodents are generally not considered a major problem in the rainfed lowland rice agroecosystem or in the lowland irrigated environment. A survey of lowland farmers in 1993 from nine districts of seven provinces in the Mekong River Valley indicated that, in most districts, rodents were not regarded as a significant production constraint (Khotsimauang et al 1995, Schiller et al 1999). Another survey of farmers in areas of lowland cultivation in Vientiane Municipality and the provinces of Savannakhet and Champassak conducted in 1994 showed that rodents were a significant problem in only one area, where 30% of farmers reported that rodents were pests. Most farmers claimed that they could manage the rodent problems encountered (Rapusas et al 1997).

In contrast, areas of lowland rice adjacent to upland areas (referred to as montane paddy rice by Linquist et al in Chapter 3) can receive very high losses from rodents. These areas are generally adjacent to areas of degraded forest, fallow regrowth, and areas of upland cropping, all of which can harbor large populations of rodents. Early-

Table 3. Summary of the timing of maximum rodent damage to various crops in each of six villages in Luang Prabang Province (from Harman 2003), based on the results of farmer group meetings.

Crop type	Village					
	Houay Khot	Houay Kha	Ladthahae	Hatsua	Houay Leuang	Mok Mouang
Dry-season lowland	Sowing (December)		Harvest (May)			
Wet-season lowland	Harvest (November)	Harvest (October)	Harvest (October)	Harvest (October)	Flowering (October)	
Upland rice	Harvest (October)	Sowing (May)	Harvest (October)	Sowing (May)	Planting (June)	Threshing (October)
Maize	Harvest (August)	Harvest (August)				Harvest (August)
Job's tears	Harvest (November)		Harvest (October)	Planting (May)	Planting (May)	
Seasame		Harvest (September)	Harvest (July)		Harvest (August)	
Melon				Flowering (August)		
Cassava						Harvest (February)

maturing rice crops in this environment are particularly vulnerable. In some villages in Luang Prabang, farmers plant only one lowland crop per year because of the potential for high rodent damage in a second crop. This "forgone loss" is not normally quantified when examining estimates of rodent damage.

Bamboo flowering and *nuu khii* outbeaks

Episodic but irregular rodent irruptions occur in many parts of Laos. These are sometimes responsible for extreme crop losses, occasionally leading to localized or widespread famine (Douangboupha et al 2003). In some situations, up to 100% of crops can be damaged through localized outbreaks of rodents (Singleton and Petch 1994). Farmers typically associate these outbreaks with the gregarious flowering and seeding ("masting") of certain bamboo species and commonly refer to them as *nuu khii* events (*nuu khii* literally means "rat of bamboo flower").

The link between bamboo masting and rodent outbreaks is made across many other parts of South and Southeast Asia, wherever there are extensive tracts of bamboo (Chauhan and Saxena 1985, Nag 1999). Similar phenomena are also reported in South America, where severe rodent outbreaks occur (Jaksic and Lima 2003), and in Madagascar. Although the ecological link between bamboo seeding and rodent outbreaks has not been documented in full anywhere in the world, it is ecologically plausible that the production over one or two years of large quantities of highly nutritious bamboo seed could trigger an explosive increase in rodent populations within the bamboo forest

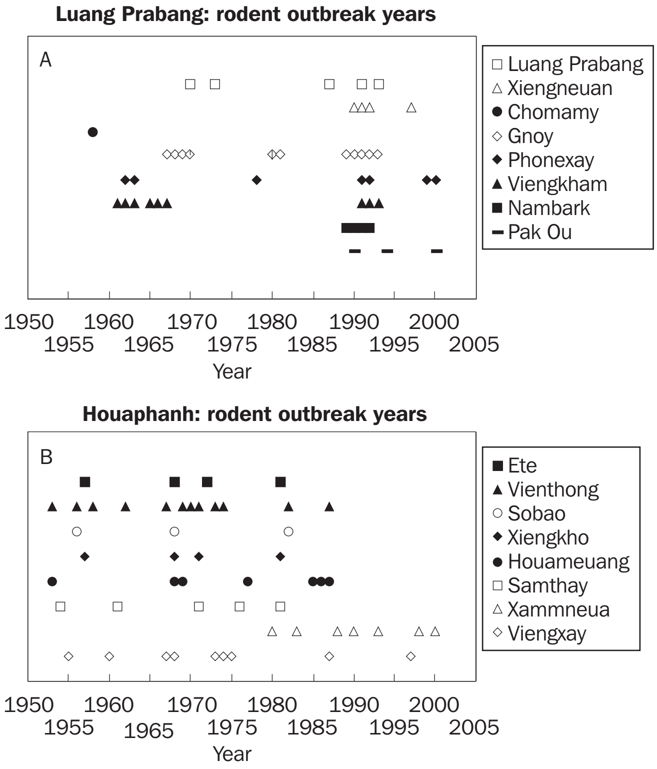

Fig. 2. Historical pattern of rodent outbreaks in various districts of two provinces of Laos (from Douangboupha et al 2003): (A) Luang Prabang in the north of Laos and (B) Houaphanh in the northeast.

habitat. Mass emigration of rodents into adjacent agricultural habitats following the depletion of the seed resource also seems plausible, given what is known of general rodent biology.

The frequency and duration of rodent outbreaks vary markedly from one province to another in Laos (Fig. 2). In Luang Prabang, the outbreaks seem to occur infrequently but tend to last 2–4 years. In Houaphanh, in the northeast of the country, they tend to be more frequent but typically fall within a single year. Although these historical records suggest that many outbreaks are localized to a particular district, there is also evidence of more widespread outbreaks, such as in 1989-93, when an outbreak affected most districts of Luang Prabang and neighboring Oudomxay in northern Laos (Douangboupha et al 2003). Because there are many species of bamboo in Laos, each with a patchy distribution in the landscape and each with a different flowering interval, irregular and localized outbreaks of the kind observed are consistent with the bamboo flowering hypothesis. In contrast, widespread and prolonged outbreaks are more likely caused by some wider environmental factors. One possible alternative cause is the El

Niño Southern Oscillation (ENSO) that has a strong influence on the climate of Laos (Holmgren et al 2001).

The species of rat or rats responsible for *nuu khii* outbreaks remains in doubt. Douangboupha et al (2003) listed six different ethnotaxa (Lao species) reported to be involved in historical *nuu khii* outbreaks: *nuu khii*, *nuu ban, nuu american, nuu na*, *nuu mon*, and *nuu tongkao* (refer to Table 1 for classifications). The following species were collected during an outbreak in Houaphanh in northern Laos in 2001: *Mus cervicolor* (identified as *nuu khii*), *Rattus rattus* (several specimens, variously identified as *nuu khii*, *nuu ban*, *nuu mon*, and *nuu tongkao*), *Berylmys berdmorei* (identified as *nuu mon* and *nuu way*), and *Bandicota indica* (identified as *nuu american* and *nuu na*). Most rodent species are quite adaptable and willing to change their diet as different food resources become available. Accordingly, many different species could probably use the temporary bamboo seed resource and then participate in *nuu khii* outbreaks. Some forest-dwelling nonpest species therefore might become temporary agricultural pests during an outbreak period.

Chronic postharvest impact

There is little information on the losses caused by rodents to stored grain in Laos (Singleton and Petch 1994). Nevertheless, farmers generally recognize this as being a significant problem and rate the damage to stored grain as equal to or greater than the field losses (Harman 2003; Table 4).

In all four upland villages (spread across four provinces, as noted above) where systematic trapping was conducted (Khamphoukeo et al 2003), members of the "house rat" group were consistently trapped in and around traditional grain stores. These species are excellent climbers and are difficult to exclude from such facilities, especially where there are overhanging trees or other vegetation. Mice (*Mus* spp.) were never trapped in these contexts and do not seem to be responsible for any postharvest damage or loss. However, this situation could change rapidly if the house mouse (*Mus musculus*) became established in rural villages in Laos (as it has done in parts of Myanmar). Farmers use several traditional methods to control rat damage to stored grain, but with limited success.

Rodent-borne diseases

Commensal rodents (rats and mice) are known reservoirs of many zoonotic diseases (Gratz 1994, Mills 1999). Rodent-borne diseases of major concern in agrarian and urban communities of Southeast Asia are leptospirosis, plague, hanta and arena viruses, lymphocytic chorio-meningitis virus (LCMV), typhus, and lungworm. Chronic high rodent numbers in places where livestock are housed, and in rice-cropping and village habitats, represent a key factor in the disease nexus (Perry et al 2002, Begon 2003).

Very little is known about the status of rodent-borne diseases in rural communities in Laos. One small study examined 48 animals (8 rat species) in the upland environment of Luang Prabang and Oudomxay provinces in northern Laos but found no individuals sero-positive for leptospirosis, LCMV, or hanta virus (Singleton et al 2003). However, in the border region between Laos and northeast Thailand, leptospirosis has had a major

Table 4. Farmers' perceptions of the most- and least-damaged field crop or stored commodity in each of six villages in Luang Prabang Province, based on two different methods. For the "seed method," farmers were asked to place seeds on an annual cropping calendar to quantify the timing and severity of damage caused by rodents. For the second method, farmers were asked to estimate the overall yield loss caused by rodents in each crop. The fact that the two methods gave different results is not unexpected given the complex relationship between rodent damage and yield loss (Aplin et al 2003c).

Damage type	Village					
	Houay Khot	Houay Kha	Ladthahae	Hatsua	Houay Leuang	Mok Mouang
Most-damaged crop (seed method)	Stored rice	Stored rice	Upland rice	Wet-season lowland rice	Upland rice	Stored rice
Crop with highest yield loss (%)	Maize and stored rice	Upland rice and maize	Stored rice	Stored rice	Stored rice	Upland rice and stored maize
Least-damaged crop (seed method)	Other stored crops	Stored sesame	Stored sesame	Stored melon	Stored sesame	Upland rice and cassava
Crop with lowest yield loss (%)	Other stored crops	Stored sesame	Stored sesame	Stored melon	Stored sesame	Cassava

impact on rural as well as urban communities (Tangkanakul et al 2001). From 1995 to 2003, the reported incidence of leptospirosis in humans showed a marked increase in this region. In 1996, 398 cases were reported, with a peak in 2000 of 14,285 cases and 362 deaths. The number of cases remained high through 2001 to 2003, with 171 deaths in 2001 and 95 in 2002. Most of the reported cases each year (ranging from 72% to 94% of those reported) occurred among rice farmers (Phulsuksombati et al 2001, Tangkanakul et al 2005). In northern Thailand in 2000, 3,914 cases of scrub typhus were reported, with most cases being male farmers (in northeast Thailand in 2000, the morbidity rate was 8.7 per 100,000 people) (Tangkanakul, personal communication). A 10-year study in northern Thailand identified 9 murid rodents as carriers of scrub typhus, with the main carriers being *R. rattus* (23%, 419 of 1,855), *R. argentiventer* (22%, 5 of 23), *B. berdmorei* (22%, 2 of 9), *R. losea* (13%, 82 of 638), and *B. indica* (9%, 52 of 564). *Rattus exulans* was a poor host for typhus, with only 2 of 146 animals infected (Coleman et al 2003). Information on leptospirosis and typhus from other Asian countries is extremely limited. Information on zoonotic viral diseases is even less available. However, some recent work in Thailand suggests that hanta viruses are quite prevalent in rodent populations in the region and thus may pose a significant risk to human health (Nitatapattana et al 2002),

Management of rodent pests in Laos

Traditional methods

Lao farmers use a variety of locally made traps and snares for rodent control, sometimes in combination with drift fences made of sticks or bamboo. These are used throughout the year, with an increase in activity as the upland rice crop matures and after harvest. Captured animals are often eaten or the meat smoked and sold in local markets.

Intensive hunting for rats is often carried out by men and children after harvest. A common target is the piles of rice straw and Job's tear stalks that are stacked around upland fields. Hunters generally place fishing nets along one side of the pile and then either disturb the pile or light a fire on the opposite side. Rats also are hunted at night with the use of air guns, crossbows, or slingshots.

Protection of stored grain

The Lao-style storage facilities in and around villages can be simply described as hut-like storage structures; these are sometimes built at ground level but more often they are raised on stilts. The roof is typically made of straw and the entrance is usually a single small window-like opening with a latch door or a standard-sized opening with a large door. The walls can be made of woven bamboo, wood, or bamboo cut into strips and tightly woven together. A mixture of buffalo dung and soil is sometimes plastered onto the walls and this helps to block any holes that rodents might use. Additional rodent deterrents include metal guards wrapped around the stilts of the structure and wire mesh nailed across the top of the storage compartment. The use of metal guards is regarded as one of the most effective methods for protecting grain stores against rodent damage (Harman 2003) but, to be effective, the store also needs to be constructed away from other buildings and overhanging tree cover. Grain stores protected by these measures usually show little or no evidence of damage or contamination by rodents. In contrast, unprotected stores in the same villages typically show much damage to the storage structure itself and heavy damage and contamination of the grain.

Rodenticide use

Until the mid-1990s, there was little use of rodenticides for controlling rodents in Laos. However, in the last decade, rodenticides have become more widely available and their use has increased, in some areas to a chronic level. The most widely used poison is a clear liquid of Chinese origin, supplied in ampoules with little if any labeling. Analysis of three ampoules found a compound similar to 1080 (sodium monoflouroacetate) in two, and no obvious active ingredient in the third (Herwig Leirs, personal communication). Anticoagulants such as coumatetralyl and zinc phosphide of Russian and Japanese origin also are widely available. Rodenticides are applied in the field only when rodent numbers are high and heavy crop damage is observed. Poison use around villages is regarded as dangerous and is generally avoided.

When mixed with paddy grain and applied in fields, the “Chinese poison” has an immediate and visible impact on rodents, with many carcasses lying around the following day. Unfortunately, the baits are also highly effective against various nontarget animals, including domestic cats, dogs, pigs, and fowl, either through direct consumption of the bait or from scavenging of carcasses. In many parts of Laos, regular rodenticide use has drastically reduced the numbers of domestic animals in villages. Farmers are painfully aware of this fact but claim to have little alternative other than to continue using these highly toxic baits. Native wildlife presumably also suffers nontarget mortality but nothing is known of the long-term impact on any species. The Lao government has a policy to discourage the use of rodenticides; however, they can still be purchased in local markets in many areas. The ecological understanding recently obtained of the major rodent pest species has the potential to provide a platform for ecologically based rodent management in Laos. In Indonesia, in lowland irrigated rice crops, such an approach has led to significant increases in yield and a greater than 50% reduction in rodenticide use (Singleton et al 2005).

Conclusions

The upland environment of Laos supports a rich array of rodent species, the great majority of which do little or no damage to crops. In developing rodent management practices, it is important to develop strategies that do not harm those species that are important members of the natural forest community and provide important ecosystem services. Important steps toward developing ecologically based and ecologically sensitive rodent management for Laos include (1) minimizing the use of indiscriminate poisoning with rodenticides, (2) focusing rodent management efforts on the manipulation of habitats and the selective culling of pest species at key times in their population cycles, and (3) encouraging farmers to work together at critical times to carry out effective control actions. Management techniques almost always need to be adapted to suit particular cropping systems and pest species (Leirs 2003), and as such are likely to differ for the different regions and rice-growing environments in Laos.

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CHAPTER 20

Weed ecology in the rice environments of Laos

W. Roder

The direct loss in rice production because of weeds in farmers' fields in Asia is reported to amount to about 20% (www.riceweb.org: Pests, diseases). In addition to this, weed control is a major component of production costs. In Laos, weeds are especially troublesome for upland rice farmers, resulting in much labor required for weeding (Table 1). Because of this, weed ecology and weed management have received high importance in research projects focusing on upland rice-growing environments (Roder 2001). In most Lao lowland rice-growing environments, weeds, although present, are less problematic.

Weed ecology and management in lowland systems

Publications by Khotsimuang et al (1995) and Inamura et al (2003) provide information on weed species, distribution, and management practices. A study by Khotsimuang et al (1995) included 141 villages in Vientiane Municipality, and Vientiane, Kham-

Table 1. Production costs for rice systems.

Parameter	Lao rice producer		United States
	Lowland	Upland	
Rice yield (t ha^{-1})	2	1.5	8.5
Value of production (US\$ ha^{-1})	300	225	1,020
Labor input (days ha^{-1})	200	294	<2
Labor for weed control (days ha^{-1})	7	159	<0.5
Labor % weed control	3.5	54	–
Cost of weed control (US\$ ha^{-1})	7	159	90
Weed control cost as % of production	2.3	71	9
Labor productivity in rice (kg day^{-1})	10	5.1	>4,000
References	Estimated based on Khotsimuang et al (1995) and Leacock et al (1993)	Roder (2001)	Livezey and Foreman (2004)

mouane, Savannakhet, Saravane, Champassak, and Sayabouly provinces, representing the most important lowland rice areas of the Lao PDR. A study by Inamura et al (2003) included 41 sites in Vientiane Municipality (Saythany and Nasaithong districts) and Luang Prabang (Xiang Ngeun, Nambak, and Luang Prabang districts), Oudomxay (Beng and Xay districts), and Luang Namtha (Namtha District) provinces.

Weeds as a production constraint

When ranking constraints to rice production, Lao lowland rice farmers generally ranked weeds third or fourth after drought and insect pests (Khotsimuang et al 1995, Schiller et al 2001). Because of low soil fertility in much of the lowland rice-growing area, weed growth is poor and the labor required for weeding is generally less than 10% of the total labor input (Inamura et al 2003, Table 1). The tall, traditional Lao rice cultivars with droopy leaves are more effective in suppressing weeds than the short, high-yielding varieties (Nantasomsaran and Moody 1995). With the introduction of high-yielding varieties, higher fertilizer applications, and increased cropping intensity in response to expanded irrigation facilities, weed competition may become more of a problem. In spite of their poor growth, weeds compete with rice for the limited nutrient and reduce rice yield. Inamura et al (2003) have shown that removing weed competition resulted in increased nitrogen-use efficiency and better harvest index.

Weed species

Weed species reported are similar across a wide range of the lowland rice-growing areas of Laos (Khotsimuang et al 1995, Inamura et al 2003, Table 2). From Luang Namtha Province in the north to Champassak Province in the south, *Ludwigia octovalvis* and *Fimbristylis littoralis* have been cited as the most important weed species (Table 2). *Ludwigia octovalvis* is listed among the seven most important broadleaf weeds of rice in Asia (IRRI 2003).

Weed management strategies

Lao lowland rice farmers are familiar with common weed management strategies. They use a combination of land preparation, water management, and manual weed control. However, weed management is hampered because of poor water control (Nantasomsaran and Moody 1995). Lack of water or water management was mentioned consistently as the main factor associated with weed problems by the farmers interviewed by Khotsimuang et al (1995) and years with lower than average rainfall were associated with increased weed competition.

Weeding in the lowland rice environments is done manually. Most farmers weed about 40 days after rice planting (Khotsimuang et al 1995, Inamura et al 2003). Weeding requirements vary substantially. Inamura et al (2003) reported the ratio of paddy fields weeded to total paddy for Vientiane Municipality, Luang Prabang, Oudomxay, and Luang Namtha provinces as 34%, 92%, 63%, and 33%, respectively. In some areas, especially in Vientiane Municipality and Luang Namtha Province, weeding was not necessary at all. In the survey by Khotsimuang et al (1995), the labor required ranged

Table 2. Weed species reported in Lao lowland rice environments.

Species[a]	Sites[b] where species reported			
	Khotsimuang et al		Inamura et al	
	(no.)	(%)	(no.)	(%)
Ludwigia octovalvis	6	86	8	100
Fimbristylis littoralis	5	71	8	100
Xyris indica	6	86	6	75
Marsilea crenata (minuta)	7	100	3	38
Ischaemum rugosum	2	29	2	25
Echinochloa colona	1	14	3	38
Cyperus difformis	1	14	1	13
Scirpus supinus	3	43	–	–
Paspalum distichum	–	–	5	63
Rottboellia exaltata	4	57	–	–

[a] Additional species recorded at 2–3 sites: (1) Khotsimuang et al (1995): *Monochoria vaginalis, Mimosa pudica, Scirpus grossus, Cyperus rotundus,* and *Eleocharis dulcis;* and (2) Inamura et al (2003): *Axonopus compressus, Ageratum conyzoides, Ludwigia hyssopifolia,* and *Sagittaria trifolia.* [b] Sites were seven provinces for Khotsimuang et al (1995) and eight districts for Inamura et al (2003).

from 2.2 to 11.5 days per ha (averaged at the village level). As recently as 2003, commercial herbicides were rarely being used for weed control in lowland situations.

Weed ecology and management in upland rice systems

Upland rice production systems in Laos have evolved from the traditional slash-and-burn agricultural systems, which were typical for the subtropical regions of Southeast Asia. Before the 1990s, little information was available on land-use systems, particularly on weed species, ecology, and management.

Weeds, the most important production constraint

In household surveys carried out in the three northern provinces of Luang Prabang, Oudomxay, and Bokeo during the early 1990s, 80–90% of the upland farmers rated weeds as their most important constraint to rice production (Table 3, Roder et al, 1997a). This rating by farmers did not refer to direct yield loss, but to the labor requirements for weeding. Some of the other important constraints frequently listed, such as land availability and labor, can be directly related to weeding requirements/problems.

Table 3. Farmers' rating of major constraints to upland rice production based on household surveys in three northern provinces of Laos.

Constraint	Respondents listing constraint (%)		
	Oudomxay (n = 32)[a]	Luang Prabang (n = 97)	Bokeo (n = 57)
Weeds	81	86	93
Rodents	12	72	61
Insufficient rainfall	47	50	2
Insect pests	69	30	2
Land availability	47	31	–
Domestic animals	16	17	23
Soil fertility	31	22	2

[a] n = number of farmer respondents.
Source: Roder et al (1997a).

Table 4. Labor requirement for upland rice production.

Activity	Days ha^{-1}
Slashing	33 (12–61)[a]
Burning	2 (1–3)
Fencing	2 (0–10)
Second burning	14 (5–30)
Weeding before planting	13 (0–40)
Planting	29 (16–44)
Weeding	146 (45–455)
Harvesting/threshing	33 (20–71)
Transportation	22 (7–47)

[a] Numbers in parentheses indicate range.
Source: Roder et al (1997a).

Farmers customarily provide adequate weed control, with 3–4 weedings per season resulting in labor inputs of 45–455 days ha^{-1} (Table 4). The most critical period for weed competition is 30–50 days after planting (Phengchangh 1998). As the fallow biomass is burned in March, about 2 months before rice planting, a first weeding is often undertaken. Weed control is by far the most labor-consuming task in upland rice production, accounting for 40–50% of total crop labor input (Table 4). Other tasks requiring appreciable labor inputs are slashing of the fallow vegetation and harvesting.

Table 5. Cover and frequency of major weeds in upland rice fields of northern Laos.

	Oudomxay Province		Luang Prabang Province					
Weed species			Viengkham District[a]		Pakseng District		Xienngeun District	
	F[b]	C[c]	F	C	F	C	F	C
Chromolaena odorata	68	9.7	32	6.5	36	1.9	64	4.4
Ageratum conyzoides	31	6.6	23	5.5	11	0.7	60	3.4
Commelina spp.	18	2.6	8	1.3	22	1.2	58	3.4
Lygodium flexuosum	13	1.8	13	1.6	28	1.8	34	1.6
Panicum trichoides	5	0.5	3	0.4	6	0.3	32	1.5
Corchorus sp.	3	0.3	8	1.5	8	0.6	10	0.4
Pueraria thomsonic			7	1.3	5	0.2	12	0.7
Panicum cambogiense			4	0.5			8	0.5
Imperata cylindrica			1	<0.1	4	0.2	4	0.2
Dioscorea sp.			4	0.4	2	0.1	<1	<0.1
Crassocephalum crepidioides	<1	<0.1	1	0.1			2	0.1
Total cover (cm m^{-1})	22		19		7		16	

[a]Additional species of importance in Viengkham District were *Cyperus trialatus* and *Pteridium* sp., with frequencies of 26% and 13% and cover of 4.5 and 3.3 cm m^{-1}, respectively. [b]F = frequency (%) in transect segments of 1 m. [c]C = cover in cm m^{-1}.
Source: Roder et al (1997a).

Weed species

With a few exceptions, *Chromolaena odorata,* introduced to Laos in the 1930s, is the most important weed found in upland rice throughout the country (Photo 20.1, Roder et al 1995b, 1997a). Following field measurements over a wide area in Luang Prabang and Oudomxay provinces, *C. odorata* contributed almost 40% of the total weed cover during the rice crop (Table 5). *Ageratum conyzoides, Lygodium flexuosum,* and *Commelina* spp. (mostly *C. benghalensis* L.) were abundant in all regions surveyed. The latter is difficult to control because it can root easily from nodes of small stem segments left in contact with moist soil. *Imperata cylindrica* and *Mimosa invisa* were present but were not regarded as being significant problems, except in relatively localized areas (Photo 20.2). In some upland areas, such as in parts of Houaphanh Province, small areas of *I. cylindrica* are deliberately maintained by farming households to provide a source of material for roofing thatch. The major weed species appear to be adaptable to a wide range of environmental conditions. Correlation analysis between elevation, fallow period, selected soil fertility parameters, and frequency of weed occurrence showed no or little relationship (Roder et al 1995a,b).

Phengchanh (1998) evaluated competition and allelopathic effects of *C. odorata* and *A. conyzoides* on traditional upland rice varieties. His studies showed that the critical time for removing the competition ended at 30 days for *A. conyzoides* and at 45

Table 6. *Ageratum conyzoides, Chromolaena odorata,* and *M. graminicola* density for fallow categories (years of fallow) observed in the weed survey (1993).

Fallow (no. of years)	*A. conyzoides* (number m^{-2})	*C. odorata* (number m^{-2})	*M. graminicola* (number g^{-1} root)
2–3	15 ± 4[a]	8 ± 2	156 ± 82
4–5	11 ± 2	8 ± 1	72 ± 28
6–8	9 ± 3	10 ± 1	41 ± 17
>8	5 ± 3	8 ± 3	32 ± 31

[a] Mean and standard error.
Source: Roder et al (1998a).

days after planting for *C. odorata.* Root exudates of both species showed stimulatory and inhibitory effects and varied with rice variety. Allelopathic effects by *C. odorata* have also been demonstrated by Nakamura and Nemoto (1994).

Shift in weed species

Within a short time after its introduction in the 1930s, *C. odorata* had become the most abundant weed and fallow species (Roder et al, 1995b, 1997a). In interviews conducted during the early 1990s, elderly upland farmers could not recollect the dominant weed species prior to the introduction of *C. odorata*. The invasion by *C. odorata* had apparently not resulted in a major displacement of other species. With a coincident reduction in the fallow period, the spread of *C. odorata* may have largely replaced tree species coppicing from old plants or growing from seeds.

With repeated cycles of short fallow periods, a shift from *C. odorata* to *A. conyzoides* (Roder et al 1998a) or to grass species (Fahrney 1999) had become apparent in the 1990s. These trends toward weed species that are more difficult to manage is likely to continue. Changes in weed composition are likely to have strong effects on the fallow vegetation and soil fertility. Studies in the 1990s documented effects of cropping intensity on the prevalence of *A. conyzoides* (Photo 20.3). The same studies also showed some association between rice yield and the prevalence of *A. conyzoides* and the root-knot nematode (Roder et al 1998a, Table 6). Farmers in most areas recognize *A. conyzoides* as their most serious weed problem (Fahrney 1999). The shift from tall-growing species or coppicing trees to weed species such as *A. conyzoides* or grasses also leads to increasing intensity and frequency of weeding with hand hoes (Photo 20.5), thereby increasing the potential for soil loss substantially (De Rouw et al 2005).

Fallow length, weeding requirement, and labor productivity

Many authors have made reference to the relationship between weed problems and the length of the fallow period (SUAN 1990, Roder 2001), but quantitative data are limited. Traditional land-use systems were influenced by factors such as climate, land availability, land tenure, population pressure, food preferences, political events, and ethnicity, yet all farmers use fallow length and fire as the most important weed management strategies (Roder 2001, Moody 1975, De Rouw 1991, Warner 1991). Fallow species composition, species characteristics, biomass produced, and biomass quality all have a direct effect on soil conditions, ease of slashing, burning temperature, weed dynamics during cultivation, and ultimately crop yield and farmers' return on labor invested. The primary functions of the fallow period are to restore soil fertility and reduce weed pressure. Long fallow periods with tree cover eliminate most of the annual weed species. Furthermore, high fallow vegetation biomass increases temperatures at the time of burning, thus decreasing viability of weed seeds, which may have been present in the topsoil. To maintain long fallow periods, large land resources and consequently low population densities are required.

Little information is available on the upland production system prevalent in Laos in the 19th century and before, but we can assume that the traditional systems evolved under low population densities. Reports by Thorel (1875), Boudene (1913), and Gourou (1942) indicate that fallow periods of 20 years and more were the norm during the time of their observations. Thorel's remarks also suggest that weeding was not necessary during the 19th century. Observations made in the 1950s mention weeding, but not to the extent that it is required today. Izikowitz (1951) gave a detailed description of slash-and-burn cultivation by Lamet farmers in northern Laos in the 1940s. He considered cutting of the fallow vegetation as the most important labor input, and reported fallow periods of 12–15 years and weeding inputs in June and July. With weeding limited to a period of 2 months only, the weeding intensity may have varied from 1 to 2 weedings per season. Halpern (1961) indicated that weed control in upland rice (slash-and-burn systems) was less labor-consuming than for lowland rice.

Based on investigations carried out in the districts of Xiengngeun and Viengkham of Luang Prabang Province, the average fallow period reported decreased from 38 years during the 1950s to 5 years in 1992, whereas the weeding requirement increased from an average of 1.9 weedings per season in the 1950s to 3.9 weedings in the 1990s (Roder et al 1997a, Table 7); this change represents a remarkable increase in the labor input for weed control. With stagnant yields, upland farmers' returns to labor inputs have therefore declined substantially (Table 7). In another study carried out in Luang Prabang, Leacock et al (1993) reported labor inputs of 268, 205, and 194 days ha^{-1} or returns to labor of 4.3 kg of grain day^{-1} for upland rice, 8.6 for lowland rice, and 13.3 for maize production. Because of the unsatisfactory returns to labor and increased expectations, Lao hill farmers are under great pressure to change their land-use practices. However, a combination of a lack of markets for alternative potential cash crops, a lack of access to credit facilities, and poor alternative employment opportunities have left them little choice but to continue producing upland rice for their own consumption.

Several authors have used remote-sensing techniques to estimate the length of the fallow period (Sandewall et al 2000). When comparing estimates of the fallow period made by remote-sensing methods with those reported in interviews, the lat-

Table 7. Trend in fallow length, weeding requirement, labor input, population density, and wage equivalent in rice.

Parameter	1950s	1970s	1990s
Fallow period (y)	38	20	5
Weeding requirement (no.)	1.9	2.3	3.9
Total labor requirement for upland rice (d ha^{-1})	226	239	294
Rice yield (t)	1.7	1.6	1.5
Population (millions)	1.8	3.0	4.2
Population density (nationally, persons km^{-2})	7.6	12.5	17.6
Labor productivity in rice (kg day^{-1})	7.5	6.7	5.1
Rice equivalent of labor wage for construction (kg d^{-1})	8.4	n.a.	5
Rice equivalent of labor wage for farm work (kg d^{-1})	6 + meal	6 + meal	4 + meal

Source: Roder (1997).

ter have often suggested comparatively shorter fallow periods. Several factors may contribute to this discrepancy, the most important being (1) remote-sensing methods integrate events over a timeframe of more than 10 years, while the interview system may only ask the farmer, “What was the fallow period for the rice field used in the year of the interview?; (2) remote-sensing methods may also include areas that, for various reasons, cannot be used further for cultivation.

Weeds for fallow improvement

Plant species regarded as weeds during the period of the rice crop may potentially become useful fallow species after the rice harvest. The composition of fallow plant species and their characteristics are important factors influencing soil fertility parameters, weed dynamics, and grain yield of the next rice crop. In most environments, *C. odorata* provides the bulk of biomass in the initial years after the rice harvest. At sites monitored by Roder et al (1997b) in northern Laos, the average aboveground biomass was 1.4 t ha^{-1} at the rice harvest, increasing to 9.8 t ha^{-1} and 15.5 t ha^{-1}, respectively, after 1 and 2 years of fallow (Photo 20.5). At rice harvest, tree and bamboo species contributed 61% to the total biomass (Table 8). Their development, however, is too slow to fill the gap left after the rice harvest and, after the first year of fallow, tree and bamboo species contributed only 37% of the biomass, whereas *C. odorata* contributed 49%. Similarly, *C. odorata* was the dominant fallow species in the initial year in slash-and-burn fields in southern Laos (Chansina et al 1991). As the duration of the fallow period increases, woody bamboo and tree species gradually replace *C. odorata* (Roder et al 1995b, 1997b). The contribution of grass species to the weed and fallow biomass is generally small, and, in contrast with some other slash-and-burn systems in Asia, *Imperata cylindrica,* although present, is rarely dominant in upland production systems of Laos.

Chromolaena odorata regrowth from rootstock after burning can seriously compete with young rice plants but, because of its growth habit (relatively few but

Table 8. Average aboveground biomass in four slash-and-burn fields in northern Laos after the rice crop (1991) and two subsequent years of fallow (1992-93).

Species	Plant biomass (t ha^{-1})		
	At rice harvest	One-year fallow	Two-year fallow
Chromolaena odorata	0.23 ± 0.07[a]	4.8 ± 0.7	4.5 ± 1.4
Lygodium flexuosum	0.14 ± 0.03	0.6 ± 0.4	0.1 ± 0.05
Other broadleaf species	0.17 ± 0.03	0.5 ± 0.3	1.3 ± 0.9
Grasses	0.03 ± 0.02	0.1 ± 0.1	0.2 ± 0.1
Bamboo	0.24 ± 0.15	2.1 ± 1.7	4.0 ± 2.0
Tree species	0.51 ± 0.11	1.5 ± 0.9	5.3 ± 1.4
Total[b]	1.4 ± 0.13	9.8 ± 1.1	15.5 ± 1.9

[a]Mean + standard error. [b]Rice grain harvested and rice stems were 1.1 and 1.2 t ha^{-1}. Source: Roder et al (1997b).

large plants, and no rooting from aboveground plant parts), it is much easier to control by hand weeding than species such as *Commelina* or *Lygodium flexuosum*. Plants growing from seeds have a comparatively slow initial growth phase and are less of a problem in the initial growth stage of the rice plant. The potential of *C. odorata* to expand rapidly and provide a protective cover in the early part of the fallow period is probably the single most important property making it a good fallow plant for the sloping fields prevailing in Laos. This fast expansion is made possible by the abundance of seed produced and its mobility. The seeds are dispersed by wind during April and May, and germination starts about the same time as the planting of the upland rice crop.

Although *C. odorata* is the most abundant weed species in upland fields in Laos, farmers regard it as a desirable fallow plant. When asked to list “good fallow plants” (or plants they like to have in their fallow fields), farmers widely favored *C. odorata* over any other species present (Roder et al 1995b, 2005). None of the respondents considered it as a bad fallow species. Farmers give various explanations for their preference of *C. odorata*, including its dominance under good soil conditions, the absence of negative effects on rice yield, it is relatively easy to control by hand weeding in the rice crop, and it has fast growth and large biomass production. Some of the plants listed as bad fallow plants, especially *Cratoxylon prunifolium* and *A. conyzoides,* are generally associated with poor rice yields. Farmers interviewed in Savannakhet Province in central Laos suggested that soil structure is better where *C. odorata* is dominant when compared with fields where bamboo is the dominant species (Keovilayvong et al 1991).

Weed and residue management strategies

Traditional upland field preparation involves burning of the slashed aboveground biomass, consisting of 4–20 t of dry matter per ha depending on the duration of the fallow period (Roder et al 1997b, 1998a). Increasing numbers of farmers have, of re-

Table 9. Effect of residue treatment on fresh weed biomass over the rice growing season (on-farm and on-station experiments, 1993-95).

Residue treatment	Weed biomass (fresh, g m^{-2})			
	1993 (on-farm)	1994 (on-farm)	1994 (on-station)	1995 (on-station)
Residue burned	430	830	220	491
Residue mulched	740	990	440	663

Source: Roder et al (1998a).

cent times, been planting a second or third rice crop before allowing the field to revert to fallow. Fields that have been cropped to rice in the previous year have relatively low aboveground biomass (approximately 1–3 t ha^{-1}), and field preparation without burning the residue is theoretically feasible. Retaining the residue as a mulch might be expected to improve soil moisture conservation and slow organic matter losses (Roder et al 1998a). With these expectations, several studies have been made to assess the effects of residue management, especially burning. These studies, undertaken over a range of environments and years, consistently showed that, compared with burning, residue mulching increased weed biomass and often reduced rice yields (Roder et al 1998a, Table 9). These studies confirmed that burning of residues not only makes land preparation easier for farmers but also offers a cheap method of weed control.

Other studies have shown that mulching with *C. odorata* or pigeon pea (*Cajanus cajan*) plant material up to amounts of 4 t of dry matter per ha did not reduce weed biomass (Roder 2001). *Arachis pintoi*, when used as a live mulch, had only a limited effect on weed biomass but strongly affected rice yield. In spite of the negative results from these various studies, it is expected that mulching may become an important strategy in evolving permanent rice production systems in the upland environment of Laos (Roder et al 1998b).

Improved fallow as a weed management strategy

Replacement of the fallow vegetation by fast-growing species, preferably nitrogen-fixing legumes, is a widely recommended technique for maintaining crop yields and suppressing weeds in slash-and-burn systems under reduced fallow periods (Roder 2001, Garrity 1993). Improved fallow systems have often been recommended as a strategy to reduce the impact of shorter fallow cycles on soil fertility, and to manage weeds (Roder 2001).

The potential of legumes to improve fallow vegetation under Lao conditions was recognized decades ago. Goubeaux (1930) listed 46 legume species tested for green manure. The presence of *Mimosa invisa*, a serious weed in some isolated upland areas, is an unpleasant testimony of those activities (Poilane 1952). Similarly, Chevalier (1952) and Poilane (1952) recommended *C. odorata* for fallow improvement in Lao PDR. The main species promoted by development agencies for fallow improvement over the past two decades have been *Leucaena leucocephala, Gliricidia sepium,* pigeon pea, and *Calliandra calothyrsus.* Little or no adoption of these species by farmers has been observed, probably because the technologies recommended were not appropriate or economical (Roder 1997).

In more recent research, increased attention has been given to the evaluation of species that have some fodder value to capitalize on the potential for increased livestock production by replacing fallow vegetation with fodder species (Phimphachanhvongsod et al 2005). The initial phase of the fallow period is currently used for grazing ruminants, but little forage is available because of the overwhelming dominance of unpalatable species such as *C. odorata.* Besides increasing the quantity of fodder, replacing the fallow vegetation with more palatable species may result in improved weed suppression through the interaction of fallow species and grazing animals. Furthermore, the activities of grazing animals should accelerate nutrient cycling and reduce the residue load (Roder 2001). Although grazing rotation systems may have high potential, only system components have been evaluated, such as species introduction and species establishment (Roder and Maniphone 1995), rather than the systems themselves.

Out of a wide range of fast-growing legumes tested in the 1990s (Roder 2001, Roder and Maniphone 1995), pigeon pea received special attention with activities focusing on collection and testing of local and introduced cultivars, establishment methods, rotation effects, residue management, and weed suppression (Roder et al 1998b). Of the legume species tested, only *Gliricidia sepium* (Photo 20.6) had a higher production of fallen litter and higher total biomass than *C. odorata* (Roder and Maniphone 1998).

The adoption of fallow management strategies and fallow species will depend largely on the farming systems currently evolving in the uplands of Laos. Pigeon pea, for example, is a very promising species but only if the seeds have a market or if the plant is used in a cut-and-carry system for ruminant or pig production. *L. leucocephala* has potential in a system where firewood has a market value. It can be expected that the improved fallow systems most likely to succeed will be systems that include grazing and that optimize nutrient and moisture management. The most promising species for such systems are *Stylosanthes guianensis, L. leucocephala,* and *Brachiaria* species. Caution needs to be exercised to avoid introducing species that have the potential to become new weed species for Laos and neighboring countries, as happened following the introduction of *Mimosa invisa.*

Other weed management strategies

Weed management strategies that have been tested in addition to residue management/mulching and improved fallow include the use of herbicides, various methods of cropping management, and tillage (Table 10). Herbicides tested had no effect on *L. flexuosum,* tree species, and woody perennials. Furthermore, chemicals with relatively good effect on *C. odorata* and other broadleaf species (2,4-D and propanil) were less effective than hand weeding (Roder et al 1995a). The application of glyphosate at 2.5 kg a.i. ha^{-1} eliminated the need for weeding before planting and reduced the weed biomass during the rice growing season. If planting can be done just before or im-

Table 10. Weed management strategies tested.

Strategy	Effect[a,b]				Adoption[b]	Limitations	References[c]
	W	L	E	RY			
Residue management—mulching							
Residue burning	√√	√√	×	√√	√√√	C loss, not possible in systems with perennials	1, 2
Mulching residues	×××	×××	√	××		Lower rice yield	1, 2, 3, 4, 5
Mulching pigeon pea	×	×	√	√√		Market for pigeon pea	1, 4
Arachis live mulch	√	×	√	û		Lower rice yield	1
Improved fallow							
Manipulating species	√	×		√		No economic benefit	1, 3, 6
Grazed fallow	√			√	√	Requires livestock	1, 7
Cropping management							
Planting density of rice	√√	××	√	√×		Labor, reduces yield	1
Intercropping	√√	××	√	√×	√	Market, increased labor	1
Crop rotation	√	√×	√×	√	√	Market	1
Tillage	√	√×	××	√×		Erosion	3, 8
Rice varieties	√	√	√	√×		Yield, acceptance	3
Herbicides							
Per-plant glyphosate	√√	√√	×	√√		Cost, policies	1
Brachiaria and glyphosate	√√	√√	√√	√		Policies	5
Postemergence	√√	√√	√	√		Cost, policies	1

[a] W = reduce (√) or increase (×) weed biomass, L = reduce (√) or increase (×) labor input, E = reduce (√) or increase (×) soil loss by erosion, RY = increase (√) or reduce (×) rice yield. [b] Trend: one symbol (√ or ×) is some trend increasing; number of symbols is increasing trend. [c] 1 = Roder (1995c), 2 = Roder et al (1998a), 3 = Fahrney (1999), 4 = Roder et al (1998b), 5 = Tivet et al (2004), 6 = Roder and Maniphone (1998), 7 = Roder (2001), 8 = De Rouw et al (2005).

mediately after glyphosate application, the first weeding after planting can be delayed substantially (Roder et al 1995c), thus reducing the labor requirement for weeding by 40–80 days ha^{-1} and reducing potential soil erosion losses. Similar reductions in labor inputs were reported by Tivet et al (2004) when testing glyphosate for the control of *Brachiaria ruziziensis* cover without slashing or burning.

Cropping strategies increasing the competitiveness of the rice crop, or combinations including other competitive crops, have the potential for reducing labor for weeding without the need for expensive chemicals that might also have potential to damage the environment. Various strategies have shown some effect on weeds, but they have several limitations, including the following:

- Hand weeding becomes more difficult (closer planting density, intercropping).
- Risk of lower rice yield or quality (planting density).
- Insufficient market for the product (pigeon pea, soybean, maize).

Invasive weed species

Changes in land use or other events and interventions, such as road construction leading to changes in the vegetation cover, often lead to colonization by invasive weed species. Laos has introduced appropriate legislation governing the movement (both import and export) of plant materials (Nhoyboukong and Khamphoukeo 2002). Yet, considering the long borders with neighboring countries, these regulations cannot prevent the movement of weed species across borders. Furthermore, a number of invasive plant species are already in the country. The most problematic introduced invasive weed species listed by Nhoyboukong and Khamphoukeo (2002) are *Mimosa invisa* and *M. pigra* in upland environments and *Echinochloa colona* and *E. crus-galli* in lowland environments. These latter two grass species are also listed among the eight most important grass weeds of rice in Asia (IRRI 2003).

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CHAPTER 21

The history of lowland rice variety improvement in Laos

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As recently as 1990, almost 98% of the area under rice cultivation in Laos, and about 97% of production, was from cropping activities associated with the annual wet season. The lowland environment accounted for about 72% of total production and the upland environment a further 25%. In 1990, only 12,000 ha were cropped to rice under irrigated conditions in the dry season. The Green Revolution of the 1970s and 1980s that brought about significant changes in the way rice was produced in most parts of Asia had little impact on rice production practices in Laos. In 1990, about 95% of the lowland wet-season crop was based on the use of traditional varieties, whereas, in the upland environment, 100% of production was based on the use of traditional varieties. It was not until after 1993, following the release of a small number of improved Lao glutinous varieties in the lowlands, that production practices started to change, initially with the replacement of many of the traditional varieties, and then more recently with increased inputs (mainly inorganic fertilizer) and increased mechanization of production (mainly land preparation and threshing).

The great diversity of the traditional rice germplasm base that existed in Laos until the mid-1990s is reflected in the results of germplasm-collecting missions that were undertaken from 1995 to 2000, in which more than 13,000 samples of rice were collected for conservation and use (Appa Rao et al 2002). Although without associated DNA analysis it is difficult to ascertain the number of distinct varieties in the collection, it is believed to number at least 3,000, making Laos second only to India in the number of varieties that are currently stored in the International Rice Germplasm Bank at the International Rice Research Institute in the Philippines.

Following the release of several improved Lao glutinous varieties in 1993, and their introduction to farmers throughout much of the main lowland rice-growing area in the Mekong River Valley, replacement of much of the traditional germplasm in this region of Laos was rapid. The basis for the adoption of these improved varieties by farmers was a combination of their greater yield potential relative to the traditional varieties, even under conditions of minimum inputs, and their greater responsiveness to fertilizer when it was applied. By the early 2000s, from 70% to 80% of the wet-season lowland rice area in many provinces in the Mekong River Valley was being planted to improved varieties. The adoption of improved varieties in the wet-season lowland areas in the north of the country was less rapid, as the varieties released during the 1990s were less well adapted to the specific growing conditions of northern Laos, where lower temperatures prevail, particularly near the end of the wet season as well as during the dry season. In the rainfed upland environment, by the early 2000s little had changed, with almost 100% of production still being based on the planting of traditional upland varieties. Most upland variety evaluation work has focused on identifying superior varieties within the traditional germplasm base.

Although changes from traditional cultivation practices in Laos have occurred only relatively recently, including the adoption of improved varieties in the lowland environment, there were some past attempts to develop improved rice varieties for use in the country. This chapter provides a history of the work that has been undertaken for developing improved rice varieties for the lowland environment of Laos.

The early history of lowland rice variety improvement

Before 1975

Agricultural research in Laos in a conventional context began in 1913 with the establishment of two small research stations by the French administrators of that time. One of these early stations was at km 42 on the road between the provincial capital of Pakse and Paksong District on the Bolevens Plateau in Champassak Province in southern Laos. This southern station was used primarily for early research on tree fruit and coffee for the Bolevens Plateau area, an elevated area of very rich volcanic soil that subsequently developed a reputation for the quality of the coffee it continues to produce. The second research station was established in the northeastern province of Xieng Khouang; its research focus was tree fruit and tea. Despite the importance of rice to the people of Laos at that time, there was almost no research interest in the crop. The first recorded instance of an attempt to introduce alternative varieties of rice was by a member of the Luang Prabang–based royal family of Laos, Prince Maha Oupalath Phetsarath, who, in the late 1940s, introduced a number of rice varieties from Vietnam for evaluation on a small research farm under the patronage of the royal family, on the outskirts of Luang Prabang. However, it is acknowledged that, at that time, there would have been regular cross-border germplasm exchange among farmers in provinces in the areas of Laos bordering Vietnam, China, and Thailand. Evidence of this is seen in the popular aromatic variety *Khao kai noi* (small chicken rice), which is currently grown in the provinces of Houaphanh and Xieng Khouang. This variety is believed to have originated from the nearby Vietnamese province of Sou-la, from where it was introduced to the Lao province of Houaphanh, immediately adjacent to Vietnam; later it was also introduced to Xieng Khouang, farther to the south. Vietnamese traders currently purchase this variety from these provinces of Laos.

The first research station to be established in Laos with a focus on rice was the Salakham Rice Research Station (SRRS), which was established in Hatsaiphong District of Vientiane Municipality in 1955. In 1972, the British government provided financial support for the construction of research laboratories for soil, entomology, and plant pathology research, together with training and administrative facilities, at this station. The focus of almost all the early research work coordinated through this station was on variety improvement. During the mid- to late 1960s, Israel provided some assistance through the Mekong Committee Secretariat for the improvement of rice varieties grown in Laos, with the introduction of several lowland varieties. In this early period, until the change of government in 1975, small amounts of assistance for rice-related research were also provided by France, the United States, and Japan. The early variety improvement activities focused mainly on germplasm collection, and the introduction and evaluation of promising lines and recommended varieties from the International Rice Research Institute (IRRI) in the Philippines and the national rice research programs of Thailand and the Philippines. The research activities of the SRRS were supported by some on-station and on-farm research (primarily on variety evaluation) in the north (Sayabouly and Luang Prabang provinces), the central region (Vientiane and Savannakhet provinces), and the south (Champassak Province). In 1964, the first high-yielding variety (HYV), the nonglutinous variety IR8 from IRRI in the Philippines, was introduced to several of these provinces; IR8 was then followed by IR253-100 (glutinous) and IR848-120 (glutinous), also from IRRI; C4-63-1 (nonglutinous) from the Philippines; and Niaw Sanpatong (glutinous) from Thailand. One aromatic variety, *Do-nang-nuan* (early-maturing, soft lady), was selected from the traditional germplasm collection, multiplied, and distributed to farmers. Some of these early introductions were distributed through USAID-sponsored agricultural development projects, as well as through other bilateral development projects. Recent collection missions have revealed that some of these early introductions are still being used on a limited scale in different parts of Laos, with the varieties often being identified by names that relate to the programs that initially introduced them, for example, *Khao Chao America* (American nonglutinous rice) and *Khao Philippines* (Philippines rice). Some varieties from these early introductions, which were adopted by farmers, carried names that reflected their country, including *Khao Cheen* (Chinese rice), *Khao Viet* (Vietnamese rice), *Khao Kampuchia* (Cambodian rice), *Khao hom phama* (aromatic Myanmar rice), and *Khao Hom Thai* (aromatic Thai rice).

The majority of the early variety introductions to Laos had nonglutinous endosperm. On account of the national preference for the consumption of glutinous rice, most of these introductions, if grown at all, were grown only on a very limited scale. Some seed multiplication of selected glutinous varieties started in 1964. Three traditional varieties, *Do-nang-nuan*, *Do-lay*, and *Keaw-lay*, were the first varieties distributed in the lowlands through the seed multiplication program. Of these, *Do-nang-nuan*, an aromatic photoperiod-sensitive variety, was the most popular. In 1971, *Khao Sanpatong*, a photoperiod-sensitive traditional variety from Thailand; IR253-100, an IRRI improved variety, both of which were introduced under a program of assistance from Israel in 1967; together with the Lao traditional variety *Khao do-hom* (early maturing, aromatic) were also included in the multiplication and distribution program near Vientiane. However, relatively few farmers actually started growing these varieties.

1975-90

In the late 1970s and 1980s, several other glutinous varieties were introduced to the country and, after evaluation, were adopted and grown on a reasonably large scale in lowland areas in the Mekong River Valley. Among these were three from IRRI in the Philippines, IR848-120, IR253-100, and IR789-98, and three from Thailand, RD6, RD8, and RD10. Variety RD10 was first introduced unofficially to a village (Sithan) in Hatsaiphong District of Vientiane Municipality and was then grown through one of the agricultural cooperatives that were established in this area in the early 1980s (Nong Khamsene Cooperative). It was subsequently distributed and promoted elsewhere in the Mekong River Valley through the Salakham Rice Research Center. In some parts of the country, RD10 became known as RD16; it is believed that the RD16 designation probably originated from indistinct labeling in its early distribution. There was later further official introduction of RD10 from Thailand, but the RD16 identity was retained by farmers in many areas. In the late 1990s, IRRI variety IR253-100 and the three Thai varieties (RD6, RD8, and RD10) were still being grown in some provinces. In 2005, these three Thai varieties were still being included among variety recommendations for the lowland environment in the Mekong River Valley; RD6 was being recommended for the rainfed environment in the central and southern agricultural regions, RD8 for the rainfed environment in the upper central region, and RD10 nationwide for both the irrigated and rainfed environments. The popularity of RD6 has been on account of its aromatic character and excellent eating quality (RD6 is based on selection within a radiation-induced glutinous mutation of the very popular nonglutinous jasmine rice *Khao dok mali* of Thailand). RD8 is sometimes grown on lower terraces under rainfed conditions (it is later maturing than RD6). It has a sturdy plant type that is not susceptible to lodging, it is large seeded, and it has good eating quality. RD10 is highly regarded on account of its good eating quality and wide adaptability (it is suited to the irrigated environment, is slightly earlier maturing than RD6, and does not need high levels of inputs to achieve reasonable yield). Between 1979 and 1989, several Vietnamese improved nonglutinous varieties were also introduced for evaluation, the most notable of which were the aromatic japonica varieties VN72 and OM80. However, once again they were grown only on a limited scale because of the national preference for the consumption of glutinous rice. Another Vietnamese nonglutinous variety introduced in the late 1970s, which was grown in parts of the Vientiane Plain, was CR203 (a variety based on the IRRI line IR8423-132-6-2-2). CR203 was noted for its high yield potential. By the late 1980s and early 1990s, CR203 had declined in popularity because of its poor eating quality. However, in the mid-1990s it regained some degree of popularity, particularly in the Vientiane Plain, because of demand for its specialized use in the production of noodles and beer.

From 1975 to 1990, considerable attention was also paid to the evaluation of Lao traditional varieties. Some of the more popular traditional varieties grown in the lowland environment are listed in Table 1. Using some of these popular traditional varieties, several crosses and selections were made at the Salakham Rice Research Center near Vientiane, with their ultimate release as named improved varieties. The first crosses were between the Thai traditional variety Sanpatong and IRRI variety IR848-

Table 1. Popular traditional rice varieties in the lowland environment of Laos during the late 1970s and 1980s.

Province	Variety name[a]	Plant type[b]	Endosperm type	Flowering date	Variety characteristics
Vientiane Province	Khitom hang nak	T	G	Mid-Oct	–
	Hom thong	T	G	End Sept-early Oct	Slightly aromatic
Vientiane Municipality	Dok tiou	I	G	End Sept-early Oct	Slightly aromatic, suited to soils of low fertility, susceptible to leaf blast
	Khao dok mai	T	G	End Oct	Slightly aromatic, good eating and grain quality
	Do deng	T	G	End Sept-early Oct	Strong culms, good eating and grain quality
	Chao deng	T	NG	Early Oct	Broad adaptability, good processing quality
	Chao peuk deng	T	NG	Late Oct	Good processing quality
Khammouane	Mak yom	T	G	Mid-Oct	Good eating quality
	Phouang malai	T	G	Mid-Oct	Sturdy culms
	Hang hee	T	G	Early Oct	–
	Sanpatong do	I	G	End Sept	Adapted to poor soils
	E-ang	T	G	End Sept	Adapted to poor soils
Savannakhet	Pakheng khao	T	G	Mid-Oct	Heavy grain, susceptible to leaf blast
	Hom-nang-nouane	T	G	Mid-Oct	Slightly aromatic, susceptible to leaf blast
	Ee phone	T	G	Early Oct	Wide adaptability, susceptible to leaf blast
	Nang ang	T	G	Mid-Sept	Wide adaptability, salinity tolerant
	Nang nee	T	G	Early Oct	Salinity tolerant
Saravane	Intob hom	T	G	Early Oct	–
Champassak	Mak Fai	T	G	Early Oct	Submergence tolerant
	Mak hing	T	G	Mid-Oct	Drought tolerant
	Mak kham do	T	G	Mid-Oct	Adapted to poor soils
	Ee khao ngan	T	G	End Oct	Sturdy culms
	Dovieng	T	G	Early Oct	Wide adaptability

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Table 1 continued.

Province	Variety name[a]	Plant type[b]	Endosperm type	Flowering date	Variety characteristics
Phongsaly	Kon kam	T	G	Early Oct	–
	Lai	T	G	Early Oct	–
Houaphanh	Kai noi	I	G	End Sept-early Oct	Aromatic, popular in northern provinces
Xieng Khouang	Khao la	T	G	Early Sept	Slightly aromatic
	Chao na	T	NG	Early Sept	Good processing quality
Oudomxay	Meuang nga	T	G	Mid-Oct	Blast and gall midge resistant
	Takiet	T	G	End Sept	Blast resistant
	Chao meuang sing	T	NG	End Sept	Good processing quality
Luang Namtha	Meuy (Hok)	T	G	End Oct	–
	Pheuang leuang	T	G	End Oct	–
Luang Prabang	Mae to	T	G	End Oct	Resistant to gall midge
	Do lai	T	G	End Oct	–
	Leua gnia	T	G	End Oct	Big panicles and sturdy culms
Sayabouly	Vang thong noi	T	G	End Oct	–
	Mae hang tob euak	T	G	Mid-Oct	Susceptible to blast

[a] Most names of traditional varieties commence with the word Khao (= rice). [b] I = intermediate plant type, T = tall plant type, G = glutinous, NG = nonglutinous.

Table 2. Varieties introduced in 1975 to 1985 that were recommended for seed multiplication and release.

Country/source	Variety/line	Endosperm type	Year released
IRRI	IR22	Nonglutinous	1978
	IR24	Nonglutinous	1978
	IR29	Glutinous	1977
	IR253-100	Glutinous	1977
	IR36	Nonglutinous	1977
	IR38	Nonglutinous	1977
	IR2823-103	Nonglutinous	1964
	IR789-98	Glutinous	1979
Vietnam	NN75-1	Nonglutinous	1984
	U9	Nonglutinous	1984
	CR203	Nonglutinous	1984
Thailand[a]	RD6	Glutinous	Before 1975
	RD10 (RD16)[b]	Glutinous	1980
	RD8	Glutinous	1984
Indonesia	B1014bpN18-1-4	Nonglutinous	1981

[a]These varieties had widespread adoption in the central and southern regions of Laos. [b]RD10 became known as RD16 in some areas.
Source: Hatsadong (personal communication).

120; the objective of these crosses was to produce varieties with the yield potential of IR848-120, while having the grain quality of Sanpatong. Several Salakham lines were established but only one, *Salakahm 1* (SLK1), demonstrated a yield potential comparable with that of IR848-120. A second set of crosses was based on parental lines of *Mae-hang* (a traditional variety with large panicles) and IR2823-103 (a nonglutinous line introduced from IRRI). The crosses aimed at producing high-yielding glutinous lines with a desired plant type and resistance to brown planthopper. Many promising glutinous fixed lines were established by 1988; however, most of these lines did not have the yield potential of IR2823-103. A third series of crosses was based on the parental lines *Ea-khao* (“white lady”—a traditional glutinous variety) and IR2823-103; however, no fixed lines were established from the progeny of these crosses.

From among the introduced varieties that were evaluated by the SRRS during 1975-85, several of them were recommended as promising lines and varieties (Table 2). From 1975 to 1990, about 1,000 t of seed of recommended varieties was produced by the Salakham Rice Research Station (Table 3). The characteristics of the promising varieties released by the SRRS before 1975, and then subsequently during 1975 to 1985, are summarized in Table 4.

Apart from the selections from among the introduced material, and promising lines from selected crosses, several Lao traditional varieties were identified as being well suited to different parts of Laos. These varieties and the areas for which they were recommended are summarized in Table 5. All were photoperiod-sensitive and therefore recommended only for wet-season lowland cropping.

Table 3. Quantity of seed of recommended varieties released by the Salakham Rice Research Station in 1975-90.

Designation	Source	Year released	Endosperm type	Quantity of seed (kg)
Sanpatong	Thailand	1964	Glutinous	46,615
Do nang nouane	Laos	1964	Glutinous	5,530
Deng home	Laos	1978	Glutinous	8,700
IR848-120	IRRI	1964	Glutinous	35,940
IR253-100	IRRI	1964	Glutinous	121,410
IR789-98	IRRI	1979	Glutinous	32,830
IR29	IRRI	1977	Glutinous	1,000
RD16(RD10)	Thailand	1980	Glutinous	162,000
RD8	IRRI	1984	Glutinous	9,200
SLK1-27	Laos	1984	Glutinous	520
SLK1-11	Laos	1984	Glutinous	450
SLK1-3-2	Laos	1984	Glutinous	1,535
SLK1-7-2	Laos	1984	Glutinous	3,740
KDML105	Thailand	1977	Nonglutinous	2,000
IR8	IRRI	1964	Nonglutinous	5,300
IR22	IRRI	1978	Nonglutinous	2,830
C4-63-1	Philippines	1964	Nonglutinous	44,080
IR36 and IR38	IRRI	1977	Nonglutinous	400,000
IR2823-103	IRRI	1964	Nonglutinous	12,080
B1014-bpN18-1-4	Indonesia	1981	Nonglutinous	7,840
NN75-1	Vietnam	1984	Nonglutinous	1,740
IR42	IRRI	1985	Nonglutinous	90,000
Total				995,340

Source: Hatsadong (1986).

Expansion of the seed multiplication and rice research network

In 1985, a new agricultural research center was established near the village of Naphok in Saythany District of Vientiane Municipality. This center was later (after 1990) to become the key center for the coordination of most research relating to the rice environments of Laos. Three other smaller stations were established with European Commission support through the Mekong Secretariat in the 1980s as rice seed multiplication and processing stations: Hat Dok Keo Station about 15 km south of the capital Vientiane, Thasano Station in Khanthabouly District of Savannakhet, and Phone Ngam Station in Pakse District of Champassak. Seed-processing facilities were established at all three stations. In the 1990s, the latter two stations also became important regional rice research centers while also continuing their rice seed multiplication roles, whereas the focus of activities of the Hat Dok Keo Station moved to horticultural research.

Table 4. Characteristics of varieties released by the Salakham Rice Research Station before 1986.

Variety designation	Endosperm type	Growth duration (d)	Yield (t ha^{-1})	Characteristics[a]
IR253-100	G	130–150	3–6	Sturdy culms, big grain, drought tolerance, wide adaptability, acceptable eating quality, low threshing ability Susceptible to bacterial leaf blight (BLB), narrow brown leafspot (NBLS), false smut, stem borer (STB), brown planthopper (BPH)
IR848-120	G	130–140	3–7	Sturdy culms, soft rice, wide adaptability, high threshing ability, low milling quality Susceptible to low temperature, BLB, NBLS, STB, BPH
IR789-98	G	130–140	3–6	Long grain and slender, good milling quality, narrow adaptability, delayed flowering Susceptible to NBLS, bakanae, and yellow-orange leaf diseases, BPH, and STB
IR848-44	G	130–140	3–5	Long grain and slender, intermediate response to fertilizer, wide adaptability, good eating quality Susceptible to NBLS and rice bug, susceptible to drought
RD6	G	22–25 October	3–4	Photoperiod sensitive, tall plant type, aromatic, good eating and milling qualities, moderate resistance to blast and brown leafspot, suitable for direct seeding, suited to middle terraces of central and southern agricultural regions Susceptible to BLB, BPH, GLH; tendency to lodge

Continued on next page

Table 4 continued.

Variety designation	Endosperm type	Growth duration (d)	Yield (t ha^{-1})	Characteristics[a]
RD8	G	24–26 October	3–4	Photoperiod sensitive, tall plant type, large seeded, good milling and eating qualities, moderate resistance to blast and brown leafspot, suited to middle terraces of central and southern agricultural regions, suitable for direct seeding Susceptible to BLB, BPH, GLH, GM; tendency to lodge
RD10 (RD16)	G	130–135	4–5	Relatively high yielding, long grain and slender grain, good milling and eating qualities, broad adaptability and can be grown in both wet and dry seasons, intermediate response to fertilizer, susceptible to flooding Susceptible to BLB, leaf blast, BPH, stem borer, and GM
KDML 105	NG	17–20 October	2–3	Photoperiod sensitive, tall plant type, aromatic, good eating and milling qualities, tolerant of saline and acid soils, resistant to root-knot nematode, suited to central and southern agricultural regions; suitable for direct seeding Susceptible to leaf blast, neck blast, BLB, orange leaf virus, grassy stunt virus, BPH, GLH, and stem borer
CR203	NG	125–130	4–6	Photoperiod nonsensitive and high yielding, suited to noodle and beer production, broad adaptability and can be grown in both wet season and dry season, suited to direct seeding, resistant to BPH, leaf blast, BLB Moderate milling and eating quality

Continued on next page

Table 4 continued.

Variety designation	Endosperm type	Growth duration (d)	Yield (t ha^{-1})	Characteristics[a]
SLK1-7-2	G	135–140	3–5	Good milling and eating quality, wide adaptability, resistance to BLB Susceptible to drought and BPH
IR8	NG	135–145	3–6	Wide adaptability, high response to fertilizer, poor eating quality Susceptible to BLB, BPH, and STB
IR22	NG	130–140	3–5	Uniform plant, good eating quality, wide adaptability Susceptible to brown leafspot, green leaf hopper, gall midge, and drought
IR24	NG	130–140	3–6	Sturdy culms, short growth maturity, good eating quality, tolerance of drought, wide adaptability, good performance under late transplanting Susceptible to yellow-orange leaf disease and stem borer
C4-63-1	NG	130–135	3–6	Intermediate plant type, good milling and eating quality, susceptible to low temperature, wide adaptability Susceptible to NBLS
IR2823-103	NG	125–130	3.5–7	Sturdy culms, erect leaves, short growth duration, wide adaptability, resistance to BPH Susceptible to adverse soil, susceptible to BLB and stem borer
IR36	NG	120–125	3–5	Wide adaptability, short growth duration, good milling quality, resistant to BPH Susceptible to drought
IR42	NG	135–145	3–5	Wide adaptability, resistance to major pests and diseases, high response to fertilizer Poor milling quality
B1014-bpN-18-1-4	NG	130–135	3–5	Wide adaptability, resistance to BPH and stem borer Poor milling quality

[a] G = glutinous, NG = nonglutinous, BPH = brown planthopper, STB = stem borer, NBLS = narrow brown leafspot, GLH = green leafhopper, GM = gall midge.

Source: Hatsadong (1986).

Table 5. Traditional varieties recommended for the wet-season lowland environment during the 1980s.

Region/province	Varieties recommended	Variety characteristics
Central region(Vientiane Municipality and Vientiane Province)	*Chao deng* (nonglutinous, red rice)	Nonglutinous, broad adaptability, and easy processing
	Chao louk pa (nonglutinous, fish fingerling rice)	Nonglutinous, suitable for swampy areas, good for noodle processing
	Khao dok mai (white flower)	Glutinous, slightly aromatic, good grain and eating quality
Southern region(Champassak Province)	*Ee khao ngan* (young lady, late-maturing rice)	Glutinous, sturdy culms
	Ee loup (young lady, drooping flag-leaf rice)	Glutinous, suited to middle and lower terraces, good grain and eating quality
	Mak phai khao (white sour berry rice)	Glutinous, suited to middle and lower terraces, submergence tolerant
	Chao lep nok (nonglutinous, bird claw rice)	Nonglutinous, adapted to acidic soils and drought-prone areas, good for noodle processing
Northern region(provinces of Luang Prabang and Sayabouly)	*Khao mae* to (mother of "To" rice)	Glutinous, gall midge resistant
	Khao Nang dom (Miss Dom rice)	Glutinous, good eating quality
		Glutinous, blast resistant, good eating quality
Northeastern region (provinces of Xieng Khouang and Houaphanh)	*Khao khai* (hairy rice)	Glutinous, aromatic
	Khao kai noi (small chicken rice)	

Adoption of improved rice varieties in lowland rice-growing areas in the late 1980s

Despite the work that had been done on variety improvement for the lowland environment from the mid-1960s through the 1980s, and the establishment of a rice seed multiplication program in the mid-1980s with EEC support, in 1990 the majority of the lowland rice-growing area of Laos was still being planted to traditional rice varieties. There were several reasons for this.

1. The lack of a developed extension service meant that seed of varieties identified as being suitable for the lowlands of Laos could not be obtained by the majority of Lao farmers. Farmers were more likely to change varieties based on farmer-to-farmer seed exchange. Hence, in areas of central and southern Laos, seed of the Thai varieties being used was often obtained by seed exchange across the Mekong River, rather than through the extension service. There was similar farmer-to-farmer seed exchange for lowland varieties involving China and Vietnam in the north of the country. The overall level of adoption of varieties introduced in this manner in the north of the country was generally much less than in the central and southern regions.

2. With glutinous rice being preferred for consumption by the majority of the Lao population, there was relatively little interest in the nonglutinous varieties that were introduced. An exception to this was the Vietnamese nonglutinous variety CR203, which, in addition to giving a high yield, was suited to noodle production, and it continued to be cultivated through the 1990s mainly for this use.
3. Rice production until the early 1990s continued to be based on a system of minimum inputs apart from family labor. In an environment where soil nutrient deficiencies were widespread and often acute (Schiller et al 1998, Linquist et al 1999) and where there was very little fertilizer use, the traditional varieties were often better adapted to Lao growing conditions.
4. Most of the improved varieties were recommended for lowland areas in the Mekong River Valley. Often, these varieties did not perform well when grown in more northern areas of the country, where lower temperatures generally prevail, particularly at the end of the wet season and during the dry season.

In the early 1990s, less than 10% of the main wet-season lowland rice-growing area in the Mekong River Valley was being planted to introduced or improved varieties. The main improved varieties being grown were RD6, RD10, and to a lesser extent RD6, all from Thailand (there were also small areas planted to improved glutinous varieties that had originated from IRRI but that were being grown under names that no longer reflected their source). The Vietnamese nonglutinous variety CR203 was still being grown on a limited scale for use in beer and noodle production. In the northern agricultural region, almost 100% of the wet-season lowland area was being planted to traditional varieties.

Recent developments in the lowland variety improvement program

1991-2004

In collaboration with IRRI, and with the support of funding provided by the government of Switzerland, in 1991 a program started to revitalize the rice research activities and capability of Laos. Coordination of the rice research program was moved from the Salakham Rice Research Station (which then served as a focus of extension-related activities) to the National Agricultural Research Center (NARC) in Saythany District of Vientiane Municipality. Infrastructure (laboratories and administrative facilities) at NARC was initially provided by FAO from 1979 to 1983. Additional training and administrative and research facilities were provided with Swiss support through the 1990s. Between 1992 and 1995, several other research stations were upgraded to become important regional research centers within a national rice research network. These key regional centers were Phone Ngam Station in Pakse District of Champassak, Thasano Station in Khanthabouly District of Savannakhet, 30 Ha Station in Phiang District of Sayabouly, Luang Namtha Research Station in Luang Namthat District of Luang Namtha, and Houay Khot Research Station in Xieng Nguen District of Luang Prabang. Smaller facilities were also established in several other provinces. All these regional centers, with the exception of the Houay Khot Station in Luang Prabang (where the research focus was mainly on the upland rice environment), played an important role in the national rice research program through the 1990s and early 2000s. Rice research also became a national priority in an effort to achieve rice self-sufficiency for the country (in 1990, the annual rice deficit was probably about 10% of the national requirement, although with significant regional differences in the level of the deficit). A major focus of the research initiatives at that time was the development of improved glutinous varieties for both the rainfed lowland and irrigated environments. However, the greatest emphasis and greatest impact have been in the rainfed lowland environment. Concurrent research programs also started on other aspects of production. The major components of the varietal improvement program that started in the early 1990s were the

- Selection and evaluation of lines based on crosses obtained from the IRRI, Thai-IRRI, and Thai breeding programs, and full participation in the IRRI shuttle breeding program.
- Introduction and evaluation of varieties and promising lines from other national rice research programs.
- Introduction and evaluation of INGER (International Network for Genetic Evaluation of Rice) material.
- Crossing of breeding lines within Laos, and selection of progeny for adaptation to Lao growing conditions.
- Evaluation and selection from among traditional varieties collected within Laos.

Apart from the broad breeding and variety improvement objectives of yield improvement and resistance to specific pests and diseases, other specific objectives within the variety improvement program have been the

- Identification of varieties suited to the drought-prone areas of central and southern Laos.
- Identification of varieties suitable for direct seeding in the rainfed lowland environment.
- Identification of varieties with low-temperature adaptation in the wet-season lowland and dry-season irrigated environments of northern Laos.
- Development of a database for the overall breeding program for Laos and the digitization of data for genetic analysis of breeding experiments.
- Introduction of multilocation trials for efficient selection of varieties with broad adaptability, as well as location-specific varieties.

These last five objectives have been given increased focus since 2000 in collaborative research programs supported by the Australian Center for International Agricultural Research (ACIAR) and The Rockefeller Foundation.

Lowland varieties released from 1990 to 2005

The variety improvement program of the early 1990s focused on the development of improved varieties for the main lowland rice-growing area in the Mekong River Valley. Further, the main initial interest was on the development of varieties for the wet-season rainfed lowland environment, rather than the dry-season irrigated environment. However, as the majority of the varieties released were photoperiod nonsensitive, many were also suited to cropping in the dry-season irrigated environment. In addition, as the primary objective of the early rice research program was the achievement of rice self-sufficiency for the country, and as the majority of the population preferred glutinous rice for consumption, the variety improvement program of the 1990s focused on developing improved glutinous varieties.

Naming of varieties

As with the naming of varieties used in the 1970s and 1980s, in which Salakham (SLK) was the prefix used to designate a new variety, the system of naming of varieties developed in the 1990s and later was one that reflected the name of the research station where the breeding lines were identified and developed. The names used were

Thadokkham (TDK)—the location of the main research center responsible for coordinating the activities of the national rice research program (Naphok Agricultural Research Center), in Thadokkham village in Saythany District of Vientiane Municipality.

Phone Ngam (PNG)—the name of the southernmost lowland rice research and seed multiplication center in Pakse District of Champassak.

Thasano (TSN)—the name of the lowland rice research and seed multiplication center in Khanthabouly District of Savannakhet in the lower central region of Laos.

Namthane (NTN)—the location of the 30-ha Rice Research and Seed Multiplication Center in Phiang District of Sayabouly in the lower northern region of Laos.

Varieties released

A total of 17 improved glutinous varieties were released in 1993 to 2005: 7 TDK varieties, 5 PNG varieties, 4 TSN varieties, and 1 NTN variety. Table 6 summarizes the distribution of the releases. The main characteristics of each of the varieties, together with the background of their parentage, are summarized in Table 7. All were glutinous varieties, and all but two (PNG2 and TDK4) are photoperiod nonsensitive, and hence potentially suitable for evaluation for the dry-season cropping regime as well as the wet season.

Some of these varieties released after 1993 are no longer being recommended. For example, following release, PNG2 was found to be susceptible to neck blast (and also leaf blast, brown planthopper, and green leafhopper) and is no longer being recommended or distributed to farmers. Variety TDK7, which was released in 2003, was also subsequently found to be very susceptible to neck blast and is also no longer being recommended to farmers. Another early release, variety PNG1, although also

Table 6. Release of new improved glutinous varieties from 1993 to 2005.

Year	Varieties released	Total released
1993	TDK1, TDK2, PNG1	3
1995	PNG2	1
1997	TDK3	1
1998	TDK4, TSN1, NTN1	3
2000	TDK5	1
2003	TDK6, TDK7	2
2004	TSN2, TSN3, TSN4	3
2005	PNG3, PNG5, PNG6	3
Total		17

susceptible to the same disease, is still widely accepted by farmers on account of its adaptability to poor soils and relatively short maturity.

Traditional varieties recommended during the 1990s and early 2000s

From 1970 to 1990, collecting missions supported by USAID, Russia, Japan, and other agencies collected more than 3,000 samples of cultivated traditional rice (Inthapanya et al 1995). Most of the samples in these collections were glutinous varieties. However, on account of a lack of appropriate storage facilities in the country, most of this germplasm collection was lost. From 1991 to 1994, a further 1,000 samples were collected, mainly from the northern provinces of the country, in a joint collecting program of IRRI and the Lao Ministry of Agriculture and Forestry (MAF). Unfortunately, the passport data for much of the collection were inadequate to allow the collection to be used. A much more comprehensive collection was made in 1995 to 2000. In a collaborative program between IRRI and MAF, supported by the Swiss government, 13,192 samples of cultivated rice and 237 samples of six wild rice species were collected. Much of the germplasm in this collection is unique to Laos and represents a range of diversity. Although these collections have undergone only preliminary evaluation, some varieties have already been identified as having unique genetic traits and are being recommended in some lowland areas (Table 8). Some are also starting to be used as parental material in the ongoing variety improvement program. The component of this collection that came from the upland environment (about 56%) is being evaluated to identify varieties with broad adaptability to that environment for wide distribution.

Future emphasis of the variety improvement program

By 2005, the variety improvement program had developed specific variety recommendations for the main lowland rice-growing areas (both rainfed and irrigated) of Laos, the Mekong River Valley. There had been a high level of farmer acceptance and adoption of the improved varieties developed and distributed during the 1990s,

Table 7. Improved rice varieties released between 1993 and 2005 for the lowland environment.

Year released	Variety name	Origin	Endosperm type	Growth duration (days)	Characteristics^a
1993	Thadokkham 1 (TDK1)	Thai-IRRI cross	G	135–140	High-yielding variety (HYV), photoperiod nonsensitive (PNS), can be grown in both wet and dry season, resistance to BPH, moderate resistance to Bl and BLB, high response to nitrogen, wide adaptability Susceptible to neck blast, bakanae disease, and GLH; poor milling quality in dry season
1993	Thadokkham 2 (TDK2)	Thai cross	G	135–140	HYV and PNS can be grown in both wet and dry season, good eating quality, moderate resistance to Bl and BLB Susceptible to BPH and GLH
1993	Phone Ngam 1 (PNG1)	Thai-IRRI cross	G	125–130	HYV and PNS, suitable to wet and dry season, good eating and milling quality; good adaptability to drought-prone areas of central Lao; resistance to GLH and Bl; moderate resistance to BLB Susceptible to neck blast and BPH
1995	Phone Ngam 2 (PNG2)	Thai-IRRI cross	G	Mid-October flowering	Photoperiod-sensitive variety, tall plant type, good milling and eating quality, good adaptability to drought-prone areas of central and southern regions Susceptible to neck blast, leaf blast, BPH, and GLH

Continued on next page

Table 7 continued.

Year released	Variety name	Origin	Endosperm type	Growth duration (days)	Characteristics[a]
1997	Thadokkham 3 (TDK3)	Vietnam	G	130–135	HYV and PNS can be grown in both wet and dry season, good eating quality, moderate resistance to Bl, good resistance to BLB, good milling quality in dry season Susceptible to BPH, gall midge, and bakanae disease
1998	Thadokkham 4 (TDK4)	Thai-IRRI cross	G	Mid-October flowering	Photoperiod-sensitive variety, intermediate plant type, good milling and eating quality, resistance to BL and BLB, moderate resistance to BPH, suitable for fertile soils Susceptible to acidic soils, GLH, and gall midge
1998	Thasano 1 (TSN1)	Thai-IRRI cross	G	140–145	HYV and PNS, suitable for wet season, good eating and quality milling quality, moderate resistance to Bl and BLB, tolerance of acidic soils Moderately susceptible to BPH, GLH, and GM; not suitable for dry season
1998	Namtane 1 (NTN1)	Thai-IRRI cross	G	130–135	HYV and PNS, can be grown in both wet and dry season, good eating quality, good milling quality in the dry season, moderate resistance to Bl, good adaptability in drought-prone areas of central and southern regions Moderately susceptible to BLB, BPH, and GLH

Continued on next page

Table 7 continued.

Year released	Variety name	Origin	Endosperm type	Growth duration (days)	Characteristics[a]
2000	Thadokkham 5 (TDK5)	Lao cross	G	125–130	HYV and PNS, short growth duration, can be grown in both wet and dry season, good eating quality, good milling quality in dry season, moderate resistance to Bl and BLB, good adaptability to high elevation in northern Laos Moderately susceptible to BPH and GLH, easy to shatter
2003	Thadokkham 6 (TDK6)	IRRI cross	G	135–140	HYV and PNS, suitable for wet and dry season, good eating quality, good milling quality in dry season, moderate resistance to Bl and BLB, good adaptability to high elevation in northern Laos Moderately susceptible to neck blast, BPH, GLH, and GM
2003	(Thadokkham 7 (TDK7)	IRRI cross	G	135–140	HYV and PNS, suitable for wet and dry season, good eating quality, good milling quality in dry season, moderate resistance to Bl and BLB, tolerance of acidic soils Very susceptible to neck blast, moderate susceptibility to BPH, GLH, and GM
2004	Thasano 2 (TSN2)	Lao cross	G	130–135	HYV and PNS, suitable for wet season, good eating and milling quality, moderate resistance to Bl and BLB, tolerance of drought Susceptible to BPH, GLH, and GM

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Table 7 continued.

Year released	Variety name	Origin	Endosperm type	Growth duration (days)	Characteristics[a]
2004	Thasano 3 (TSN3)	Lao cross	G	135–140	HYV and PNS, suitable for wet and dry season, good eating and milling quality, resistance to BLB Susceptible to Bl, BPH, GLH, and GM
2004	Thasano 4 (TSN4)	Lao cross	G	125–130	HYV and PNS, suitable for wet and dry season, good eating and milling quality, drought tolerance Susceptible to Bl, BLB, BPH, GLH, and GM
2005	Phone Ngam 3 (PNG3)	IRRI cross	G	130–135	HYV and PNS, suitable for wet season, good eating and milling quality, moderate resistance to Bl, tolerance of acidic soils, suitable for drought-prone areas of central and southern regions Susceptible to BLB, BPH, GLH, and GM; susceptible to low temperature; not suitable for dry season
2005	Phone Ngam 5 (PNG5)	IRRI cross	G	125–130	HYV and PNS, suitable for wet and dry seasons, good eating and milling quality, moderate resistance to BLB, tolerance of acidic soils, suitable for drought-prone areas of central and southern regions, suitable for direct seeding Susceptible to Bl, BPH, GLH, and GM
2005	Phone Ngam 6 (PNG6)	IRRI cross	G	130–135	HYV and PNS, suitable for wet season, good eating and milling quality, moderate resistance to BLB, suitable for drought-prone areas of central and southern regions Susceptible to Bl, BPH, GLH, and GM; susceptible to low temperature; not suitable for dry season

[a] BPH = brown planthopper, Bl = blast, BLB = bacterial leaf blight, GLH = green leafhopper, GM = gall midge.

Table 8. Characteristics of Lao traditional varieties recommended for the lowland environment in the early 2000s.

Variety name[a]	Origin	Endosperm type	Flowering date	Variety characteristics	Areas recommended
Nang nouane (soft lady)	Savannakhet	G	5-10 Oct	Large grains, good eating quality, and broad adaptability Susceptible to lodging, gall midge (GM), blast (Bl), bacterial leaf blight (BLB), brown planthopper (BPH), and green leafhopper (GLH)	Upper and middle terraces in provinces of central and southern regions; small plains in northern provinces of Sayabouly, Luang Namtha, Oudomxay, and Houaphanh
Hom nang nouane (fragrant soft lady)	Savannakhet	G	15-20 Oct	Big grain, aromatic with excellent eating quality, good vegetative vigor, and strong culms Susceptible to lodging under fertile conditions; susceptible to GM and BPH, moderate susceptibility to Bl and BLB	Main plains in central and southern regions
Meuang nga	Oudomxay	G	10-15 Oct	Good eating quality, resistance to Bl and GM, wide adaptability Susceptible to lodging, BPH, GLH, and BLB	Central and southern regions and lowland areas of northern provinces of Luang Namtha, Bokeo, Luang Prabang, and Sayabouly
Ta khiet (frog's eye)	Oudomxay	G	5-10 Oct	Big grain, good eating quality, resistance to Bl, suitable for rice-growing areas of some northern provinces—Oudomxay, Luang Namtha, Luang Prabang, Sayabouly, Xieng Khouang Susceptible to lodging, BPH, GLH, and BLB	Central and southern regions, and lowland areas of northern provinces of Luang Namtha, Oudomxay, Xieng Khouang, and Luang Prabang
Mark hing (hing fruit)	Champassack	G	10-15 Oct	Tolerance of late drought Susceptible to Bl, BLB, and GM	Drought-prone areas (late drought) in central and southern agricultural regions

Continued on next page

Table 8 continued.

Variety name[a]	Origin	Endosperm type	Flowering date	Variety characteristics	Areas recommended
Dok mai (flower)	Vientiane Municipality	G	10-15 Oct	Big grain, good eating quality, good adaptability to low soil fertility Susceptible to BLB, BPH, and GLH	Upper and middle terraces in central and southern regions
Lai keo (clear lined)	Luang Prabang	G	15-20 Oct	Good eating quality Susceptible to BPH, GLH, and BLB; only moderate susceptibility to gall midge	Central and southern regions, and northern provinces of Oudomxay, Luang Namtha, Bokeo, Luang Prabang, and Sayabouly
Dok tiou (tiou flower)	Vientiane	G	Late Sept-early Oct	Tolerance of late wet-season drought and poor soil fertility Susceptible to Bl, BLB, BPH, GLH, and GM	Drought-prone areas of central and southern regions
Kai noi (small chicken rice)	Houaphanh	G	Late Sept	Bold grain, good milling and eating quality, performs well in northern provinces and can grow in upper terraces of main plains of central and southern regions Weak stem, susceptible to BLB, BL, BPH, and GLH	Northern provinces, upper terraces of main plains in central and southern regions

[a] Most names are preceded by the prefix *Khao,* which means rice.

Table 9. Projections for population growth and rice consumption requirements.

Year	Population[a]	Milled rice consumption requirement (000 t)[b]	Total paddy production requirement (000 t)[c]
2000	5,100,000	918	1,866
2005	5,800,000	1,044	2,122
2010	6,400,000	1,152	2,341
2015	7,100,000	1,278	2,597
2020	7,700,000	1,386	2,817

[a]Source: National Statistical Center. [b]Based on a requirement of 180 kg milled rice/person/year (WFP/FAO). [c]Assumes seed, distilling use, and postharvest losses of 18% before milling, and a milling conversion of 60% of the remainder (MAF 2000).

with more than 70% of wet-season rice cultivation in the Mekong River Valley being based on improved varieties, and 100% of the dry-season irrigated environment. Between 1990 and 2000, official rice production statistics indicated an approximate 48% increase in rice production from about 1.5 million tons to 2.2 million tons. Most of this increased production came from cropping activities in the wet-season lowland environment. The country was also officially reported to have achieved rice self-sufficiency in 1999 (although it is acknowledged that significant areas were still suffering from significant chronic rice deficits, particularly those still largely dependent on upland rainfed crop production, and the yields being reported are also regarded as inflated and actual rice production is probably below that reported).

Population growth projections for Laos predict a population of about 7.7 million by 2020; this represents an approximate 33% increase in the population from 2005 (Table 9). The projected paddy rice requirement to meet the rice consumption needs of the 2020 population is about 2.8 million tons. This compares with about 2.5 million tons officially reported as being produced in 2004. With official government policy for the upland environment focusing on a move from the growing of annual crops to more sustainable forms of agriculture in that environment, combined with a greater use of the dry-season irrigation potential for nonrice crops, the wet-season lowland environment (both rainfed and irrigated) will become increasingly important in meeting national rice production needs (in 2004, official statistics indicated that the upland environment accounted for about 200,000 t of rice, while the dry-season irrigated environment accounted for about 340,000 t). Rice research relating to the wet-season lowland environment will need to focus on a combination of reducing year-to-year production variability in this environment and raising the yield potential. In terms of the impact this is likely to have on the future variety improvement program, the following areas of focus are likely:

- Improved drought tolerance of varieties grown under rainfed conditions in the Mekong River Valley.
- Development of varieties well suited to direct seeding rather than transplanting.

- Development of varieties better adapted to the specific growing environment of the montane lowlands (lowland areas at higher altitudes).
- Incorporation of improved resistance to gall midge for varieties in areas prone to gall midge infestation.
- Incorporation of improved disease resistance into varieties, particularly for leaf and neck blast, whose problems appear to have been increasing in recent years.
- Development of improved nonglutinous varieties to meet an expected increase in consumption of nonglutinous rice in the main population centers.
- Development of specialty or "boutique" rice for a limited export market.

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Notes

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CHAPTER 22

Advances in agronomic research in the lowland rice environments of Laos

J. Basnayake, S. Fukai, Sipaseuth, J.M. Schiller, and C. Monthathip

Rice cultivation accounts for more than 80% of the land in agricultural production in Laos. The most important rice production system is the wet-season lowland, which in 2004 accounted for about 75% (575,500 ha) of the total rice area and 78% (1,970,000 tons) of total production. Although during the 1990s there was a significant expansion in the area being serviced by irrigation (mainly to allow second cropping in the dry season—78,000 ha were cropped in the 2003-04 dry season—but also to provide an expansion of the wet-season irrigated area), the majority of the production from the wet-season lowland environment remains rainfed-based. In both the medium and longer term, it can be expected that the wet-season lowland environment will remain the most important rice-producing environment within Laos, with the majority of production continuing to come from rainfed-based cropping, subject to weather vagaries. The significance of the potential effects of weather on production is reflected in the fact that, in the 37-year period from 1966 to 2002, in almost every year, at least part of the country was affected by either drought or floods, or a combination of both (Schiller et al 2001). The drought problem in the main wet-season lowland rice-growing area, the Mekong River Valley, is aggravated by the permeable nature of the sandy soils that prevail in much of the area. Farmers throughout the central and southern regions rank drought as one of their most serious production constraints (Schiller et al 2001).

Systematic agronomic research targeting improved productivity in the different rice production systems of Laos began in 1990. The impact of the research output has been significant, particularly through the development and adoption of improved varieties in the wet-season lowland and dry-season irrigated production systems. Since 1990, the adoption of improved varieties in the wet-season lowlands of the main lowland rice-producing area in the Mekong River Valley has resulted in their replacement of traditional varieties in most of the cropping area (Schiller et al 2000, and Chapter 21, this volume). Most of these new varieties have been Lao improved glutinous varieties. The ongoing agronomic research program has tackled a range of other production constraints in each of the lowland rice-producing environments, both the wet-season rainfed lowland environment and the dry-season irrigated environment, resulting in the formulation of a range of technical recommendations capable of reducing the impact of the periodic wet-season droughts, as well as helping raise the yield potential of crops grown in these environments. This chapter summarizes the contribution of the agronomic research to yield improvement in the lowland environment since the early 1990s.

Agronomic practices in the wet-season rainfed lowland environment

The rainfall pattern throughout most of Laos is weakly bimodal, with a minor peak in May and early June, and a major peak in August and September. About 75% of the annual rainfall is received between May and October. In most provinces of the Mekong River Valley, total annual rainfall ranges from 1,500 to 2,200 mm. In some of the more northern provinces (Sayabouly and Luang Prabang), the total drops to 1,200 to 1,300 mm. The pattern of distribution can vary from year to year, causing large fluctuations in rice production. Early wet-season drought is a common occurrence from mid-June to mid-July, corresponding to the period when the monsoons change from southeast to southwest. The effects of this drought can be reduced by appropriate cropping practices, including matching crop phenology with water availability (Fukai 1999, Fukai et al 1999). Late wet-season drought occurs if the regular monsoon rains end early (in most areas, some rain continues to be received until early to mid-October). Fukai and Cooper (1995) have demonstrated that late-season drought alone can reduce grain yields by an average of 30%. The potential impact of different management practices on minimizing the impact of both early and late wet-season drought in the rainfed lowland environment is outlined in the following sections.

Effects of sowing dates on the performance of local and improved cultivars

At the beginning of the wet season, seedbed sowing usually takes place in early May to early June, depending on the timing of the onset of the early wet-season rains. Delaying sowing beyond this period increases the risk of exposing the crop to late wet-season drought, particularly when photoperiod-insensitive and mildly sensitive varieties are grown. When strongly photoperiod-sensitive varieties are sown late in July and August, the crop often flowers when the plants are still small, with a resulting significant decline in yield. This is the case whether the crop is direct-seeded or transplanted (Figs. 1A and 1B). Under normal conditions, a yield decline of 40% to 50% can result when seedbed sowing is delayed until late July. Early sowing (early June) is not appropriate for all situations, however, with notable exceptions being (1) under conditions of high soil fertility, when excessive growth during a long vegetative phase may lead to lodging, particularly for photoperiod-sensitive varieties; (2) under weedy conditions when an extended period of land preparation is required to provide good weed control before transplanting; (3) when short-maturity varieties are being grown, early sowing can mean that flowering of such varieties takes place during the period of peak rainfall (in August and September), resulting in poor fertilization and low grain yield (variety SK12 in Fig. 1C) (Sipaseuth et al 2001a,b).

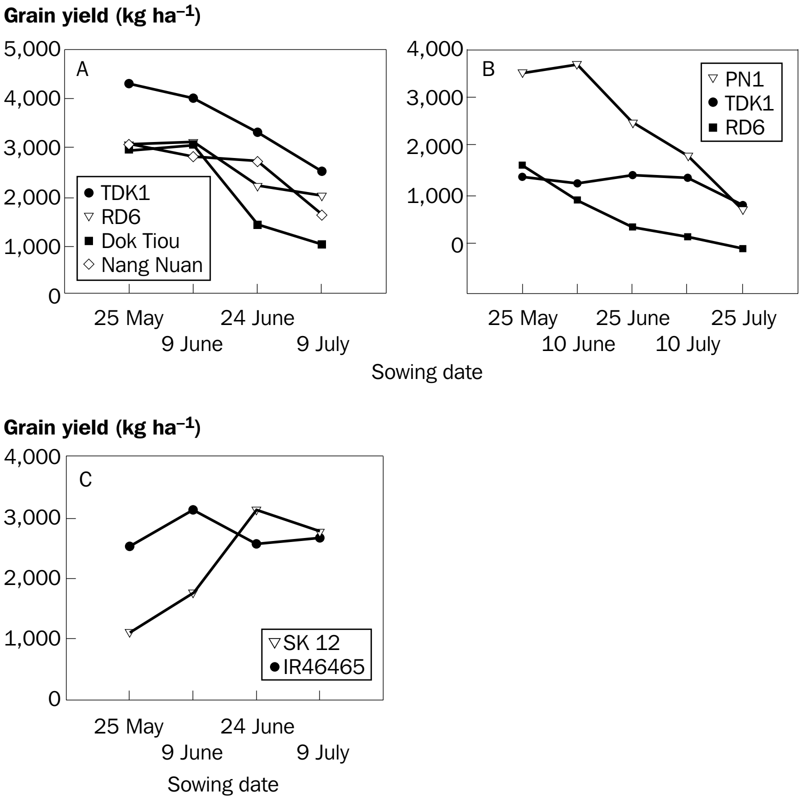

Fig. 1. Effect of sowing date on grain yield of popular cultivars grown in (A) Vientiane Municipality (transplanted in 1994), (B) Savannakhet Province (direct seeded in 1996), and (c) Champassak Province (transplanted in 1994).

Effects of seedling age at transplanting on crop grain yield

In addition to the importance of sowing date for maximizing wet-season grain yield, with the period late May to mid-June being the optimum period for transplanting, seedling age at transplanting can also be an important yield determinant (Fig. 2). In 1997 and 1998, studies were undertaken in Vientiane Municipality and Savannakhet Province on the relative impact on grain yield of the use of 25- and 45-day-old seedlings for several of the more popular improved Lao varieties. In addition to the studies further confirming the importance of early sowing and transplanting, the yield from the use of 25-day-old seedlings was, on average, 22% higher than that of 45-day-old seedlings, with the yield advantage of the younger seedlings being consistent across all sowing dates studied, from 25 May until 25 July (Sipaseuth et al 2001a,b). There are several agronomic advantages from the use of young seedlings for transplanting: the root system in young seedlings can recover qickly after pulling from the seedbed and subsequent transplanting, less damage occurs to the developing buds of secondary

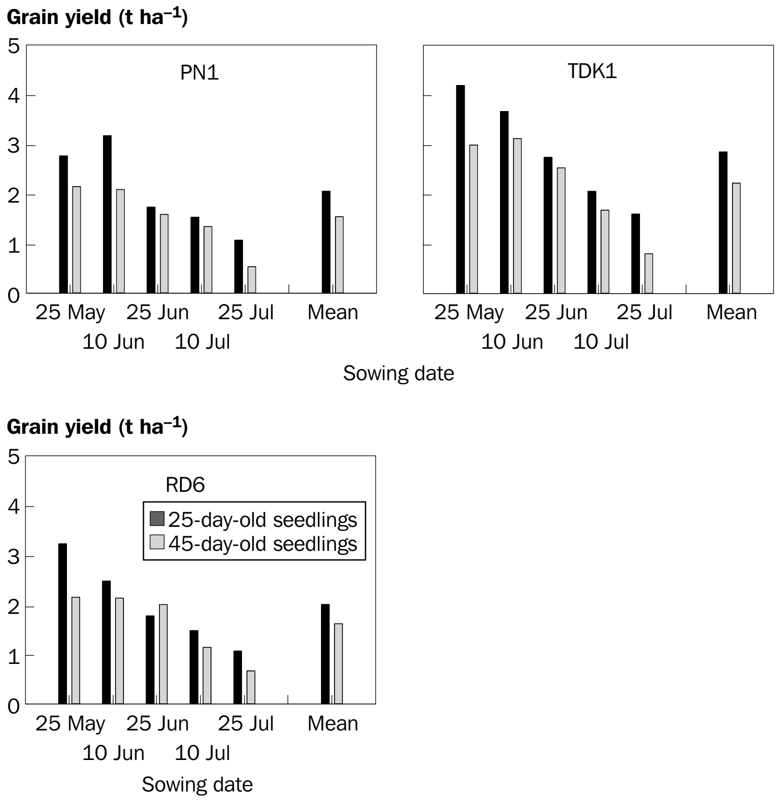

Fig. 2. Effects of time of sowing and seedling age at transplanting on wet-season grain yield in three popular Lao cultivars, PN1, TDK1, and RD6, in Vientiane Municipality.

tillers during transplanting of young seedlings, and younger seedlings are less exposed to leaf desiccation after transplanting than are older seedlings.

Effect of hill spacing and nitrogen application regime on grain yield

In some conditions, high plant densities increase grain yield independent of the need for increased fertilizer application. Under farming conditions in Vientiane Municipality, in the absence of fertilizer N, increasing the planting density from 16 to 44 hills m^{-2} was found to increase grain yield by an average of 63% for some of the popular improved Lao varieties (Fig. 3). When fertilizer N was applied, often the level of yield response was found to increase with increased planting density. For variety Namtane-1 (NTN1), at a planting density of 44 hills m^{-2}, the yield response to the application of 90 kg N ha^{-1} was as much as 75% (relative to zero), while at a planting density of 16 hills m^{-2} the response to the same level of N was less than 10%. High planting densities can also suppress early weed growth as well as reduce later weed competi-

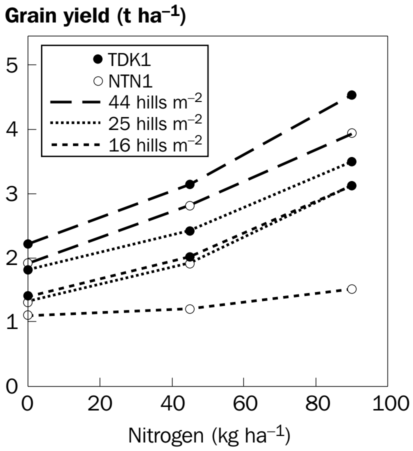

Fig. 3. Effects of hill spacing and nitrogen fertilizer application on grain yield of two popular rice varieties, TDK1 and NTN1, in Vientiane Municipality.

tion. Reduced tillering under high planting densities and low fertilizer inputs tends to reduce the proportion of unproductive tillers, resulting in a higher harvest index. This suggests that, at higher planting densities, the crop can better exploit nonfertilizer soil nutrients, including N. Further, any fertilizer N applied at higher planting densities is used more efficiently than at lower densities. When higher plant populations are achieved by increasing plant number per hill, from 3 to 6 (as distinct from an increase in the density of hill plantings), tillering decreased and the panicle/tiller ratio increased by an average of 8% (data not shown).

Establishment method for direct seeding

Direct seeding is becoming an increasingly popular establishment method in the rainfed lowland environment of Laos, particularly in areas where labor is becoming less available and/or labor costs are increasing. It can be expected that direct seeding in areas of the Mekong River Valley will become increasingly popular near the larger provincial towns, where alternative off-farm employment opportunities are becoming increasingly available. Direct seeding can be done either by broadcast wet seeding or row seeding using mechanical row-seeders (Fig. 4).

Comparative studies of broadcasting and row seeding in Vientiane Municipality and Savannakhet have demonstrated similar yields within a season (Fig. 5) (Sipaseuth et al 2000). Although there might be no yield difference between row seeding and broadcasting, the relatively recent availability of low-cost row-seeders is making their use an attractive option. Direct seeding of wet-season lowland crops is increasing in popularity in Savanakhet, which has the largest area of wet-season lowland rice of any single province in Laos (134,740 ha in 2004).

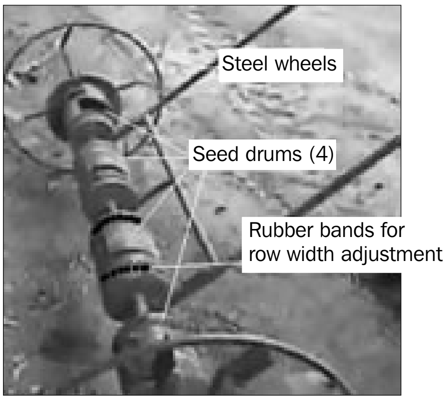

Fig. 4. Row-seeder (drum) for direct seeding (modified to allow adjustments in row spacing for different conditions).

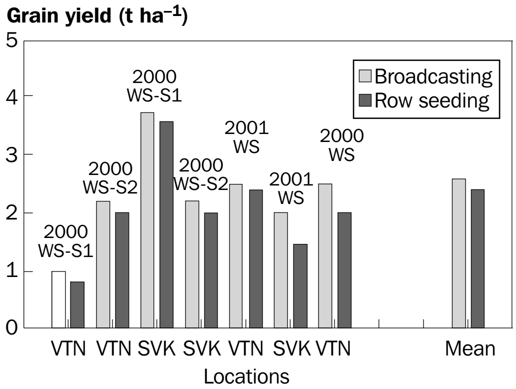

Fig. 5. Comparative yields between broadcast and row-seeded plots in wet-season (WS) rainfed lowland rice crops in Vientiane Municipality (VTN) and Savannakhet Province (SVK) in 2000-02 (S1 and S2 indicate two different sowing times).

Variety differences for weed competition in wet-season direct-seeded rice

The potential effects of weed competition on grain yield depend on weed density and on the ability of different rice varieties to tiller and effectively compete with weeds for available nutrients and water (Fukai 2002, Sipaseuth et al 2002). Cultivar differences for grain yield variation under different weed conditions are evident in the information summarized in Table 1. Weeding before tillering has been found to increase grain yield by about 37% in experiments conducted in Vientiane Municipaity and by as much as 45% in Champassak Province. Those genotypes that have the highest yield potential

Table 1. Yields (kg ha^{-1}) of 12 rice genotypes established under direct seeding and grown under weeded and unweeded conditions, 1998 wet season, Vientiane Municipality and Champassak Province.

Genotype	Vientiane		Champassak[a]	
	Weeded	Not weeded	Weeded	Not weeded
IR68102-TDK-B-B-33-1	2,470 a	1,821 a	1,456 de	1,019 bcd
IRUBN4-TDK-1-2-1	2,246 a	1,184 abc	1,973 a	899 bcd
TDK1	2,660 a	1,683 abc	1,959 a	809 d
IR57514-PMI-5-B-2-1	2,514 a	1,642 ab	1,914 ab	940 bcd
IRUBN8-TDK-1-1	2,217 a	978 bc	1,707 bc	917 bcd
Dokmay	2,621 a	1,200 abc	1,924 ab	1,082 b
RD6	2,227 a	1,198 abc	2,123 a	1,299 a
NSG 19	2,014 ab	975 bc	1,318 e	1,008 bcd
IR58821/IR58821/CA-7	1,313 b	639 c	1,629 cd	814 cd
Mahsuri	2,129 a	1,423 abc	2,007 a	1,062 b
IR49766-KKN-52-B-23	1,851 ab	1,060 abc	1,971 a	1,028 bcd
Hom Nang Nuan	1,858 ab	1,230 abc	1,478 de	1,054 bc

[a] In the Champassak study, yields in both weeded and nonweeded experiments were low on account of bird damage at maturity. Means with the same letters are not significantly different at the 5% significance level.

were also found to give the highest grain yield under unweeded conditions. Cultivars with good early establishment, medium plant height, good lodging resistance, and good root systems generally perform well when direct-seeded (e.g., varieties PNG5 and IR68102-TDK-B-B-33-1, which were released in 2005) (Fukai 2002).

Effect of seeding rate on yield of direct-seeded rice

Studies in two wet seasons (2001 and 2002) in Vientiane Municipality of the effects of increasing seeding rate on grain yield for direct-seeded rice revealed that there was no increase in yield for either broadcast or row-seeded crops when the seeding rate was increased above 75 kg ha^{-1} (as high as 200 kg ha^{-1}). This result is in contrast to the effects of increasing plant density in transplanted rice. However, in Savannakhet Province, in a 2001 wet-season study where the crop was affected by weed competition and yields were comparatively low relative to the Vientiane study, there was a positive response to the increased seeding rates. Grain yield increased by 26% and 29% in broadcast and row-seeded crops, respectively, when the seeding rate was increased from 50 to 200 kg ha^{-1} (Fig. 6A). The high seeding rates resulted in increased plant density in both the broadcast and row-seeded establishment methods (Fig. 6B). There was a significant increase in 1,000-grain weight as seeding rate decreased to 50 kg ha^{-1} when seed was broadcast (Fig. 6C). Increased seeding rates resulted in reduced weed weight at 30 DAS in both broadcast and row-seeded establishment methods (Fig. 6D). Overall, the higher seed rates and high rice plant densities resulted in a decline in weed competition, thereby contributing to higher grain yields (Fig. 7).

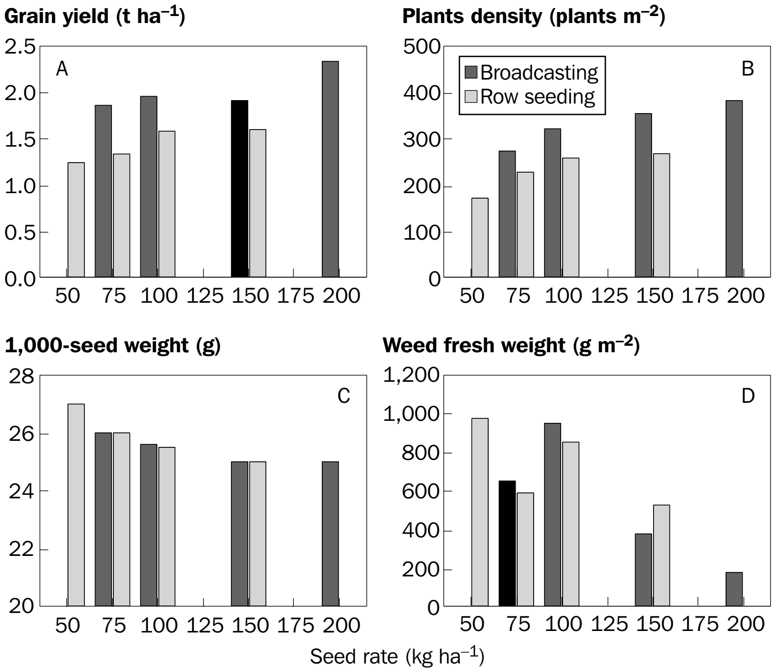

Fig. 6. Effect of seeding rates on (A) grain yield, (B) plant density, (C) 1,000-seed weight, and (D) weed weight at maturity for crops established using broadcasting and row seeding in Savannakhet Province in the 2001 wet season.

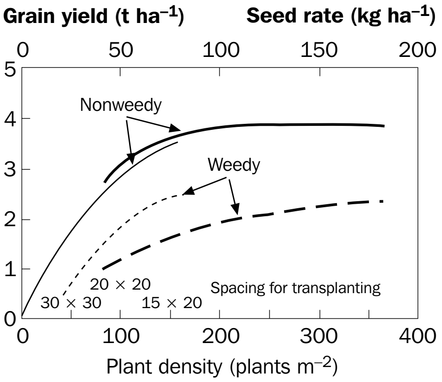

Fig. 7. Schematic diagram showing the relationship of yield variation in response to different population densities, for direct-seeded and transplanted rice crops, in the presence and absence of weeds (the thin lines represent transplanted crops and thick lines direct-seeded crops).

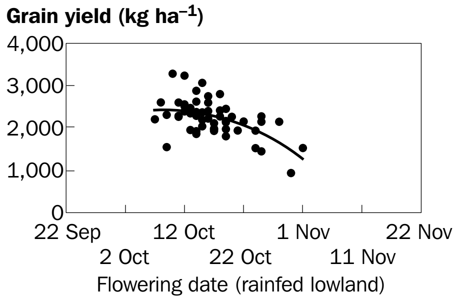

Fig. 8. Grain yield variation of cultivars of different maturity times when sown in mid-July 2001 under rainfed lowland conditions in Vientiane Municipality.

Maturity time of varieties appropriate for the rainfed lowlands

The maturity time requirement of photoperiod-insensitive cultivars for the wet-season plantings is determined by the time of sowing. Almost all Lao traditional cultivars are photoperiod-sensitive, while almost all the improved varieties released since 1993 are photoperiod-insensitive. The maturity time requirement of photoperiod-insensitive cultivars for the wet-season plantings is determined by the time of sowing. For normal rainfed lowland wet-season crops for which seedbed sowing is recommended to take place in early June, followed by transplanting in early to mid-July, most photoperiod-insensitive and -sensitive cultivars flower in late-September to early October. Apart from the risks associated with early sowing of there being a lack of standing water in the paddies at the time of transplanting, the other important yield determinant is water availability at the time of flowering (Inthapanya et al 2004). The potential effect of flowering dates on grain yield of varieties of differing maturity time is illustrated in Figure 8. The planting of photoperiod-sensitive varieties that flower as late as mid-October should be avoided in all areas where sandy soils with poor water-holding capacity can result in the absence of any standing water in the paddies at the time of flowering. This situation applies to most areas of lowland rice cultivation in the Mekong River Valley. Under such conditions, only varieties that flower in late September and very early October should be grown. For photoperiod-insensitive varieties for which flowering and maturity time are largely determined by time of sowing, the longer the maturity time of the variety, the earlier sowing needs to take place. However, in the absence of supplementary irrigation for seedbed sowing, flexibility in setting the sowing date outside the range determined by the onset of the wet-season rains is not always an option, and a delay in sowing due to the late onset of rains can result in greater potential exposure to late wet-season drought at flowering.

Drought and toposequence position

The rainfed lowland rice ecosystem is diverse and, in most areas of Laos (but particularly in rainfed lowland areas of the Mekong River Valley), three subecosystems

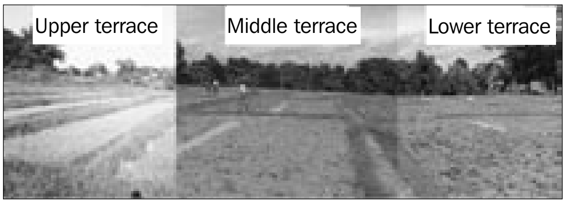

Fig. 9. The three subecosystems—upper, middle, and lower terraces—that are found in much of the rainfed lowland rice environment in Laos.

are usually distinguished in the toposequence—the upper terrace, the middle terrace, and the lower terrace (Fig. 9). Differences are large in rainwater availability at difference positions in the toposequence. Water availability at positions higher in the toposequence is not as great as in positions lower in the toposequence because of the downward movement of water through the soil profile, and also the lateral movement of water from high to low positions (Tsubo et al 2005).

It is also generally recognized that soils in the lower terraces have a higher clay content and become saturated earlier in the wet season, making them suitable for land preparation and planting earlier than in the upper and middle terrace areas. Further, at the end of the wet season, water remains available longer in the lower terraces than in the upper parts of the toposequence. The soils in the upper terraces, on account of their often higher sand content, are more drought prone as well as generally less fertile than the soils in the lower terraces. At the end of the wet season, they dry out more rapidly than the soils in the lower terraces. As water disappears, drought conditions can develop much earlier in the upper terraces, causing yield variation among cultivars within different maturity groups. Cultivar requirements for different parts of the toposequence can therefore be quite different (Basnayake et al 2004). This is clearly demonstrated in the results of a comparative evaluation of nine genotypes evaluated in Phonethong District of Champassak Province in the 2000-02 cropping seasons (Table 2). Genotypes best suited to planting in the upper terraces are those with a high yield ratio when planted in this environment. The planting of early-maturing cultivars in the upper terraces can reduce the potential effects on yield of drought because of the early end of the wet-season rains. This result also highlights the importance of careful selection of the terrace environment in which genotypes are evaluated for potential release as improved varieties, as well as the need for specific recommendations as to the most appropriate growing environment for individual varieties, after release.

Potential yield and farm income responses to technology adoption in the rainfed lowland environment

Between 1994 and 1998, studies were undertaken in villages in the rainfed lowland environment of Laos, one in the southern province of Champassak and the other in the central province of Vientiane, of the potential impact on rice production and related

Table 2. Grain yield at top and low positions and yield ratio of 9 high-yielding genotypes in Champassak Province.

Genotype	Yield (kg ha^{-1}) in upper terrace	Yield (kg ha^{-1}) in lower terrace	Yield ratio (upper/lower)
TDK94018-6-1-3	2,755	3,175	0.86
IR70825-47-12-5-TDK-2-3-B	2,742	2,479	1.10
IR70183-74-1-1-1	2,664	3,327	0.80
PNG1	2,558	2,654	0.96
IR70824-TDK-5-B-1	2,356	2,970	0.79
ILOUP	2,330	3,204	0.72
RD6	2,233	3,638	0.61
LR2427	2,245	3,416	0.65
IR70824-TDK-44-2-B-1-2	2,230	2,866	0.77

farm household welfare from the adoption of improved rice production technologies (Schiller et al 2000). Part of the technology packages related to improvements in agronomic practices, the main change being to get farmers to adopt higher plant populations through closer hill spacing (a reduction from 30 × 30 cm often used to a spacing of 20 × 20 cm) and an increased number of plants per hill (an increase from 2–3 to 4–5 seedlings). The technology package also included the adoption of the first of the improved glutinous varieties developed by the Lao national rice research program, Thadokkham-1 (TDK1) and Phonengam-1 (PNG1). In both villages, the equivalent of an application of 60-30-0 kg ha^{-1} of NPK fertilizer was also recommended in the form of the compound fertilizer 16-20-0 and urea (46-0-0). The compound fertilizer containing P was applied immediately before transplanting, in the last phase of land preparation (the soils in much of the Mekong River Valley of Laos are highly P deficient, Linquist and Sengxua 2001). Application of N was divided equally between transplanting and 35 and 55 DAT for the two medium-maturity varieties. The adoption and impact of the recommendations were monitored and measured over five wet seasons, 1994 to 1998. Farmers who adopted the combination of technical recommendations more than doubled their yields and net returns in both provinces, with average yields of 3.2 to 3.7 t ha^{-1} being readily achieved when all recommendations were adopted; these yields were also about 1.4 t ha^{-1} higher than when farmers adopted just improved varieties (Fig. 10). An economic analysis of the impact of the adoption of the technology packages showed that net returns closely reflected the changes in grain yield. Greater detail of the impact of the technology adoption can be found in Schiller et al (2000). The results of the study clearly indicated that to achieve the maximum potential benefits from improved technology adoption in the rainfed lowland environment, full technology packages should be recommended and they need to be adopted by farmers.

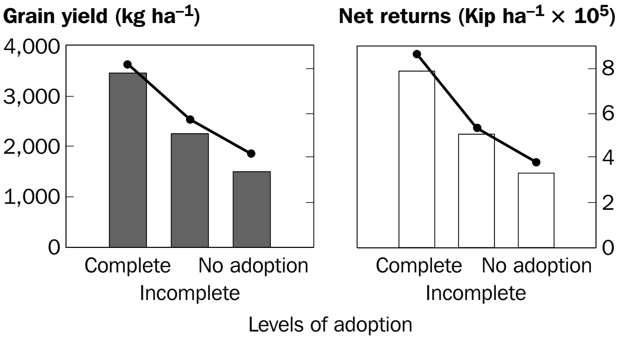

Fig. 10. Impact (grain yield and net returns) of technology adoption at the village level in Champassak and Vientiane provinces for improved lowland rice production (Schiller et al 2000). Bars indicate grain yield and the line shows the net income; complete = all recommendations adopted, incomplete = mainly the adoption of improved varieties.

Agronomic practices in dry-season irrigated lowland rice cultivation

From 1990 to 2001, dry-season irrigated rice area increased by 750% (from 12,000 ha in 1990 to 102,000 ha in 2001). Grain production from this environment also increased more than tenfold, from 41,000 t to 436,000 t. Most (95.5%) of this expansion has taken place in the central and southern agricultural regions. In 2001, there was still only about 6,500 ha developed for irrigation in the northern agricultural region. However, by 2004, not all the potential dry-season irrigable area was being used because of a combination of high pumping costs, poor water reticulation (and resulting poor water-use efficiency) in some irrigation scheme areas, and relatively low grain prices.

The normal cropping cycle for dry-season cropping in the main irrigation scheme areas in the Mekong River Valley involves seedbed sowing about mid-November and harvesting in March and April (two of the hottest months). Average rainfall in most areas during this period is less than 15% of the total, and any form of cropping is reliant on irrigation. The main production constraints faced in most dry-season rice cropping areas are the potential effects of low temperatures near the period of seedbed sowing and early seedling growth and the potential effects of high temperatures in some areas during March and April, about the time of flowering. The mean minimum temperature during the sowing period varies from 5 to 15 °C in the north and from 12 to 18 °C in provinces of the Mekong River Valley (Sihathep et al 2001). Maximum daytime temperatures in March and April in the Mekong River Valley can reach 36 °C, and can reach 35 °C in the north of the country.

Agronomic research relating to dry-season irrigation cropping has focused on nursery management, time of sowing and transplanting, seedling age at transplanting, and plant density. Studies have also been conducted on plant density effects on direct-seeded crops.

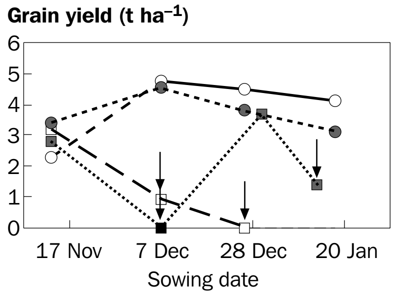

Fig. 11. Grain yield for dry-season irrigated rice at different sowing dates at four sites: Vientiane Municipality (●) and Champassak (○) (central and southern Laos, respectively) and Luang Namtha (□) and Xieng Khouang (□) (northern and northeastern Laos); (arrows indicate the severe effects of low temperature on the grain yield of varieties TDK1 and RD10).

Effects of sowing date on the performance of local and improved cultivars

Seed germination is poor and sometimes fails when the average minimum temperature at sowing falls below 12 °C. As noted, the mean minimum temperature during the sowing period (mid-November to early January) in the northern region varies from 5 to 15 °C (Fukai et al 2003). The potential effect of these temperatures on grain yield has been clearly demonstrated in studies undertaken in 2000 to 2002, in an examination of crop performance in the two northern provinces of Luang Namtha and Xieng Khouang relative to Vientiane Muncipality and Champassak in the central and southern regions, respectively (Basnayake et al 2003). The results (Fig. 11) clearly show the potential effect of low temperature when sowings take place in the northern region in the coldest months of December and January. In contrast, there was much less impact of sowing date on yield in Vientiane Municipality and Champassak Province, where mean temperatures were about 10 degrees higher than for the northern provinces, as well as being above the critical 12 °C required for seed germination (Sihathep et al 2001).

Seedbed management to reduce low-temperature impact in the northern region

In areas of northern Laos where average temperatures during December and January can fall below 12 °C, the level critical for germination and early seedling, two management options have been developed to raise the temperature in the seedbed (Fukai et al 2003). The first option is the use of plastic sheeting to cover the seedbed immediately after sowing, with the plastic being removed when the seedlings are about 5 cm tall. The second option is to cover the seedbed with a plastic dome until

Fig. 12. Farmers in Xieng Khouang Province pulling seedlings from a nursery protected by a plastic dome during the dry season (December).

Table 3. Mean grain yield (t ha^{-1}) when plastic covers and plastic domes were used during nursery establishment at different locations at higher elevations in northern Laos in the 2002-03 and 2003-04 dry seasons.

Province	Cropping season	Control (unprotected)	Plastic cover	Plastic dome	LSD ($P<0.05$)
Luang Prabang	2002-03	4.03	4.29	3.84	ns[a]
Sayabouly	2002-03	3.22	4.21	3.69	0.56
Xieng Khouang	2002-03	4.04	4.21	4.24	0.17
Luang Namtha	2002-03	3.48	3.62	3.56	ns
Xieng Khouang	2003-04	2.18	2.58	2.32	0.12
Luang Namtha	2003-04	3.60	3.72	3.68	ns

[a] ns = nonsignificant at the 5% level.

the seedlings are tall enough for transplanting (Fig. 12). Nighttime temperatures inside the plastic dome when such measures have been implemented have been found to be about 4 °C higher than the external ambient temperature, resulting in improved germination and seedling growth. The use of such domes or plastic covers in areas where low temperatures affect seedbed rice has been shown to increase yields by an average of over 0.5 t ha^{-1} (Table 3). An additional benefit of the use of the plastic covering that has been reported by farmers is that it helps protect the seedlings in the nursery from rodent damage.

Effects of seedling age at transplanting in the dry season

Although seedling age at transplanting can be an important determinant of yield for wet-season lowland rice crops, it is less important in dry-season irrigated crops in

Table 4. Grain yield (t ha^{-1}) of variety TDK5 from dry-season irrigated crops using transplanted 25-, 35-, and 45-day-old seedlings grown at four locations in northern Laos.

Province	Yield (t ha^{-1}) in relation to seedling age at transplanting (days)		
	25	35	45
Luang Namtha	3.62	3.60	3.44
Luang Prabang	4.03	3.60	4.14
Xieng Khouang	3.88	4.00	3.90
Sayabouly	3.67	3.68	3.63
Mean (nonsignificant)	3.80	3.72	3.78

areas affected by low temperatures, particularly in the north of the country (Table 4). The reason for the lack of a relationship between seedling age and final yield for dry-season crops in northern areas is that, under low-temperature conditions, plants require a longer vegetative period to achieve physiological maturity (often from 30 to 45 days longer than in the area of the Mekong River Valley). For most cultivars grown at low temperatures in the northern region, the growth duration for flowering is much longer than in the wet season. However, in the main dry-season rice-growing areas of the Mekong River Valley (MRV), the effect of seedling age on grain yield in the dry season is similar to that of wet-season cropping. The use of young seedlings (less than 30 days old) for transplanting in the dry season is important in the MRV, as the temperature is favorable most of the time for rapid vegetative growth.

Seedling number per hill and population effects on grain yield in dry-season irrigated rice

Studies were undertaken in 1995 and 1996 in Vientiane Municipality of planting density for transplanted dry-season irrigated rice, using the two popular varieties TDK1 and RD10. In both years, yield improved when planting density was increased from 16 to 44 hills m^{-2} (Fig. 13). In the 1995 study, average yield increased by about 16%, while in 1996 the improvement was about 54%. Variety RD10 also had yield improvement from increasing the number of seedlings per hill from 3 to 6, with average yield increasing by 9%, but TDK1 did not show the same yield response. The lack of a yield response for TDK1 to the higher seedling number per hill was probably because this variety has a high tillering capacity (with an average of about 10 tillers per plant) and there is less advantage from increasing seedling number per hill above three. The yield advantage from increased plant populations, whether through reduced hill spacing (i.e., increased density of hills) or increased plant number per hill, is likely to be manifest mainly with varieties with a low tillering capacity.

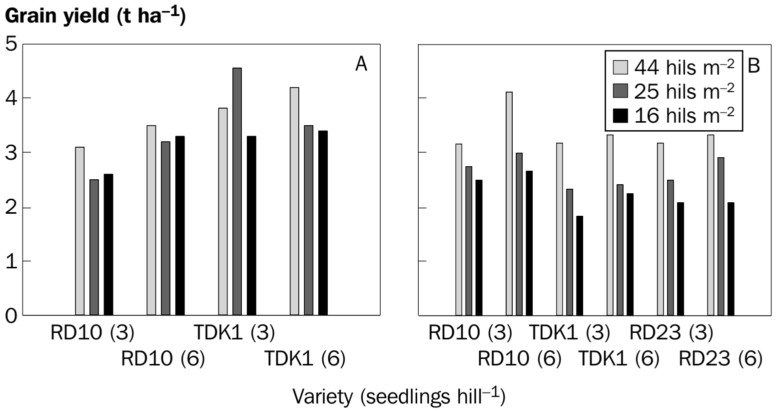

Fig. 13. Effects of hill spacing and number of seedlings transplanted per hill on grain yield of (A) two popular varieties in 1995 and (B) three varieties in 1996, in Vientiane Municipality (the number in parentheses next to the variety name is the number of seedlings per hill).

Population effects on the yield of direct-seeded dry-season rice

In studies undertaken in Vientiane Municipality in the 2001-02 and 2002-03 dry seasons, it was apparent that seeding rates higher than 75 kg ha^{-1} did not result in higher grain yields (Table 5). The yield advantage associated with high seeding rates with wet-season cropping (see Fig. 6) was largely associated with the effect of reducing weed competition. In the dry-season environment with direct seeding, better water management in the establishment phase of the crop generally allows better weed control, and so this potential advantage of high seeding rates is lost.

Double rice cropping in the irrigated environment

There are opportunities to grow two rice crops, one in the wet season and one in the dry season, in areas of Laos serviced by irrigation facilities. Wet-season cropping in such areas would require only supplementary irrigation (supplementary to rainfall) rather than having total reliance on irrigation scheme supplies. Dry-season rice cropping in northern areas where mean minimum temperatures are below 12 °C during the time of seeding and early seedling growth will continue to remain difficult. However, with early planting in November or the adoption of improved seedbed management practices such as those described earlier, it is possible to double-crop these areas and achieve yields the equivalent of those achieved in provinces in the central and southern agricultural regions along the Mekong River Valley (Table 6).

Double cropping in the northern areas of the country will require an ongoing program of varietal selection to develop varieties with a greater tolerance of low temperatures that is required in the main irrigated areas in the Mekong River Valley.

Information on the optimum sowing and maturity dates for the wet-season and dry-season crops allows estimates to be made of growth duration (transplanting to

Table 5. Effects of seeding rate (kg ha^{-1}) on grain yield (t ha^{-1}) for direct-seeded crops in Vientiane Municipality, in the 2001-02 and 2002-03 dry seasons.

Seeding rate (kg ha^{-1})	Yield (t ha^{-1}) 2001-02	Yield (t ha^{-1}) 2002-03	Mean yield (t ha^{-1})
75	4.43	3.57	4.00
100	4.68	3.25	3.97
150	4.58	3.63	4.11
200	4.73	3.42	4.08
Mean	4.61	3.47	4.04
LSD 5%	ns[a]	ns	ns

[a]ns = nonsignificant.

Table 6. Grain yield and optimum sowing date in the dry and wet season and total yield for five locations in Laos.

Province	Dry season		Wet season		Total yield (t ha^{-1})
	Yield (t ha^{-1})	Optimum[a] sowing	Yield (t ha^{-1})	Optimum[a] sowing	
Luang Namtha	4.06 (5)	Mid-Nov	4.16 (3)	Early June	8.22
Xieng Khouang	3.09 (5)	Mid-Nov	4.74 (3)	Early July	7.83
Luang Prabang	4.23 (2)	Late Dec	3.81 (2)	Early July	8.03
Sayabouly	3.58 (2)	Early Dec	5.13 (2)	Mid-June	8.71
Vientiane	3.73 (3)	Early Dec	2.44 (1)	Mid-June	6.17

[a]The grain yield for each season is for the optimum sowing date at each location (the numbers within parentheses represent the number of years of experimentation on which the yield estimates are based).

harvest) and between-crop interval (the period between harvesting of one crop and transplanting of the next). Growth duration for dry-season crops in the northern region (Luang Namtha, Xieng Khouang, and Luang Prabang) can be as much as 45 days longer than for provinces in the Mekong River Valley (Vientiane and Sayabouly) for the same variety because of the effects of low temperature in the northern region on extending the vegetative growth phase of photoperiod-insensitive varieties (Table 7).

For variety TDK5, the growth duration for dry-season cropping in Sayabouly and Vientiane was only about 112 days, whereas, when the same variety was grown in Xieng Khouang, growth duration reached 157 days. For wet-season cropping, crop growth duration in the northern provinces for the same variety was reduced (relative to dry-season crops) by between 22 days (Luang Prabang) and 61 days (Xieng Khouang). Crop duration is not only important from the context of the cropping calendar (thereby

Table 7. Growth duration (days) for the dry-season (DS) crop, duration from DS to wet season (WS), WS duration, and duration from WS to DS for the optimum sowing date at each location. The estimations are based on the transplanting and harvesting dates of variety TDK5.

Location	DS growth duration (d)	Duration from DS to WAS (d)	WS growth duration (d)	Duration from WS to DS (d)
Luang Namtha	138 (20 Dec-6 May)	64	102 (9 Jul-19 Oct)	62
Xieng Khouang	157 (16 Dec-21May)	70	96 (30 Jul-3 Nov)	43
Luang Prabang	120 (24 Jan-23 May)	68	98 (30 Jul-5 Nov)	80
Sayabouly	112 (5 Jan-26 Apr)	70	115 (5 Jul-28 Oct)	69
Vientiane	111 (5 Jan-25 Apr)	77	97 (11 Jul-16 Oct)	81

providing sufficient time for seedbed planting between succeeding crops), but also in being able to ensure that the critical stages of the physiological growth of the crop are not exposed to conditions that affect final yield potential. For dry-season crops in the northern region, this means avoiding the potential effects of high temperature when flowering occurs in April, when temperature can reach as high as 35 °C. For wet-season crops in drought-prone areas of the Mekong River Valley, the flowering of crops in early to mid-October needs to be avoided to reduce the potential impact of late wet-season drought. Crop duration will become an increasingly important consideration in areas where double cropping is combined with direct seeding, for which the interval between successive crops becomes more critical.

Conclusions

The agronomic studies undertaken in the lowland rice environment from the mid-1990s to 2004 clearly indicate a potential for some agronomic practices to have a significant impact on yield potential, as well as to minimize the impact of year-to-year variation in production caused by periodic droughts and, in the case of dry-season irrigated cropping in the northern region, the potential impact of low temperature. However, as was also clearly indicated in the results of studies presented on technology adoption by farmers in Vientiane and Champassak in the central and southern regions, the adoption of improved agronomic practices represents only one component of the overall technology package that farmers need to maximize production potential. Improved varieties and the implementation of appropriate soil fertility management practices are also integral components of packages that need to be adopted by farmers in both the rainfed and irrigated lowland environments.

The current low-temperature and growth duration constraints to both wet-season rainfed and dry-season irrigated rice crops in the northern agricultural region will probably be alleviated through the development of varieties better adapted than those currently available to the particular growing conditions experienced in this region. Improved drought tolerance might also be expected in varieties developed for the more drought-prone areas of the Mekong River Valley. When used in combination with the agronomic practices capable of alleviating some of the potential impact of drought, these varieties will further help reduce the year-to-year variability in production that is still a major constraint in wet-season crops that are outside potentially irrigable areas, and that can be expected to constitute the major source of rice production for Laos for the foreseeable future. The importance of these lowland areas will be further augmented, as the area under rainfed upland rice cultivation declines in line with government policy to adopt more sustainable agricultural practices in such areas. The focus of ongoing agronomic studies in the main lowland rice-growing area of the Mekong River Valley should include studies on improved water-use efficiency (including the continued evaluation of varieties for improved drought tolerance), together with the continued evaluation of direct-seeding practices. Proper land leveling and the development of improved drainage, both of which can be facilitated with an expected increase in the mechanization of production, might be expected to lead to the wider adoption of direct seeding and/or use of younger seedlings for transplanting. Further research attention also needs to focus on the use of supplementary irrigation to reduce the impact of drought on wet-season rice cultivation.

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CHAPTER 23

Soil fertility management in the lowland rice environments of Laos

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Agriculture is the main livelihood of approximately 95% of the rural households in Laos, and rice is the single most important crop. Rice provides about 70% of the total calorie supply and constitutes around 60% of total agricultural production (UNDP 1998). Given this situation, any increase in rice production contributes to a general improvement in the welfare of rural households (Schiller et al 2000). In addition, heavy demand for increased production comes from the fast population growth. The population of Laos is growing at 2.5% per annum and is expected to increase from 5.3 million in 2000 to about 7.7 million in 2020. Another factor contributing to growing rice demand is the expected increase in per capita consumption connected to the fast development process in Laos. The major share of the necessary production increase can come only from rice-based lowland systems, which currently supply 88% of the total rice production. Although varying from year to year, the majority of lowland rice is produced in rainfed systems (about 80%), whereas irrigated lowlands contribute about 20% of lowland rice production (MAF 2002, Chapter 3).

During the last 15 years, rice-based lowland systems in Laos underwent considerable changes, ranging from a much improved infrastructure, which increased the number of farmers with access to markets and income opportunities outside of agriculture, to the establishment of considerable irrigation capacity and the development of improved rice production technologies. Although, based on these developments, considerable productivity increases were achieved after 1990 (rice production increased from 1.5 million tons in 1990 to 2.3 million tons in 2001; FAO electronic data base), considerable scope remains for further improvement. Given the now widespread use of improved, input-responsive varieties in lowland environments (see Chapter 21), appropriate crop and natural resource management (CNRM) becomes an increasingly important concern. Farmers are often quick to adopt suitable improved germplasm, but the dissemination and adoption of adjusted CNRM technologies is a necessary second step and a much slower process that is vital to further improving productivity while maintaining system sustainability. Within this context, this chapter summarizes recent research results and developments related to integrated nutrient management of rice-based lowland systems in Laos and proposes some future challenges and opportunities.

General characteristics of rice-based lowlands in Laos

For the purpose of this chapter, two broad regions of lowland rice cultivation are distinguished (Fig. 1). In mountainous northern Laos, lowland rice cultivation is confined to valley areas with characteristic soil, climate, and ecological conditions (included in this region are the provinces of Xieng Khouang and Saysoumboun, which are more usually part of the central region for agricultural statistical purposes). In the central and southern agricultural regions of the country, where about 80% of the total lowland rice area is located, rice is grown mostly on the plains adjacent to the Mekong River (Vientiane Municipality and the provinces of Vientiane, Borikhamxay, Khammouane, Savannakhet, Saravane, and Champassak). Development of irrigation capacity increased significantly from 1995 onward, with the area of dry-season rice increasing from 13,000 ha in 1995 to 102,000 ha in 2001 (MAF 2002). Most of this expansion has been on the Vientiane Plain (Vientiane Municipality and Vientiane Province) and on the six main rice-growing plains in central and southern Laos, particularly in the provinces of Savannakhet and Champassak. Consequently, more then 90% of the irrigated lowlands are situated in central and southern Laos.

The agroclimatic characteristics of the rice production environments are described in detail in Chapter 4. We can generalize that total annual precipitation is higher in the central and southern regions (about 1,900 mm per year) than in the northern region (about 1,400 mm per year), that variability of monthly rainfall is high in both regions, causing regular occurrence of intermediate drought spells or flooding during the cropping season, and that minimum and maximum temperatures are mostly favorable for rice cultivation. Only in the northern region are low temperatures at the onset of the dry season a regular production constraint.

The soils of Laos have been characterized using the FAO/UNESCO soil classification criteria (FAO 1998). This shows that the predominant lowland rice soils in the central and southern regions are Acrisols. Acrisols are strongly weathered soils with a clay-enriched subsoil, they are dominated by low-activity clay minerals, they have a low base saturation (<50%), and the percentage of H and Al in the exchange complex is high. Thus, the soil pH is usually close to 5.5 or lower, and the soils have a low inherent fertility. The typical visual characteristics of lowland rice Acrisols are their mottled appearance due to red, iron-rich patches in a usually gray, bleached soil matrix, which reflects exposure to regular flooding and subsequent drying cycles (gleyic or stagnic properties). Associated soils also frequently used for lowland rice cultivation in central and southern Laos are Cambisols. They occur in areas with younger parent material than for the Acrisols, are less weathered, and are generally more fertile than neighboring Acrisols. Because of a similar soil water regime, they do have gleyic properties in common with many Acrisols. In northern Laos, the same soil types as in the southern and central regions are typical in the lowlands. Especially in the larger valleys, where no recent sedimentation of soil material occurred, Acrisols predominate. In narrow valleys, on the fringes of wider valleys, and in low-lying areas, where new soil material is deposited from further upslope or the river (colluvium or

Fig. 1. Map of Laos showing northern (shaded) and central/southern Laos as used in this chapter. The north is mountainous and most of the lowland rice is confined to valley areas, whereas most lowland rice in the central and southern region is grown on the plains adjacent to the Mekong River. About 80% of all lowland rice in Laos is grown in the provinces of Vientiane, Borikhamxay, Khammouane, Savannakhet, Saravane, and Champassak.

Table 1. Some topsoil characteristics (0–0.2 m) of paddy soils in central and southern Laos. Shown are average, minimum, and maximum values of 12 fields in representative lowlands of southern Laos.

	$pH_{H_2O\ 1:1}$ –	TOC[a] (mg kg^{-1})	TSN[a] (mg kg^{-1})	Available K[b] (cmol kg^{-1})	Olsen P (mg kg^{-1})	Clay	Sand (%)	Silt
Average	5.3	8.7	0.8	0.12	3.4	26	26	48
Minimum	4.2	3.2	0.2	0.06	2.3	4	1	25
Maximum	6.5	19.7	1.9	0.26	5.8	47	71	82

	CEC	Exch. Ca	Exch. Mg (cmol kg^{-1})	Exch. Na	Exch. K	Base sat. (%)	Exch. acidity	Exch. Al (cmol kg^{-1})
Average	8.1	2.8	1.2	0.15	0.08	49	0.7	0.5
Minimum	2.1	0.3	0.2	0.05	0.04	20	0.1	0.0
Maximum	12.6	5.3	2.7	0.30	0.19	72	3.3	2.8

[a]TOC = total organic carbon, TSN = total soil N. [b]Available K was determined by extraction with 1 M ammonium acetate.

alluvium), Cambisols are associated soils. But, as in central and southern Laos, gleyic or stagnic properties are common.

Analysis of lowland paddy soils (0–0.2 m) of Laos indicates that 80% of the soils in the central and southern region contain less than 2% organic matter (>1.2% soil organic C), 68% are coarse-textured (sandy, loamy sands, and sandy loams), and 87% have a pH (H_2O) of less than 5.5. In contrast, soils in the north are more fertile: 66% of these soils contain more than 2% organic matter, 80% are loams or clay loams, and 52% have a pH of more than 5.5. Some typical topsoil characteristics of central and southern lowlands and their range are given in Table 1. The soil data presented confirm the general trends described by Linquist et al (1998), but also show the large spatial variability of soil characteristics.

Until the early 1990s, only 2% of the total rice area in Laos was irrigated, and rainfed lowland rice production was based on traditional practices. Mostly traditional varieties were grown and mechanization of any aspect of production or postharvest processing was exceptional. No agrochemicals were used by the majority of farmers, and farm residues were the main source of nutrient inputs. Since the mid-1990s, there have been considerable changes in lowland rice production, reflecting a combination of advances in research and the efforts of government and development agencies. Improved varieties have been developed and were adopted by the majority of lowland farmers, particularly in the main rice-growing areas in the Mekong River Valley (Chapter 21; Table 2). Especially, improved modern-type varieties (TDK, PNG, and TSN varieties) provide important yield gains compared with traditional and improved traditional-type varieties (RD and KDML varieties from northeast Thailand). Possibly because of different sample sizes, locations, and methods used, average yields reported by official statistics are higher (2.8 t ha^{-1} in 1990, 3.0 t ha^{-1} in 1995, and 3.3 t ha^{-1} in

Table 2. Varieties, inorganic fertilizer use, and average yields in lowland systems, central and southern Lao PDR, from 1990 onward. Based on Pandey (2001) and Shrestha (2004).

Item	Year		
	1990	1996	2001
Planted area (%):			
Traditional varieties	95	79	25
Improved varieties, traditional-type	5	21[a]	46
Improved varieties, modern-type	0	–	29
Farmers using inorganic fertilizer (%)	–	60	93
Average yield (t ha^{-1}):			
Traditional varieties	–	1.3	1.4
Improved varieties, traditional-type	–	1.5[a]	1.9
Improved varieties, modern-type	–	–	2.3

[a]Average for improved traditional and modern-type varieties.

2001; MAF 2002) but show a trend similar to the survey data presented in Table 2. Many farmers also adopted improved crop management practices, including higher transplanting densities, the use of low rates of inorganic fertilizer, splitting fertilizer applications, and increased use of organic fertilizers (Shresta 2004). The same survey indicated that land preparation is becoming increasingly mechanized, as is postharvest processing, and that pesticide use remains low.

Recent changes in technology adoption have been most pronounced in irrigated areas, particularly in dry-season irrigated crop production. The potential of many irrigation schemes for providing supplementary irrigation during the wet season, even during periods of drought, has generally been underused. Dry-season irrigated rice cropping reached a peak of 102,000 ha in 2001, but by 2004 had dropped to 77,000 ha (see Chapter 3), the decline probably being the result of a combination of increasing costs of production and marketing problems. Diversification into nonrice crops on paddy fields is limited and mostly restricted to the irrigated dry season and relatively small areas. Only one (rice) crop per year is grown in purely rainfed areas.

Nutrient management and agroeconomic sustainability in the lowlands of Laos

Research efforts to increase the productivity of lowland rice in Lao PDR included a large number of researcher-managed field trials on various aspects of nutrient management, mostly farmer-managed field trials to assess the agroeconomic performance and sustainability of different nutrient management options, and socioeconomic surveys covering a range of nutrient management issues. The main objectives of the researcher-managed trials conducted from 1991 to 2001 were to determine the most limiting nutrients, identify appropriate fertilizer rates, evaluate different application strategies, and assess integrated nutrient management options (including the use of residues, inorganic fertilizer, and green manure). Most of the trials examining these issues were conducted in farmers' fields under the supervision of local researchers and had a randomized complete block design with usually four replications. The germplasm used was the regionally preferred improved modern-type variety, and the chosen sites represented all major lowland rice areas in Lao PDR (Linquist et al 1998, Linquist and Sengxua 2001, 2003).

To evaluate the agroeconomic performance of nutrient management options in farmers' fields and under their management, survey data and farmer-managed field studies can be used. The survey information reported in this chapter was collected in the 1996 wet season (700 farmers from 15 villages in the provinces of Champassak and Saravane; Pandey and Sanamongkoun 1998) and in the 2001-02 wet and dry seasons (240 households from 12 villages in Champassak and Savannakhet provinces, and Vientiane Municipality; Shrestha 2004). Another main source of information for the agroeconomic performance evaluation of different nutrient management options was on-farm trials conducted between 2003 and 2005. In these trials, four collaborating farmers were selected at each of six sites (two sites each in Vientiane, Savannakhet, and Champassak provinces). Participating farmers tested a set of nutrient management options over two seasons, using their preferred crop management practices.

Major nutrient deficiencies and toxicities

From 1992 to 1998, a total of 43 on-farm nutrient omission experiments were conducted throughout the country in the rainfed lowland environment during the wet season. Nitrogen was deficient at most sites (Fig. 2), but N deficiency was more prevalent in central and southern Laos. In some cases, a missing N response was attributed to recent land clearing, high soil organic matter content (i.e., high indigenous-N supply), and/or high residue applications. Phosphorus was the second most limiting nutrient, with 71% of the central and southern sites responding to P, and 37% in the north. At about 30% of the central and southern sites, the soils were so P deficient that there was no response to other nutrients unless P was applied. K was much less limiting than N and P (25% in the central and southern region, 11% in the north). Approximately 25% of the sites showed some response to the application of S, but responses were small and in most cases nonsignificant, although severe deficiencies were observed at some sites, for example, in Sekong Province.

Similar results were achieved for the irrigated dry season in 22 NPK omission trials undertaken from 1992 to 1999. With one exception, all sites showed a significant N response, 79% of the central and southern sites and 50% of the sites in the north responded to P application, and potassium was limiting at 29% of all central and southern sites and at 50% of the sites in the north. Dry-season yields without fertilizer were only 1.5 and 1.7 t ha^{-1} for the central and southern region and the north, respectively, whereas significantly higher average yields without fertilizer were recorded in the wet season (2.0 and 2.6 t ha^{-1} for the central and southern region and the north, respectively).

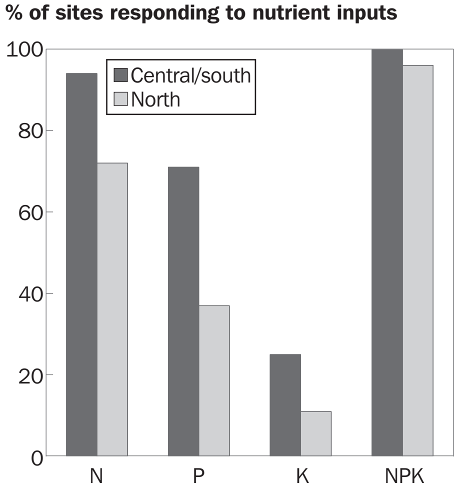

Fig. 2. The percentage of sites at which rainfed lowland rice responded to the addition of nitrogen, phosphorus, and potassium. Data represent means of 43 NPK omission trials (24 in the central and southern region and 19 in the north) conducted from 1992 to 1998 in the wet season.

No detailed analysis of toxicities and their importance is available for the rainfed lowlands in Laos, but Fe toxicity symptoms are regularly observed in farmers' fields, most often in paddies situated mid-slope, where iron-rich groundwater surfaces. Aluminum toxicities are also likely given the frequently very low soil pH and significant amounts of exchangeable Al (see Table 1); however, symptoms are rarely severe enough to be easily recognized in the field.

Effects and suitable rates of inorganic fertilizers

To evaluate the response of rice to N application, experiments were conducted at 20 sites (12 in central and southern Laos, 8 in northern Laos) from 1993 to 1998. The fertilizer-responsive, modern-type variety TDK1 was used in all trials. In all regions, there was a linear response to N applications up to 60 kg N ha^{-1}. Higher N doses did not increase yields in the north, but yield response remained linear up to 90 kg N ha^{-1} in the central and southern region (Fig. 3). Improved modern-type varieties (i.e., TDK1) usually showed higher yields and a better N response than traditional varieties in the central and southern region (Linquist and Sengxua 2001, Pandey, 2001).

Even though not all areas will show immediate benefits from the application of P, a general P application is advised because soil P levels are generally low and P deficiency is widespread, especially in central and southern Laos (see Table 1 and Fig. 2). Long-term strategies of P management with adjustments to reflect average yields are possible because P is highly immobile in the soil and seasonal fluctuations of crop

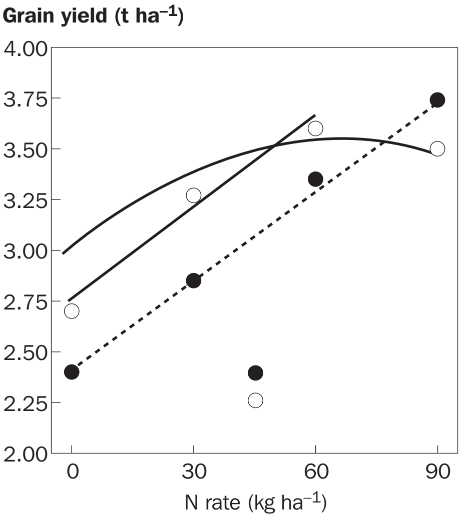

Fig. 3. The grain yield response of TDK1 to added N fertilizer in central/southern and northern Laos. The data represent means of 20 experiments (12 in the central and southern region and 8 in the north). The linear straight regression line for the northern points is added to illustrate that the response rate up to 60 kg N ha^{-1} is identical in both regions.

P needs can be buffered by the residual effects of applied P (data not shown). The P application rate can therefore be adjusted to reflect average yield levels (or target yields) based on crop P uptake. This approach also ensures that the P balance is near neutral, even if few crop residues are returned to the field. Table 3 shows the average N, P, and K uptake for improved modern-type varieties, indicating necessary P doses of 2.5 to 3.5 kg P (5.7 to 8.0 kg P_2O_5) per t grain yield if all crop residues are removed from the field and no organic fertilizers are used. However, responses to P application were quite variable across sites, which was attributed to the positive correlation of clay content and soil P-fixation capacity. Therefore, Linquist and Sengxua (2001) have proposed variable P doses for which first-time P application recommendations are 6–13 kg P ha^{-1} on sandy soils, 13–19 kg P ha^{-1} on loam soils, and 19–26 kg P ha^{-1} on clay loam and clay soils. Phosphorus applications for following seasons are adjusted to reflect target yields.

Potassium responses were observed on only a relatively small number of soils (Fig. 2). Where K deficiency occurred (e.g., Phiang District of Sayabouly Province), significant responses to K application and a strong correlation with the occurrence of the fungal disease brown spot were observed (data not shown). K deficiency is expected to increase in the future because of the increased use of fertilizers containing only N and P and the low soil-K supply of coarse-textured soils (Table 1), especially when

Table 3. Concentration and uptake of N, P, and K in rice straw and grain at harvest for improved modern-type varieties in rainfed lowlands of Laos. Based on Linquist and Sengxua (2001) (S1) and experimental data from the wet season 2003 (S2; n = 60).

	S1		S2		S1		S2		S1	S2
Item	Nutrient concentration				Nutrient per ton of grain yield[a]					
	Grain	Straw	Grain	Straw	Grain	Straw	Grain	Straw	Total	Total
	(%)				(kg t^{-1})				(kg t^{-1})	
N	0.79	0.32	0.88	0.37	7.9	4.8	8.8	5.5	12.7	14.3
P	0.19	0.04	0.24	0.07	1.9	0.6	2.4	1.1	2.5	3.5
K	0.28	0.79	0.32	1.09	2.8	11.9	3.2	16.4	14.7	19.6

[a] Assumes an average harvest index of 0.4 according to field data, i.e., if rice grain yield is 1 t ha^{-1}, straw yield would be 1.5 t ha^{-1}.

few crop residues are recycled. Rice straw at harvest contains about 80% of plant K (Table 3); therefore, straw management is critical for the K balance of the system. As Figure 4 shows, K deficiency can be induced quickly on many soils if the cropping intensity is high, fertilizers containing N and P only are used, and straw remaining on the field is burned or grazed (the dominant farmers' practices at the trial sites). Although these results were obtained in irrigation scheme areas, the same development can be expected in the rainfed lowland environment, albeit at a slower rate.

Limited data are available for a comparison of yield response to inorganic fertilizers in the wet (mostly rainfed) and dry (irrigated) seasons. As described above, the observed frequencies of N, P, and K deficiencies were similar in both seasons. Lower average temperatures in the dry season might influence indigenous nutrient availability and biological N fixation; however, the extent of such effects remains speculative, although average dry-season yields were lower in the unfertilized treatments of nutrient omission trials (Table 4). Higher dry-season solar radiation should increase the yield potential of crops grown during this time, but this does not influence the fertilizer response at low to medium fertilizer application rates. Comparisons of the full NPK treatment (60-13-17 kg N-P-K ha^{-1}) included in the nutrient omission trials (1992 to 1999: 43 wet-season trials, 22 dry-season trials) show that average yields were 3.4 t ha^{-1} (central and southern region) and 3.5 t ha^{-1} (north) in the wet season versus 2.7 t ha^{-1} (central and southern region) and 3.4 t ha^{-1} (north) in the dry season (Linquist and Sengxua 2001). However, these differences have to be interpreted with caution, as a much smaller number of sites was evaluated in the dry season. In the central and southern lowlands, lower average yields in the dry season were also observed in the participatory on-farm trials conducted between 2003 and 2005 (details below; Table 6). The highest-yielding nutrient management option tested resulted in a yield of 3.8 t ha^{-1} in the wet season and 3.2 t ha^{-1} in the dry season. In these trials, suboptimal irrigation by farmers might have contributed to a lower dry-season response.

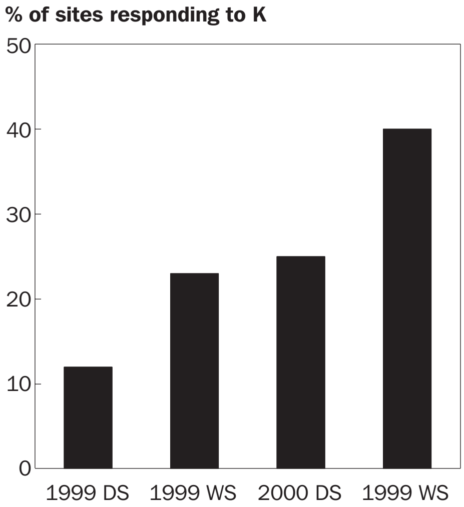

Fig. 4. Results of four seasons (DS and WS = dry and wet season, respectively) comparing the use of 16-20-0 NPK fertilizer and 15-15-15 NPK fertilizer as a basal fertilizer for rice. The graph shows the percentage of sites (total of 17 sites) at which use of 15-15-15 NPK fertilizer produced yields at least 0.4 t ha^{-1} greater than where 16-20-0 NPK fertilizer was used.

Integrated nutrient management solutions

The examples above show that, based on improved modern-type varieties, the use of inorganic fertilizers can effectively increase yields of rice-based lowland systems in Laos. But they also indicate that a balanced nutrient management strategy needs to be developed and adopted to avoid unsustainable nutrient management practices, and that improved crop residue management needs to be part of this strategy. Another important issue is the development of feasible application strategies especially adjusted to the variable water availability in rainfed systems.

Recycling residues has several potential advantages: the residues contain micronutrients not commonly found in inorganic fertilizers, they can contain substantial amounts of nutrients that would be expensive to apply as inorganic fertilizers (e.g., K in rice straw), and application of organic residues can maintain or even increase soil organic matter, which generally has a positive influence on soil fertility. Low costs are also often cited as an advantage of residues, but, as Pandey (1998) has pointed out, if input costs for their production and application (e.g., labor, land, and transportation) are included, nutrients from residues can often be more expensive than nutrients from inorganic fertilizers. Figure 5 shows some results from trials evaluating the effect of residues on yields and fertilizer-use efficiency. The application of inorganic fertilizer alone increased yields by 134% in Champassak Province and by 107% in Saravane Province, whereas residues alone increased yields by about 50% at both sites. In

Table 4. Agroeconomic indicators of different nutrient management options for lowland rice during 2003 to 2005 in Laos. On-farm results are presented separately for rainfed systems on coarse-textured soils, for irrigated systems in the dry season (DS), and for mostly rainfed rice in the wet season (WS). Improved modern-type varieties were used in all treatments.

Treat-ment	N-P-K applied	Org. material applied (kg ha^{-1})	Com. organic fertilizer	Grain yield 14% MC (t ha^{-1})	Yield gain over T2	AE[a] of applied N (kg kg^{-1})	Costs[b] of fertilizer treatment (US$ ha^{-1})	Gross value paddy	V/C ratio versus T2 –	V/C ratio versus T6 –	Benefit increase over T2 (US$ ha^{-1})
Wet season 2004, rainfed rice, coarse texture (n = 11)[d]											
T2	0-0-0	0	–	1.57 c	–	–	0	204	–	–	–
T3	69-7-13	2,000	–	2.55 a	0.98 a	9	75	332	1.7	1.14	52
T4	33-4-8	2,000	–	2.36 ab	0.79 ab	13	51	307	2.0	1.20	51
T5	0-0-0	2,000	1,864	2.28 ab	0.71 ab	–	200	297	0.5	–	–108
T6	0-0-0	2,000	–	1.95 bc	0.37 b	–	6	253	7.9	–	42
Dry season 2003-04 and 2004-05, irrigated rice, medium texture (n = 16)[d]											
T2	1-0-0	563	–	2.04 c	–	–	3	224	–	–	–
T3	65-8-9	2,000	–	3.24 a	1.20 a	11	72	349	1.8	1.53	56
T4	34-4-5	2,000	–	2.83 b	0.79 b	8	42	305	2.1	1.56	42
T5	1-0-0	2,000	2,375	2.56 b	0.52 b	–	222	278	0.2	–	–165
T6	1-0-0	2,000	–	2.33 bc	0.29 b	–	7	250	6.1	–	22
Wet season 2003 and 2004, rainfed rice, medium texture (n = 20)[d]											
T2	4-1-0	250	–	2.32 d	–	–	4	282	–	–	–
T3	64-10-9	2,000	–	3.76 a	1.44 a	14	66	451	2.7	1.74	107
T4	35-6-6	2,000	–	3.34 ab	1.02 b	13	41	400	3.2	1.53	81
T5	0-0-0	2,000	2,300	3.27 bc	0.94 b	–	236	392	0.5	–	–122
T6	0-0-0	2,000	–	2.88 c	0.55 c	–	6	347	27.2	–	63

[a]Agronomic efficiency of applied N in kg grain per kg N applied was calculated in comparison to treatment 6. [b]Treatment costs did include costs for fertilizer and application. Costs of collection/production of organic matter were not included. [c]The average exchange rate during the trial period was US$1 = 10,000 Kip. [d]Values in a column followed by a common letter are not significantly different at $P = 5\%$ according to Duncan's multiple range test.

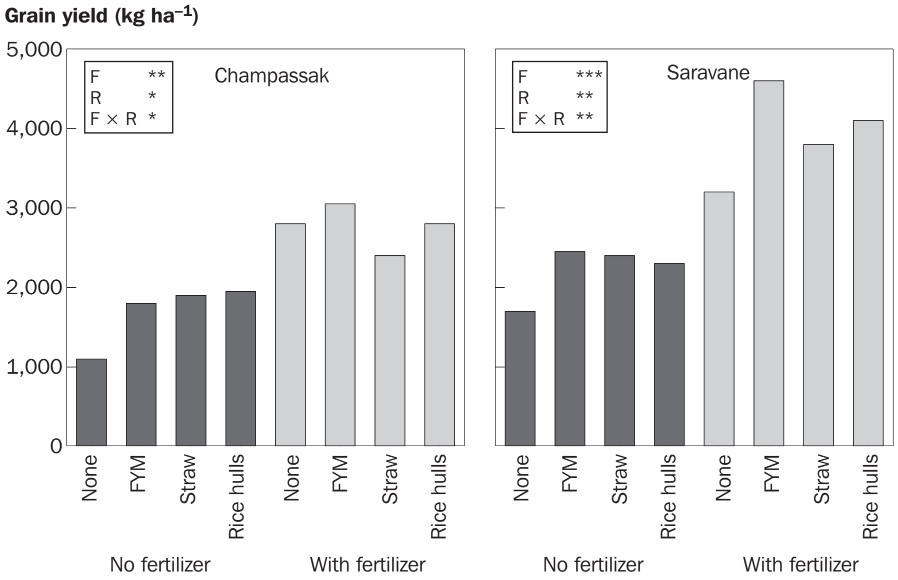

Fig. 5. Grain yield response to on-farm residues (2 t ha^{-1} on a dry-weight basis) with and without inorganic fertilizer. The inorganic fertilizer was applied at 60-13-17 kg ha^{-1} of N, P, and K, respectively. *, **, and * indicate a significant difference at *P* = 0.05, 0.01, and 0.001, respectively. F = inorganic fertilizer, R = residue, FYM = farmyard manure.**

Saravane, the responses to inorganic and organic fertilizers were additive, but significant negative interactions were observed in Champassak. These results confirm that organic fertilizers are a possible source of nutrients for increasing rice yields for cash-poor farmers. But, as most residues contain little N and P (see Table 3), large yield increases as a result of using organic fertilizers alone will not be possible. However, combinations of organic and inorganic fertilizer can increase yields substantially and contribute to sustainable improvements in soil fertility. Linquist and Sengxua (2001) also tested green-manuring technologies (data not shown) but did not recommend their use in Laos mainly on account of the high P requirements of green manures and the low indigenous-P supply of most soils in Laos (green manure crops were found to need twice the P input of that necessary for rice).

The benefits from combined use of organic and inorganic fertilizers are also indicated by partial nutrient balances conducted for several nutrient management options shown in Table 5. The balances account only for nutrients applied and for nutrient removal with the crop; however, they can be used as an indicator for sustainability. The partial balance for treatments with very limited fertilizer use (T1 and T2) was highly negative for N, P, and K. The use of improved varieties and application of organic materials reduced P and K losses slightly, despite higher yields (T6). Integrated fertilizer options combining organic and inorganic fertilizers resulted in positive or almost balanced N and P balances (T3 and T4), but the K balance remained negative, reflecting the dominant use of 16-20-0 NPK fertilizer. Application of organic materials

Table 5. Partial nutrient balance of different nutrient management options for lowland rice in the 2003 wet season in Laos (n = 12). Traditional varieties were used in treatment 1 whereas improved modern-type varieties were used in all other treatments. Treatment-dependent nutrients applied are shown as input from inorganic and organic fertilizer.

Treatment		T1	T2	T3	T4	T5	T6
				(kg ha^{-1})			
Grain yield		2,270	2,790	4,170	3,724	3,550	3,130
Straw yield		4,330	4,120	5,310	5,250	5,090	4,280
Nutrient removal (with grain and 1/2 straw)	N	27.0	28.1	44.0	39.1	36.6	31.8
	P	7.5	7.2	10.8	9.8	9.1	8.1
	K	35.4	33.8	40.5	38.5	31.8	33.2
Input from inorganic fertilizer	N	4.5	7.1	66.0	34.7	0	0
	P	0.4	0.7	10.8	6.0	0	0
	K	0	0	4.0	3.1	0	0
Input from organic fertilizer	N	1.0	2.1	10.0	10.0	60.6	10.0
	P	0.3	0.6	3.0	3.0	18.3	3.0
	K	1.0	2.1	10.0	10.0	28.5	10.0
Balance	N	–21.5	–18.9	32.0	5.6	24.0	–21.8
	P	–6.8	–5.9	3.0	–0.8	9.2	–5.1
	K	–34.4	–31.7	–26.5	–25.4	–3.3	–23.2

and commercial organic fertilizer (T5) resulted in positive or neutral balances for N, P, and K, but, as indicated below, this option is not economically viable.

An average input of about 30 kg N ha^{-1} per crop from biological N fixation (BNF) has been reported for rice systems (Roger and Ladha 1992, Greenland 1997) although this amount can be lowered by the application of inorganic N (Roger 1996). Therefore, BNF might explain the negative N balances of treatments without significant inorganic N inputs (T1, T2, and T6 in Table 5), whereas positive N balances in the other treatments indicate N losses to the environment. It is questionable whether natural nutrient replenishment could compensate for the estimated P and K losses in T1, T2, and T6 (Table 5). Rainwater does contain considerable amounts of S but hardly any N, P, or K (Linquist and Sengxua 2001). The irrigation water in central and southern Laos can contribute about 0.5 kg P ha^{-1} and about 20 kg K ha^{-1} for a fully irrigated crop (Linquist and Sengxua 2001), but irrigation will also increase leaching losses.

The average yield increases shown in Table 2 and related higher nutrient exports are a recent development, and the capacity of existing systems to maintain current yield levels without increased nutrient inputs is uncertain. Nutrient balances for T1 and T2 (Table 5) might be extreme because of the very low average nutrient inputs, but they confirm the results shown in Figure 4. Negative K balances in the rainfed lowland environment have also been reported by Wihardjaka et al (1998) in Central Java. Medium levels of inorganic fertilizer inputs and low average yields resulted in slightly positive partial NPK balances for most farmers in a study in northeast Thailand (Wijnhoud et al 2003), but Vityakorn (1989) concluded that the biophysical sustainability of rice-based rainfed lowlands in Thailand might be limited to lower paddies because of nutrient inflows from fields higher in the toposequence. The partial nutrient balances in Table 5 confirm that recycling organic residues can reduce nutrient losses considerably, but even their use might not prevent unsustainable nutrient losses and unbalanced nutrient availability. In addition, increasing opportunity costs of labor make the use of organic fertilizers less attractive in many rainfed environments (Pandey 1998). Therefore, inorganic fertilizers will continue to have an important role, not only for increasing yields but also for maintaining the productivity of rainfed lowland rice environments.

Existing fertilizer management recommendations for rainfed environments are often derived from irrigated environments and are, as a consequence, rather rigid with regard to the rates and the optimal application timing. They are therefore not very helpful for farmers who have to cope with considerable variations in water availability in time and space. This problem concerns mainly N (urea) application, as P and K are normally applied prior to or at about the time of transplanting, when sufficient water is available. To solve this problem, Linquist and Sengxua (2003) have developed the concept of "windows of opportunity," in which "time-periods" instead of specific crop development stages are recommended for N application. This increases the possibility that adequate soil-water conditions for N application will occur at the recommended application time, thereby minimizing N losses due to nitrification-denitrification processes. The best N fertilizer response was observed when N was applied in three splits: around transplanting, at active tillering, and around panicle initiation (PI). The first N split can be applied in the period from just before transplanting to 30 days after transplanting without a significant effect on yield. The last application can be made between 2 weeks before and 1 week after PI (Fig. 6).

Agroeconomic evaluation of different fertilizer options

The general objective of researcher-driven nutrient management trials is to establish fertilizer-yield relations, to determine achievable yields, and/or to test the efficiency of different application strategies. To reach this goal, crop management conditions between sites/seasons are kept as uniform as possible, and close-to-optimal crop management practices are used. Economic parameters are rarely included. In contrast, farmers almost never pursue the goal of yield maximization for a specific crop. Instead, they follow several (sometimes contradicting) objectives, including optimizing returns on their investment (land, labor, and capital), to integrate all their activities on- and off-farm, to fulfill social/cultural obligations, to keep production risks at acceptable levels, and to sustain their resource base. This results in a considerable variation in crop management practices, which can be accentuated by the varying crop management skills of individual farmers. To evaluate the effects of such factors on the agroeconomic performance of nutrient management options, which will determine their acceptability and adoption by farmers, surveys or farmer participatory experiments can be used.

The first survey with this objective, following the introduction of improved crop production technologies in the lowland environment of central and southern Laos, was conducted by Pandey and Sanamongkhoun (1998) during the 1996 wet season.

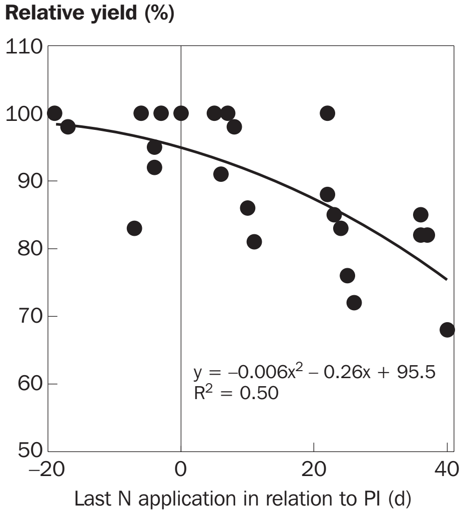

Fig. 6. "Window of opportunity" for N application at panicle initiation (PI). Relative yield (relative to the highest yield at each site) in relation to the timing of the last N application. The x-axis is the timing of the last N application relative to PI (i.e., PI is day 0).

Although 66% of the farmers reported using some fertilizer, the area being fertilized was only 48% of the area covered by the survey, and application rates were low (farmers who used fertilizers applied on average 37 kg ha^{-1}, with N and P_2O_5 being in equal proportions). About 60% of the farmers had commenced using inorganic fertilizers only in 1994. Fertilizers were used for both improved and traditional varieties, and were mostly applied on the middle terraces in the toposequence. Farmers who applied very low fertilizer rates usually confined the use of fertilizer to seedbeds or those parts of fields where rice did not grow well. The adoption of inorganic fertilizer use (and the use of improved varieties) was mainly determined by accessibility of the village. Soil type, contact with extension agents, education, and family size had no significant bearing on adoption. High-risk environments reduced the use of both inorganic fertilizer and modern varieties. The observed nutrient response to inorganic fertilizer (only N response was evaluated) was comparable to that in the rainfed environment of other countries (8 to 17 kg grain per kg of N applied), while the nutrient-to-grain price ratio was higher than in most other countries in the region (the price of 1 kg N was equivalent to 4.4 kg paddy). The highest net returns per land unit were observed when inorganic fertilizer use was combined with the use of improved varieties, confirming the higher fertilizer response of modern varieties reported by Linquist and Sengxua (2001). Based on this survey, Pandey (2001) concluded that more widespread use of inorganic fertilizers and/or the use of higher fertilizer application rates are unlikely

Table 6. Average farm-gate prices for fertilizer, paddy, and labor in southern Laos from 2003 to 2005.[a]

Fertilizer type	N-P_2O_5-K_2O 16-20-0	N-P_2O_5-K_2O 15-15-15	N-P_2O_5-K_2O 46-0-0	Commercial organic fertilizer	Paddy	Labor
			(US\$ kg^{-1})			(US\$ day^{-1})
	0.26	0.29	0.28	0.11	0.12	1.53

[a]The average exchange rate during the trial period was US\$1 = 10,000 Kip.

unless the return to investment can be improved through either lower fertilizer prices or increased fertilizer response.

Recent rapid changes in socioeconomic conditions in Laos, changes in farmers' crop management practices (see Table 2), and the considerable advances in the development of appropriate crop management technologies were the rationale behind the farmer participatory testing of different fertilizer management options between 2003 and 2005. Evaluated were unfertilized treatments with traditional and modern varieties, different combinations of organic and inorganic fertilizer rates, and one treatment testing "commercial" organic fertilizer. The last option was included on account of the establishment of factories for the production of organic fertilizer in all the main lowland rice-producing regions, providing a product of variable composition (including poultry manure, peat, rice straw, etc.) with variable nutrient content. In addition, farmers were being subjected to considerable marketing pressure to purchase and use the organic fertilizer.

Average prices of inputs and outputs are given in Table 6. In most cases, they varied only slightly between regions and seasons; exceptions were the comparatively high price for commercialized organic fertilizer in Savannakhet Province (US\$0.17 per kg) and the low paddy price during the 2003-04 dry season in Champassak (\$0.09 per kg). The average inorganic nutrient-to-paddy price ratio ranged from 2.2 to 2.4 (the price of 1 kg N was equivalent to 2.2 to 2.4 kg paddy) depending on the fertilizer type, which is roughly half the ratio reported by Pandey (2001), and this represents much more favorable conditions for inorganic fertilizer use. Reported labor prices were used to calculate costs related to fertilizer use based on average labor requirements. Costs for the collection/preparation of organic fertilizers were not included.

An overview of agroeconomic results for all treatments using improved modern-type varieties is presented in Table 4. The results were separated for the wet (mostly rainfed) and dry seasons (irrigated), and, within the wet season, for sites with coarse- (sandy) and medium (loamy)-textured soils. This distinction was made on account of the potential effects of soil texture on water-holding capacity, soil fertility, and fertilizer response. This association was reflected in the lower yields with or without very low application rates (T2) and a lower fertilizer response (T3–T6) for coarse-textured soils. General yield trends are identical for all three data sets and yields increase in the sequence T2 < T6 < T5 < T4 < T3 even though yield differences were not always statistically significant because of the high variability between fields. Average yield was lowest for coarse-textured soils in the wet season and highest for medium-textured soils in the wet season. Occasional pest pressure (weeds, birds) and suboptimal water supply (Champassak) contributed to the lower yields and yield response in the dry season, but these effects could not be quantified.

When compared to the unfertilized treatment (T2), all fertilizer options with the exception of the use of commercial organic fertilizer (T5) resulted in acceptable value/cost (V/C) ratios. Many agroeconomic studies have shown that small-scale farmers accept and adopt technologies only if they provide at least a return of 50% to 100% on their investment (V/C ratio ≥1.5 to 2) (CIMMYT 1989). The highest V/C ratios were achieved by the organic fertilizer treatment (T6) on account of the low costs of organic material (though not included in the treatment costs was the cost of production/collection of the organic matter). The results obtained from the use of organic fertilizer, with an average yield improvement of 0.4 to 0.6 t ha^{-1} relative to the unfertilized situation, were similar to results reported by Linquist and Sengxua (2001), and confirmed that the application of organic materials at medium rates (about 2 t ha^{-1}) represents a good option for farmers having no access to inorganic fertilizer. However, these yield gains represent the upper possible and sustainable limit given that the total straw yield was 2.4 to 3.4 t ha^{-1} (rainfed and irrigated production, respectively) and recognizing that farmers often have other potential uses for rice straw. When organic fertilizer had to be purchased for application (T5), this was always associated with negative returns. The comparison of the yield gains achieved with commercially available organic fertilizer (T5) and "conventional" organic fertilizer (T6) indicated that the former was approximately as effective as the latter, but the yield response was at a very high cost. Thus, commercial organic fertilizer cannot be recommended to rice farmers in the lowland environments of Laos.

Intentionally, none of the treatments tested was based on the application of inorganic fertilizer alone because the application of organic materials is highly recommended for the lowlands of Laos to avoid soil nutrient depletion, especially with respect to K and micronutrients (see Table 5). Hence, the agroeconomic response to inorganic fertilizer alone had to be estimated by comparing treatments T3 and T4 with T6 (Table 4). The observed value/cost ratios indicate an acceptable return to inorganic fertilizer on medium-textured soils (V/C ratios ≥1.5) but returns to investment were low on coarse-textured soils (V/C ratios ≤1.2). Although these calculations might have underestimated the actual response to inorganic fertilizer because of negative interactions of organic and inorganic fertilizer in some cases (Fig. 5), they do confirm repeated observations of limited response to inorganic fertilizer on very sandy soils in the wider region (Ragland et al 1987, Willet 1995, Haefele et al 2006). Although further studies are needed before final conclusions can be made, the results reported here suggest that fertilizer recommendations for coarse-textured soils (loamy sands or coarser) should give priority to the application of organic sources of plant nutrients, possibly accompanied by low rates of inorganic fertilizer (note the decreasing rate of return with higher fertilizer rates). Additional reasons for such a recommendation are that coarser-textured soils are often found in higher landscape positions, which are also more drought-prone and therefore represent a higher risk for any investment in inputs. It must be emphasized that this conclusion is targeted only at rainfed lowlands with coarse-textured soils; there are no indications that finer-textured soils in purely rainfed systems react any different than similar soils within irrigated schemes. This is confirmed by an analysis of 75 experiments in central and southern Laos from 1991 to 1999 by Linquist and Sengxua (2001), which showed good fertilizer response (mean agronomic efficiency of 15 kg grain per kg N applied) without excluding sites adversely affected by drought, flooding, or insect damage.

Future challenges and research opportunities

This overview of the results of nutrient management research for rice-based lowland systems in Laos shows that impact-oriented technologies are available, and that they are an important component of ongoing efforts to increase and maintain system productivity. Recommendations for extension and farmer use have been formulated, and are also available through the Internet at the IRRI Knowledge Bank. These guidelines describe the principles of nutrient management for rainfed lowland rice in Laos and provide simple advice on where, when, and how to use fertilizer. However, further development and testing of such guiding principles for input use and assisting with decision support tools should be a priority for rainfed lowlands in and beyond Laos. The frequent occurrence of abiotic stresses typical for these environments requires site-specific adaptation of nutrient management at the field level to make the best use of the scarce resources available to smallholder farmers. Particularly, substantial differences in field water availability caused by even small height differences in the toposequence can greatly influence production potential and risk (Oberthuer and Kam 2000). Consequently, a framework for site-specific nutrient management should consist of a combination of (1) regional nutrient management principles based on on-farm research with (2) farmers' site-specific knowledge of local water and soil resources, and (3) real-time (in-season) interventions based on field observations. The regional component refers to a "recommendation domain" with similar system components and conditions, for example, the lowlands in Laos or rainfed lowlands in northeast Thailand. Within this domain or region, farmers would have to choose from a few options developed and evaluated for specific production situations within the domain/region. In practice, these options could be presented in the form of a decision tree (Lampayan et al 1994). The last element would consist of flexible management advice allowing adjustment during the season as proposed by Linquist and Sengxua (2003).

Another important research issue is an adequate CNRM strategy for diversified cropping systems. Rice farmers often are reluctant to fully use existing irrigation capacity. Increasing energy (fuel) costs combined with stable or even declining paddy prices can be expected to exacerbate this problem. Only crops with a higher market value (relative to rice) will have the potential for increasing returns from dry-season irrigated cropping. Resulting challenges are to identify new sustainable cropping systems and to develop adjusted integrated nutrient management options. Changes in the cropping system will affect many factors determining soil fertility, including the annual duration of submerged soil conditions, the amount and quality of residues recycled, the residual effects of nutrients applied in one crop on the other crop, and disease and pest cycles. Understanding and managing these factors and their effect on soil fertility will be necessary to optimize the productivity of the new systems.

Further important changes in lowland rice production systems might occur in the near future to reflect recent advances in stress-tolerance breeding. Discoveries of quantitative trait loci for improved tolerance of acid soils and Al toxicity, of submergence, and of P deficiency (Mackill 2006) are targeting unfavorable environments like the lowlands of Laos, while marker-assisted breeding is allowing the rapid transfer of such traits into locally adapted germplasm. Largely unknown at this stage is the effect the use of such germplasm might have on natural resource management and the soil resource base, especially in fragile systems with limited buffering capacity. Without adequate nutrient replacement, the use of such germplasm could induce increased and accelerated soil nutrient depletion. Where fertilizers are applied, higher stress tolerance could contribute to higher fertilizer-use efficiency, higher productivity, and reduced nutrient losses. More stress-tolerant germplasm could also lead to the clearing and use of currently unproductive land, thus reducing remaining “wasteland” areas further. Agronomic research should examine such issues in advance to evaluate the possible consequences of such changes, while at the same time developing strategies for the best use of new and appropriate technologies.

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Notes

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CHAPTER 24

Improving upland rice-based cropping systems in Laos

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Upland rice is the main crop grown in the highlands of northern Laos and along the Lao-Vietnam border in southern and central Laos. Upland rice is traditionally grown in slash-and-burn systems; the importance of this system and the production practices in it are described in Chapter 3.

The Lao-IRRI project began research on upland rice systems in 1991. Then, little was known about the Lao upland systems and their constraints, although Fujisaka (1991) had conducted a preliminary survey of the upland rice systems in northern Laos. Much of the early upland work conducted by the Lao-IRRI Project focused on characterization of the upland environment for biological, physical, and social factors. During the 1990s, the Houay Khot Research Station in Luang Prabang Province was upgraded (it is now the headquarters of the Northern Agriculture and Forestry Research Center, NAFReC) and most of the upland rice research was conducted at this station (and some research was also being conducted by the Lao-Swedish Forestry Program at the nearby Thong Khang Research Station). Research conducted during this period focused on variety collection and evaluation, weed management, evaluation of alternative crops to grow in upland rice-based systems, evaluation of a wide range of cover crops, and nitrogen-fixing trees. This work, which was conducted through 1995, is reported on by Roder (2001). It is not the purpose of this chapter to summarize this book, but rather to focus on the challenges currently facing upland rice farmers and the progress of research for developing solutions for the highlands.

A couple of key changes took place in the mid-1990s that have changed the direction and urgency for upland rice research. First, the government policy of land allocation started in the mid-1990s and, second, there has been considerable village migration from remote areas to roads (with the opportunities of markets, schools, electricity, and clean water). These factors have led to increased pressure on land, have shortened the fallow periods between crops, and have led to increased rice deficits (this is described in more detail later). This situation provided a sense of urgency for improved systems and in 2000 a shift took place from primarily on-station research to on-farm integrated and participatory research. The primary focus of this chapter is the on-farm research that took many of the technologies developed from 1991 to 1999 on-farm to test and further develop with farmers.

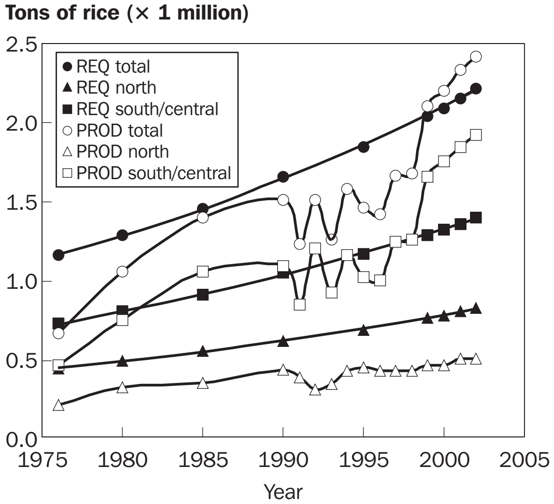

Fig. 1. Lao rice production and rice requirement by region from 1976 to 2002.

The upland rice system in Laos: a system in peril

Government statistics show that Laos is sufficient in rice domestically, but, in northern Laos, rice deficits (and consequently poverty) are common. Government statistics (Fig. 1) and survey data (i.e., ADB 2001) indicate that the situation is getting worse.

The current situation is ultimately the result of increased population pressure on limited land resources. Population pressure is increasing for several reasons. First is growth due to the annual population growth rate of 2.8% (UNDP 1999). Second is the land allocation policy that started in the mid-1990s with the intent of stabilizing or reducing slash-and-burn agriculture. This multistep process limits farmers to three or four upland fields—in effect allowing for a maximum of only two or three years of fallow. Third is village migration, causing increased pressure along roads. With roads, electricity, and water available along major road corridors, many remote villages are moving to the roads. Thus, upland field areas near the roads are under increasing pressure.

Land allocation was enforced to stop pioneering shifting cultivation (the cutting and burning of old or virgin forests) in order to protect forests and watersheds. Farmers are permitted to practice rotational shifting cultivation among the three to four fields they are allocated. According to the National Statistics Center (NSC 2004), the frequency of pioneering shifting cultivation is about half the level it was in 1997-98; however, rotational shifting cultivation is on the increase. The increase in rotation shifting cultivation is expected with a decline in pioneering cultivation.

The traditional rotational system for upland rice in slash-and-burn systems is a single year of rice followed by a long fallow. Roder (2001) reported that as late as

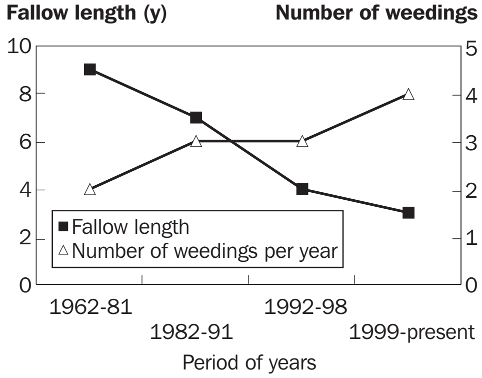

Fig. 2. Changes in fallow period and number of weedings required per season in upland rice from 1962 to 2002 (from Trosch 2003).

the 1950s fallow periods were as long as 40 years. Results from a study conducted in the northern provinces of Luang Prabang and Oudomxay (Trosch 2003) show that average fallow lengths declined from 9 years in the period from 1961 to 1981 to only 3 years now (Fig. 2). In fact, several villages in this survey reported only 2-year fallows. These short fallows are the result of farmers adhering to the land allocation policy and practicing rotational shifting cultivation among the plots they have been allocated. While it is not possible to state a figure for a minimum sustainable fallow period, it is generally accepted that 2- or 3-year fallows are not sustainable under current management practices. Short fallow periods have rendered these systems unsustainable as soil quality (because of nutrient depletion and erosion) is declining, weed pressure and labor inputs are increasing, and yields are declining, with the end result being lower returns on productivity and increased poverty. This has been confirmed in a number of surveys in which farmers report yield declines and increased poverty as a result of short fallows (i.e., Trosch 2003, ADB 2001).

Upland production constraints

Results from a 1992 household survey (Roder 2001) indicate that farmers perceive weeds to be the main problem in their upland rice fields, with 85% of farmers mentioning them (Fig. 3). Pests are the next biggest problem mentioned by farmers. Pests include rodents (54%), insects (34%), domestic animals (15%), wild animals—mostly wild boars (11%)—and disease (8%). Drought is mentioned as the third biggest problem (47% of the farmers mentioned it). Other problems mentioned were land availability (41%), labor (24%), soil fertility (21%), and soil erosion (15%). The latter problems (and weeds), just mentioned, are likely to be of greater significance now, following land allocation and the resulting short fallow systems. These problems will not all be discussed in this section; weeds are discussed briefly above as well as in Chapter 20, land availability issues are discussed above and in Chapter 3.

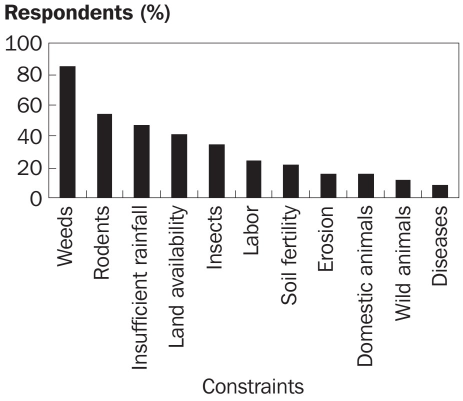

Fig. 3. Constraints to rice production in slash-and-burn systems (household survey conducted in 1992 with 129 correspondents from four districts in Luang Prabang and Oudomxay provinces). Land availability includes the constraint of short fallow and insect pests are mostly white grub. Data from Roder (2001).

Weeds. Weeds and weed management are addressed in detail in Chapter 20, so here the problem is discussed only briefly. Fallow length and the labor required for weeding are closely related. Long fallows that are dominated by perennial weeds require only two weedings, whereas fallows of only two or three years (dominated by annual weeds and grasses) require four to five weedings (Fig. 2). Weeding alone accounts for about 50% of the total labor requirement of upland rice (150 person-days per year or more). As fallows shorten, farmers have to work harder but receive lower rice yields.

Drought as a problem. Upland rice is rainfed and drought is often a problem. Analysis of rainfall data and upland rice yields at Houay Khot suggests that early-season drought (i.e., May) has little effect on rice growth, provided the drought is not severe enough to kill the crop. Upland rice is most sensitive to drought during tillering and panicle initiation and total rainfall from June to August is significantly correlated with upland rice yields (Fig. 4).

Soil fertility. Relatively little research has been done on the soil fertility status of upland soils. Soil nutrient deficiencies of 10 soils (from Pak Ou District, Luang Prabang) were measured in a pot study. Results show that nitrogen (N) and phosphorus (P) were deficient in all soils, potassium (K) in 50% of the soils, and sulfur (S) in 80% of the soils (Table 1). When P was not added, biomass decreased the most (only 29% compared to when all nutrients were added). K was only marginally limiting as average yields decreased to only 83% when K was not added.

From 1991 to 2003, 26 fertilizer trials were conducted in upland rice fields. Only 7 of the trials resulted in a significant grain yield response to applied fertilizer (Table 2). In all cases where there was a significant yield response, the response was

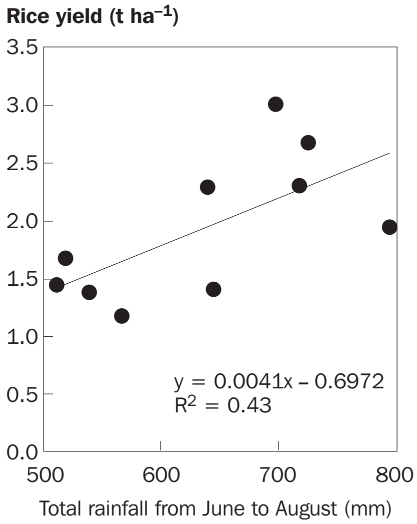

Fig. 4. Upland rice grain yield in relation to total June to August rainfall at Houay Khot, Luang Prabang. Data are from 1992-2003; however, in two years, rainfall data were not available.

Table 1. Relative biomass of rice grown in soils (from five villages in Pak Ou District) in response to different nutrients. "All" indicates the addition of all nutrients to the pots, whereas the other pots had all nutrients minus N, P, K, or S. Fallow length and soil parameters are provided for each site.

Relative biomass response to nutrients						Site and soil (0–15 cm) parameters				
Village/site	All	–N	–P	–K	–S	Fallow (years)	Total N (%)	Organic C (%)	Bray P (mg kg–1)	pH
HS-1	100	31	29	89	54	2	0.22	2.13	5.77	5.95
HS-2	100	57	32	96	45	4	0.23	2.48	4.30	5.97
HS-3	100	54	41	99	60	7	0.19	1.91	5.47	5.03
HS-4	100	62	28	76	76	9	0.20	2.13	4.53	4.75
HL-1	100	25	35	70	29	7	0.22	2.17	4.60	5.81
HL-2	100	51	18	76	72	5	0.26	2.56	2.23	4.80
PC-1	100	26	35	70	32	3	0.17	1.65	3.95	6.04
PC-2	100	28	31	81	31	59	0.17	1.84	3.90	5.85
MM-1	100	58	21	87	86	6	0.28	3.11	3.13	4.74
MM-2	100	63	16	89	92	?	0.27	2.96	5.35	4.52
Mean	100	46	29	83	58					
% sites deficient		100	100	50	80					

Table 2. Summary of fertilizer trials conducted on upland rice from 1994 to 2003.

Fertilizer applied (kg ha^{-1})			Number of sites tested	Sites with significant yield response	Comments
N	P	K			
30	0	0	18	3	–
30	20	0	2	0	–
40	30	0	2	2	N increased yields at both locations. P had no effect on yields at either location.
0	20	20	1	0	–
100	50	50	3	2	When NPK was added, yields doubled at two sites (no response at one site). No significant response to P applied alone.

to N (applied either alone or with P and K). There was never a response to P applied alone for several possible reasons:

1. The application rates were too low to observe a response given the high field variability. Where N rates were only 30 kg ha^{-1}, a yield response occurred at only 15% of the sites. In contrast, when N rates were 40 kg ha^{-1} or higher, the yield response was significant at 57% of the sites. In fact, where 100 kg N ha^{-1} (+P) was applied, yields doubled at two of the three locations (the site where there was no response had been in a 15-year fallow and soil fertility would have been high).
2. In most cases (70%), N was applied alone. It is possible that at some sites P would be limiting and there would not be a response to N unless P were also applied.
3. Traditional varieties were used in all cases. Traditional varieties are usually not highly responsive to fertilizer.
4. Fertilizer uptake may have been low due to runoff.

In summary, upland soils are deficient in N and P. Fertilizer responses would have been more visible in the field if higher rates were used, both N and P applied, and responsive varieties used. Such nutrient deficiencies are expected in soils, especially under short fallows. Soil fertility needs to be managed in a sustainable and economically viable manner. These issues will be discussed below.

Pests and diseases. The main upland rice pest mentioned by farmers is rodents. Rodents and their management are discussed separately in Chapter 19.

White grub (scarab beetle) is the main insect pest to upland rice. It has a one-year life cycle. During the dry season, adults live 1 to 2 m underground. With the onset of rains, adults emerge, flying to nearby trees in search of food and mates. Eggs are laid about the time farmers plant rice. The larvae eat living roots of plants (including rice). White grub damage is most severe in dry years as the white grub may largely denude the rice crop's root system.

Studies monitoring white grub in Luang Prabang and Oudomxay at weekly intervals indicate that the damage increased until about 6 to 8 weeks after planting, after which it declined. In these studies, up to 50% of the hills were damaged by white grub but the number of damaged tillers was relatively low (less than 25%). No studies have evaluated yield loss due to white grub or white grub control.

While these are the most common pests and diseases identified by farmers, nematodes and root aphids may be problems, especially in intensive cropping systems. Some diseases that occur are blast, leaf scald, and brown spot. Again, these diseases are more typically found under more intensive systems with which most farmers are not yet familiar.

Development of alternative systems

These issues have created a demand from farmers and government agencies for alternative agricultural solutions. Such technologies have not been adequately introduced along with land allocation. Solutions can focus on (1) improved rice production systems or (2) developing alternative cash crops that allow for income generation and cash to buy rice. Experiences from other Asian countries suggest that farmers are much more likely to diversify into other crops once they have achieved self-sufficiency in rice. Thus, rice sufficiency is a platform for diversification. Lao-IRRI and NAFRI have been working together to develop sustainable rice-based systems for the Lao highlands since 1991. Research has focused on improving both upland rice and highland paddy systems. In this chapter, upland rice systems are discussed while highland paddies are covered in Chapter 25.

As agricultural systems intensify, traditional slash-and-burn systems with forest fallows are replaced by annual cropping systems (Fig. 5). Agricultural intensification generally results in the intensification of land use and labor. In Laos, traditional upland rice production practices have not changed despite shorter fallows. Research is being conducted to identify improved cropping systems that are sustainable under the current land-use practices, thus focusing on systems with zero (annual cropping) to 2- or 3-year fallows. A multifaceted research approach is used that combines the development of suitable varieties with alternative rice-based cropping systems (Fig. 5).

Improved short-fallow systems

Varieties. Traditional upland rice varieties are grown extensively in the Lao uplands; in fact, no known improved upland varieties are being grown. The diversity of varieties is high, with most villages growing 10 to 20 different varieties and a single farmer growing, on average, two or three varieties. These varieties have been selected for long-fallow conditions and are usually not suited to the short fallows that many farmers are currently using.

Since 1991, the Lao-IRRI Project has been collecting and preserving traditional Lao varieties. The Lao gene bank currently has over 13,000 accessions, with about half being upland rice varieties (Chapter 9). These varieties are being screened to identify

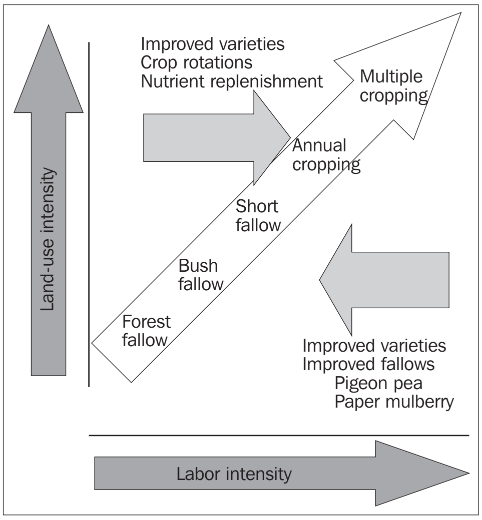

Fig. 5. Pathways for the intensification of shifting cultivation (after Raintree and Warner 1986). Research areas are highlighted.

early and medium-duration varieties that perform better under short fallows. Final testing and evaluation of varieties are done through participatory variety selection (PVS) trials under farmer management and have been conducted in all the northern provinces. Final selection of varieties is based on farmer preference and yield. Currently, two glutinous upland rice varieties have been identified that yield 0.3 to 0.5 t ha^{-1} more than local check varieties (an 18–27% increase in yield) (Fig. 6). Nok is an early-duration variety that has good yield and receives high farmer preference ratings because of its large seeds and panicles, ability to perform in poor soils, and high quality (aroma and softness). Makhinsoung is a medium-duration variety that also receives high farmer preference ratings, but its grain quality is lower than Nok's.

While most of the research has focused on glutinous rice, the program has started evaluating nonglutinous varieties that are preferred by certain ethnic groups (i.e., the Hmong and Aka). These varieties originate from Laos and other countries. On-farm testing began in 2003.

Cropping systems. In slash-and-burn systems, fallows provide several important functions, which include the following. First, they allow time for nutrients to be replenished in the soil. Nutrients are added to the system through nitrogen (N) fixation, rainfall, leaf litter, and exploitation of deep soil layers by deep-rooted plants. Second, weeds are reduced. Under long-fallow systems, annual weeds die out and are replaced by perennial weeds, which are much easier to control. Third, biomass builds up. High biomass generally (not always) means more nutrients but also more biomass to burn. A hot burn kills many weed seeds. Finally, pest cycles are broken.

Two-year weedy fallows are not sustainable under current management practices and improved systems will require some form of fallow enrichment. Since N is gener-

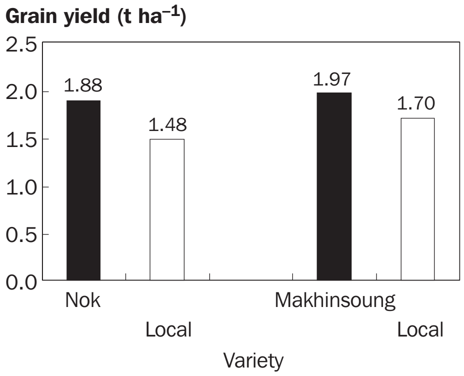

Fig. 6. Grain yields of Nok and Makhinsoung compared with those of local check varieties. Data are over 5 years and represent more than 25 locations in most provinces of northern Laos.

ally the most limiting nutrient, shrubby legumes are often used for fallow enrichment. These legumes not only add N to the system (through N fixation), but many are deep rooting and are able to extract nutrients from soil layers that rice cannot. Through leaf fall, these nutrients are moved to the soil surface, where rice and other crops can use them. Many shrubby legumes also grow fast and can develop a high amount of biomass in a relatively short period of time.

Through on-station research conducted from 1991 to 2000, four promising fallow species emerged: leucaena (*Leucaena leucocephala*), pigeon pea (*Cajanus cajan*), paper mulberry (*Brousonnetia papyrifera*), and crotalaria (*Crotalaria anagyroides*). All are legumes except paper mulberry, which is an indigenous fallow in northern Laos. The system involves establishing the species with rice in the first year. Following the rice harvest, the species are left to grow as a 2- or 3-year fallow, after which, they will be cut, burned, and planted to upland rice again. Through participatory on-farm research with these species, farmers preferred paper mulberry and pigeon pea as potential fallow species. Based on further discussions with farmers, the requirements of a good fallow or rotational species are that it

- provides some economic benefit,
- is easy to grow and maintain,
- needs minimum labor, and
- maintains or improves rice yields.

The challenge for research is to not only identify such species but ones that also address the long-term challenge of sustainability so that yields are maintained, soil fertility is replenished, weeds remain under control, and soil erosion decreases. The two most promising systems (paper mulberry and pigeon pea) are discussed separately below.

Table 3. Effect of rotational crops on rice yields, weeds, nematode infestation, and soil parameters. From a three-year study at Houay Khot, Luang Prabang. Rice was grown in all treatments in the 1st and 3rd years. In the 2nd year, different crops were grown.

Rotational crop	Rice yield (t ha^{-1})			3rd-year observations				
	1st y (t ha^{-1})	2nd y	3rd y (t ha^{-1})	Weeds (fresh wt.) (t ha^{-1})	Nematodes (# g^{-1} root)	Soil pH	Soil Total N (%)	Soil Olsen P (mg kg^{-1})
Continuous rice	3.4	1.8	1.3	5.1	63	6.3	0.26	5.2
Pigeon pea	3.3	–	2.3	3.2	13	6.5	0.28	7.0
Cowpea	3.4	–	1.6	5.2	33	–	–	–
Stylo	3.2	–	1.8	3.3	21	–	–	–
Maize	3.5	–	1.8	3.3	10	6.3	0.24	4.6
Natural fallow	3.2	–	2.2	4.9	2	6.0	0.25	5.8
LSD (5%)	ns		0.5	1.4	33	ns	ns	2.0

Source: Roder et al (1998).

Rice-pigeon pea. Pigeon pea is one of the most promising crops for rotation with rice. The rice-pigeon pea system is as follows: pigeon pea is planted with rice in the first year (Photo 24.1). Pigeon pea will continue to grow after the rice has been harvested. Pigeon pea is a perennial and pods can be harvested once a year—usually in March and April for the local varieties. The pigeon pea remains in the field (it can survive for 2 to 3 years) until the field is ready to be prepared for the next rice crop and then is cut. When planting the next rice crop, pigeon pea will need to be planted again.

Roder et al (1998) provided a review of the pigeon pea research conducted in Laos through 1996. Research included pigeon pea variety evaluation and evaluation of pigeon pea as an improved fallow. In summary, local pigeon pea varieties were well suited for use as a fallow crop. Improved varieties yielded higher but local varieties performed better in terms of total biomass production and weed suppression. Compared with other potential rotational crops, pigeon pea was also better. In a 3-year crop rotation trial, it was reported that rice yields were higher following pigeon pea (Table 3). Furthermore, pigeon pea decreased weeds and nematodes in rice and increased available soil P. These results were supported by another study that compared 1-year fallows of pigeon pea and leucaena with natural fallow and continuous rice. After the third year, rice yields (rice yields are generally low because of drought) were highest following the pigeon pea fallow (Fig. 7).

Two main problems with using pigeon pea as a fallow crop for rice were mentioned by Roder et al (1998). First, 15 months after planting, only 9% of the pigeon pea survived (despite it being a perennial) because of weed suppression. Second, upland rice yields were up to 60% lower when rice was grown with pigeon pea. Recent research on pigeon pea has focused on trying to solve these problems. Findings suggest that

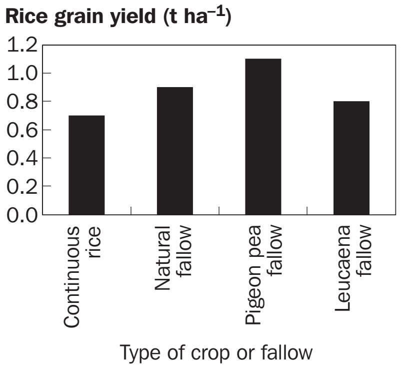

Fig. 7. Rice grain yields in the third year following either continuous cropping or different types of fallow. Pigeon pea and leucaena were planted with rice during the first crop at a spacing of 1.25 × 1.25 m. In the third crop, leucaena was cut and allowed to recopice and pigeon pea was cut and replanted.

using a low pigeon pea density (1.25 × 1.25 m) in combination with delayed planting (planting pigeon pea 3 weeks after rice) results in good pigeon pea growth and does not reduce rice yields. Roder et al (1998) used close plant spacing (1.0 × 0.25 m) and often planted at the same time. Furthermore, using wide pigeon pea spacing appears to increase pigeon pea vigor. In one study conducted in nine farmers' fields, pigeon pea was planted at 1.25 × 1.25 m spacing and 78% of the pigeon pea was still surviving 18 months after planting. Wider spacing is likely to reduce grain yields. When plants are planted close together, grain yields for local varieties averaged over 1 t ha^{-1}, compared with about 0.5 t ha^{-1} with wide plant spacing.

Despite its promise as a fallow crop, farmers have been slow to adopt because of the limited market potential of pigeon pea in Laos. In 2003, when a market was available, farmers showed considerable interested in the system. Economically, it appears to be a viable option. In the first year, rice yields are the same as without pigeon pea. Assuming a 0.5 t ha^{-1} pigeon pea yield at US$0.16 kg^{-1} (the price being offered in 2004), a farmer can expect to receive $80 from the pigeon pea in the first year, more than a 25% increase in average household income. This figure does not take into account the second-year pigeon pea harvest (a second-year harvest is possible but yields are lower), a yield increase of rice following a pigeon pea fallow, and reduced weeding requirement after pigeon pea. From the labor standpoint, pigeon pea is also attractive. Planting at a wide spacing requires little labor (about 1 person-day) and seed (4 kg ha^{-1}). No additional labor is required until harvest. Although the harvest requires a significant amount of labor, demands on labor are low during March and April.

Table 4. Survival and growth of different paper mulberry planting materials established in upland rice and yield of upland rice.

Planting material	Survival at end of first wet season (%)	Paper mulberry height (cm)	Rice yield (t ha^{-1})
Seedling	80	139	2.13
Root sucker	42	85	2.05
Root cutting	5	51	2.13

Evaluation of a pigeon pea-rice rotation is continuing, with research focusing on different fallow lengths. Different varieties are also being evaluated, with special attention being given to pod borer resistance. Pod borer insects bore into pigeon pea pods and can significantly reduce yields.

Rice-paper mulberry rotations. Paper mulberry has become an important cash crop in northern Laos. The inner bark is harvested and used for paper production. Paper mulberry is an indigenous fallow species and research has focused on the feasibility of intensifying paper mulberry as a rotational crop between rice crops (Photo 24.2). After establishing paper mulberry into upland rice, it will continue to grow after the rice has been harvested. The paper mulberry is harvested 1.5 to 2 years after establishment and harvesting can continue until the next rice crop, at which time all the paper mulberry is harvested and the trees cut down in order to prepare the field for rice. The paper mulberry will regenerate from roots and stems during the rice-growing season to continue the next cycle. Research on rice-paper mulberry rotations has focused on the following aspects:

1. Paper mulberry establishment into upland rice fields: Three planting materials were tested (seedlings in polybags, root suckers, and root cuttings). Survival and growth were best for the seedlings, followed by root suckers (Table 4). In all cases, paper mulberry growth was slow during the first year of establishment and did not reduce rice yields. However, because of slow initial growth, weeding is still necessary after the rice harvest until the paper mulberry has become fully established.
2. Rice production following paper mulberry: When paper mulberry regenerates from its roots and stems, it is highly competitive with rice (unlike the establishment phase). To sustain rice yield, the regenerated paper mulberry needs to be managed carefully by maintaining a low density and a canopy that is below the rice. Densities of more than 1 plant 4 m^{-2} have been shown to reduce rice yields (Fig. 8).
3. Nutrient cycling: Research is ongoing to study nutrient cycling in these systems to determine whether such systems are sustainable in terms of maintaining or building soil fertility.
4. Models are being developed to estimate paper mulberry bark yield.

Although this system is indigenous to Laos, few farmers have intensified the system by planting and closely managing paper mulberry. As long as the market remains

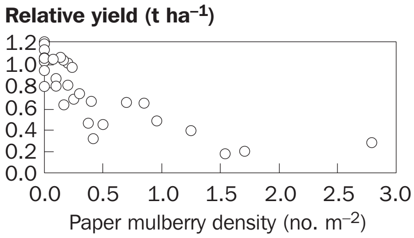

Fig. 8. Relative yield of rice at varying densities of paper mulberry.

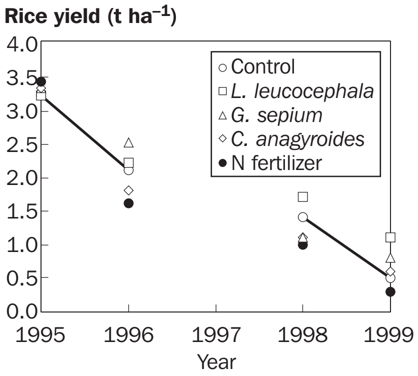

Fig. 9. Rice yields during a 5-year cropping period with different shrubby legumes planted with rice. Legumes were planted in hedgerows at 1.5-m spacing with 4 rows of rice grown in between. In 1997, rice was planted but no rice harvest data were available.

good for paper mulberry, this system has potential. It is also attractive in that most of the labor requirement for paper mulberry is during periods when labor demand is low. The main limitation is that cattle and buffaloes graze on paper mulberry leaves, so the area needs to be protected.

Alternatives for annual cropping

Annual cropping, as referred to here, is the yearly production of annual crops on a given plot of land. Developing improved annual upland rice-based systems presents a unique challenge compared to other cereal crops. Yields decline rapidly when rice is continuously cropped. In a 5-year experiment conducted in Luang Prabang, upland rice yields declined from more than 3 t ha^{-1} to 0.5 t ha^{-1} when rice was grown every year (Fig. 9). Such results are seen elsewhere in Laos (Table 3, Fig. 7), Asia (George et al 2001), and South America (Evenson et al 1995, Sanchez 1983). The reasons

Table 5. Comparison of variety performance under continuous rice cropping. At all sites, rice had been grown every year for at leas the previous two years.

Variety	Houay Khot	Tinpha (kg ha^{-1})	Long Lao	Variety mean
Chao Mat	2,430	1,565	1,925	1,973
Laboun	1,406	604	1,034	1,015
MHS	1,404	459	337	733
Nok	965	367	729	687
Vieng	959	240	169	456
ANOVA ($P<0.05$)	0.0001	0.0000	0.0000	

for this yield decline are not well understood, but research suggests that soil fertility decline is not solely responsible. Yields declined when N fertilizer (30 kg N ha^{-1} at booting) was applied or when rice was grown between legume hedgerows (Fig. 9). Results of other studies also indicate that nutrient limitations (including phosphorus) are not responsible for the rapid yield declines observed when rice is grown continuously (George et al 2002, Evenson et al 1995, Sanchez 1983). Increased weed pressure associated with successively cropped fields may be a cause of declining rice yields; however, it is probably not the sole cause. Even when weeds are well controlled (as in the experiments above), rice yields continue to decline. Some evidence suggests that the nematode *Meloidogyne graminicola* is a factor (Prot and Matias 1995). Indeed, nematode numbers and nematode infected roots are higher in successively planted rice (Table 3). Although the cause of the yield decline is not clear, it may be a combination of the above factors. Current research is focusing on understanding the cause as well as developing sustainable upland rice-based systems.

Varieties. There has been limited research testing varieties in continuous upland cropping systems. However, some varieties seem to do better than others when continuously cropped. In an experiment conducted in Luang Prabang in 2002 in a field in its third rice cropping cycle, several varieties produced yields from 1.4 to 2.0 t ha^{-1}, whereas the rest yielded 0.5 t ha^{-1} or less. In 2004, this work was continued at three sites that had been continuously cropped with upland rice for at least the previous 2 years. Five varieties were compared: Chao Mat, Laboun, Nok, Makhinsoung, and Vieng. Nok and Makhinsoung were two promising varieties for short-fallow systems and Vieng is a popular local variety in the Luang Prabang area. Across sites, Chao Mat (a nonglutinous variety) yielded 2.0 t ha^{-1}, which is above the national average for upland rice (Photo 24.3) (Table 5). Laboun, a glutinous upland variety from Savannakhet, yielded 1.0 t ha^{-1}. Vieng, the local variety, yielded less than 0.5 t ha^{-1}, whereas Nok and Makhinsoung yielded about 0.7 t ha^{-1}. These data clearly show that certain varieties perform better under intensive annual cropping systems. Nok and Makhinsoung, which are good varieties for short-fallow systems, do not perform well under intensive continuously cropped rice systems. It is not clear why some varieties perform well under these situations and others do not, but this is currently being investigated.

Improved varieties will be an important component of annual cropping systems; however, they will need to be integrated into appropriate cropping systems.

Cropping systems. Little research has been conducted on intensively cropped annual upland rice systems. Based on the research conducted, the following points can be made.

Crop rotations. Rotation with other crops will be necessary for sustainable systems; however, research to date to identify suitable rotational crops is not promising. Rice yields continued to decline when cowpea, maize, and stylo were used as rotational crops (Table 3). The most promising species has been pigeon pea (Table 3, Fig. 7), which can be grown as a perennial or an annual. Research is ongoing to study the potential of rice and pigeon pea in more intensive annual systems. Pigeon pea is not a host for nematodes (Roder et al 1998) and, if planted properly, can limit the growth of other weeds that may be alternative hosts for nematodes.

Nutrient replenishment is necessary. Nutrient replenishment will be necessary in any intensive cropping system where crop products are removed annually. In slash-and-burn systems, long fallows allow for natural soil rejuvenation. In annual systems, such enrichment can come from crops being rotated with rice (such as cover crops, green manures, or hedgerows) or from fertilizers. These are discussed separately below.

Nutrient replenishment from companion crops. Hedgerows are often promoted as a good source of nutrients for annual crops grown between alleys. A study was conducted in Luang Prabang to evaluate the growth of rice between different hedgerow species (leucaena, crotalaria, or glircidia). In all cases, rice yields declined (Fig. 9). Rice is currently being evaluated in a system where it is grown between stylo that is planted along the contour lines (Photo 24.4). Stylo could potentially be used as a forage for livestock or could be cut and left in the field. As discussed earlier, nutrient limitations do not seem to be the cause for the yield decline. However, if suitable crop rotations and varieties are used between the hedgerows, rice may grow better and the hedgerows may provide a valuable source of plant nutrients.

Cover crops are another option to be considered for upland rice. Again, little research has been done on the topic but there are several considerations. First, care must be taken that the cover crop does not compete for water, light, and nutrients with the rice. Cover crops have been most successful in areas with long wet seasons. In northern Laos, the wet season is short and rainfall is variable. Crops that offer the most promise in these conditions are those that can be established into rice late in the growing season and then become a dry-season fallow crop. Second, as mentioned above for the alternative fallow crops, farmers are not likely to grow a crop that does not itself provide some form of economic benefit. Finally, if the cover crops require a lot of labor to establish, manage, and harvest, many farmers may not be interested. For most farmers, labor is too limiting to spend growing a crop that cannot be harvested.

Scope for fertilizers. Farmers will unlikely apply fertilizers to upland rice in the near future for at least three reasons.

1. Varieties currently being used are traditional and have limited response to fertilizer. As discussed above, fertilizer trials to date have shown only a small response.
2. Fertilizer application is labor-intensive. Dibbling fertilizer (as opposed to broadcasting) may be necessary to prevent fertilizer runoff, especially on steep slopes. Dibbling requires significant labor. Furthermore, many fields are located a long way from the village and are accessible only by foot, making it difficult to get the fertilizer to the field.
3. Fertilizer application is risky. Even if the response to fertilizer is good, uncontrollable factors such as drought and pests can reduce yields, making the fertilizer application a waste.

Conclusions

Declining upland rice yields as a result of increased land pressure are resulting in rice deficits and poverty in northern Laos. The diversity and complexity of the uplands requires an integrated and participatory research approach to identify suitable and sustainable cropping systems. Although alternatives to upland rice can be developed, it has been our and others' experience that farmers prefer to grow at least a portion of their rice needs. Once rice security is assured, farmers are much more willing to test alternatives. In this paper, we have discussed some potential technology options that can maintain or increase upland rice yields in these systems. Given the diversity and complexity of the uplands, these alternatives have limited recommendation domains and may not be suitable for all upland rice-growing areas in Laos. Ongoing upland rice research will continue to be necessary to continue to meet the challenges faced by upland farmers.

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Notes

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CHAPTER 25

Montane paddy rice: opportunities for increasing food security in the highlands of Laos

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Laos is the most mountainous country in Southeast Asia, with 35% of the area having slopes of 8–30% and 54% of the area having slopes of greater than 30% (FAO). The main mountainous areas are in the north (the focus of this chapter) and along the Lao-Vietnamese border. Lowland rice (paddy) is grown in the highlands either in flat valley bottoms or on terraced hillsides (see Chapter 3 for a description) and in this chapter will be referred to as “montane paddy.” Food security is a problem in the highlands (ADB 2001) and increasing paddy productivity or expanding paddy area are two options for improving food security there.

Northern Laos has some extensive valleys such as those found in the provinces of Sayabouly and Luang Namtha, where lowland rice production is basically similar to that of the large plains in the southern and central agricultural regions of the country. Large irrigation schemes have been developed and the livelihood of farmers centers on lowland rice production. Extensive lowland areas are limited in the north, and in most areas farmers rely on their upland fields to grow upland rice and other rainfed upland crops. However, in many of these “upland” villages (villages normally have 35 to 100 households), there are small areas of paddy land ranging from less than 1 ha to about 10 ha (Photo 25.1).

This chapter is divided into four sections. In the first, the expansion of highland paddy area and the driving forces behind paddy expansion are discussed. The effects of montane paddy on food security and farmer livelihoods is discussed in the second, while the third presents a cost-benefit analysis of paddy development. The fourth section covers the research issues being examined and related progress.

In the first three sections, the report of Trösch (2003) is referred to extensively. In 2003, Trösch conducted a survey to better understand the role of paddy in the livelihoods of highland farmers. The survey was conducted in three districts (Phonsay, Pak Ou, and Namo) in the provinces of Luang Prabang and Oudomxay, and included 93 households in 9 villages (Table 1). Households with and without lowland paddy were selected in each village. The total lowland area per village ranged from 0.2 to 22 ha. The percentage of households owning lowland rice fields averaged 35%, and ranged from 2% (Houay Thoum in Pak Ou) to 89% (Namo Neau and Pangdou Tai in Namo). The average area of paddy (for those farmers with paddy) in each village

Table 1. Overview of lowland holdings in the nine villages surveyed in 2003.

Province (district)	Village (no. of households)	Lowland area (ha)	Households with lowland rice	Average size of lowland holding (ha)	Lowland area for each village household (ha)
Luang Prabang (Phonsay)	Huayman (48)	2.25	5	0.45	0.05
	Thapho (57)	6.3	13	0.48	0.11
Oudomxay (Namo)	Namo Neau (56)	22.12	50	0.44	0.39
	Pangdou Tai (18)	8.75	16	0.55	0.49
Luang Prabang (Pak Ou)	Hatsua (56)	3.64	5	0.73	0.07
	Haouyleaung (63)	12.6	20	0.63	0.20
	Haouythum (41)	0.2	1	0.20	0.005
	Latthahae (109)	16.73	28	0.60	0.15
	Packaek (125)	30	49	0.61	0.24

Source: Trösch (2003).

Table 2. Resource allocation in relation to area (ha) of lowland owned.

Lowland ownership category	Total land resources available[a] (ha)	Average amount of lowland (ha)	Average amount of upland[a] (ha)	Percentage of upland area used for upland rice
None	1.39	0	1.39	69
> 0 and < 1 ha	1.44	0.46	0.98	68
> 1 ha	2.41	1.55	0.86	38

[a]Does not include fallow fields.
Source: Trösch (2003).

ranged from 0.2 ha in Houay Thoum to 0.73 ha in Hatsua. With the exception of one farmer, all households surveyed owned upland fields. For the purpose of analysis, the households were divided into three categories based on how much lowland they owned: (1) those that had no lowland (n = 54), (2) those that owned less than 1 ha of lowland (n = 29), and (3) those that owned more than 1 ha of lowland (n = 10). Total land resources (not including fallow upland areas) were similar for households with little or no paddy area. Those with a small amount of paddy also had less upland area (Table 2). Households with more than 1 ha of lowland had less upland area than other households, but their total land resource of 2.4 ha was, on average, 1 ha more than for the other categories.

Table 3. Wet-season lowland rice area (000 ha) by province in the northern region of Laos.

Year	Bokeo	Houaphanh	Luang Prabang	Luang Namtha	Oudomxay	Phongsaly	Sayabouly	Northern region
1991	4.29	6.83	7.97	2.03	12.50	4.85	9.08	47.55
1992	4.88	7.21	7.73	2.54	5.04	4.75	11.94	44.08
1993	6.08	6.54	8.64	5.01	6.83	4.85	9.28	47.24
1994	6.45	7.55	8.77	5.15	7.01	4.69	13.96	53.58
1995	7.08	8.29	8.21	5.80	7.52	5.31	17.99	60.21
1996	6.88	9.61	9.13	7.21	8.25	5.63	19.43	66.14
1997	8.50	10.23	9.37	7.00	8.69	5.70	17.79	67.28
1998	9.15	9.52	9.53	7.07	7.82	5.72	20.25	69.05
1999	9.78	11.29	9.68	7.49	8.73	5.75	20.33	73.03
2000	10.20	11.40	9.80	7.90	9.20	5.40	21.50	75.40
2001	10.37	11.54	10.26	10.29	9.77	5.79	21.67	79.69
2002	11.53	11.47	10.67	10.74	9.81	4.94	21.62	80.77

Paddy development in Northern Laos

Expansion of the montane paddy area

In the northern region, the province of Sayabouly has the largest lowland paddy area (over 22,800 ha in 2002), with all of the other northern provinces having from 10,500 to 13,000 ha, with the exception of the most northerly province of Phongsaly, which has only 5,000 ha (Table 3). The lowland area in the north expanded steadily during the 1990s, a process that continues to the present day. In 1991, the total area of rainfed lowlands in the northern region was 47,000 ha; by 2002, it had increased to nearly 81,000 ha—an increase of almost 70% (Table 3 and Fig. 1). This 6% annual increase in lowland paddy area in the north was considerably higher than for the country as a whole (3.7% per year). There has also been an increase in the dry-season (irrigated) paddy area in the north. Until 1994, the total dry-season lowland rice area remained below 2,000 ha; however, from 1995 to 2000 this area expanded to almost 8,000 ha (Fig. 1), but since then has stabilized at 6,000 ha. The greatest expansion of lowland rice area in the north has been in the provinces of Bokeo, Luang Namtha, and Sayabouly, all of which have relatively large flat areas that are easy to convert to paddy cultivation. However, the expansion has not been confined to these provinces. Trösch (2003) reported that in the nine "upland" villages covered by her survey, lowland area increased only a little from 1962 to 1998; however, from 1998 to 2002, the total area of lowland paddy increased from an average of 3.5 ha per village to more than 12 ha per village (Fig. 2). Although the growth rate was not uniform between villages, all villages expanded their lowland rice area to some degree after 1992.

Why farmers have expanded their lowland paddy area

Three policy initiatives may have either directly or indirectly supported the expansion of rice paddy in the north. First, the government provides an exemption from the payment of land tax for the first three years after construction of lowland terraces. This

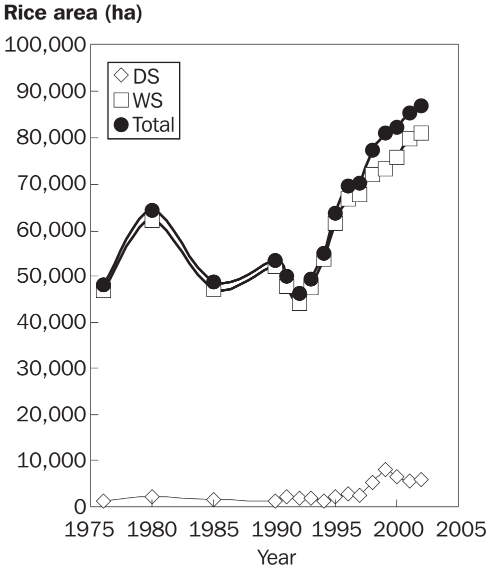

Fig. 1. Wet-season (WS) and dry-season (DS) lowland rice area in the northern region of Laos from 1976 to 2002.

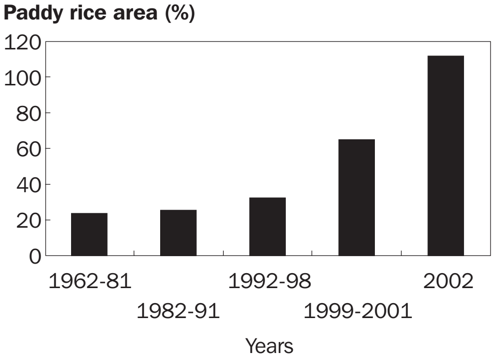

Fig. 2. Changes in rice paddy area from 1962 to 2002. Data adapted from Trösch (2003) and from a survey conducted in 9 upland villages (Luang Prabang Province: Phonsay and Pak Ou districts; Oudomxay Province: Namo District) and each had at least some paddy land.

Table 4. Reasons why farmers develop lowland fields.[a]

Reasons	Percentage of respondents
Lowland rice production requires less labor input than upland rice production (higher productivity) and so there is more time for other activities	25
Response to the government policy of stopping slash-and-burn shifting cultivation	21
Higher yields and higher yield stability (=> higher food security) than in upland rice cultivation	11
Farmer has had appropriate land for lowland cultivation	11
Farmer does not like shifting rice cultivation	11
Parents of the farmer already cultivated lowland rice	7
Time period in which lowland rice cultivation is labor-intensive is shorter than in uplands	7
Lowland rice cultivation has a higher sustainability than upland rice cultivation	4
Farmer does not have enough satisfactory fertile upland area since land allocation	4

[a]Responses are from 28 farmers who owned at least some lowland rice fields (Trösch 2003).

exemption amounts to about 12,000 kip per ha per year (about US$1.20 in 2004). Second, the Agricultural Promotion Bank of Laos (APB) provides credit to farmers interested in developing paddy land. The extent to which these initiatives have contributed to the rapid expansion of the lowland rice area in the north during the 1990s is unclear; however, it is generally acknowledged that these tax and credit incentives have probably not been the major incentive in influencing the decision of farmers to expand their paddy area (Trösch 2003).

The main policy initiative that seems to have encouraged the expansion of lowland paddy area in the north is that of land allocation. Although the objective of land allocation is to stop slash-and-burn agriculture in upland fields, the immediate effect has been to shorten fallows to only two or three years. Such short fallows are unsustainable and the declining upland rice yields in areas covered by the land allocation program have forced farmers to seek alternative production systems. One option available to farmers has been the expansion of lowland paddy area. Trösch (2003) reported that stopping shifting cultivation in response to the land allocation program, associated with the limited area of fertile land available under the land allocation policies, was one of the main factors influencing farmers' decisions to develop lowland paddy area (Table 4). Data showing the rapid expansion of the paddy area in the late 1990s (after land allocation) also support this consensus (Fig. 2).

Farmers also mention two other reasons for wanting to develop lowland paddy area (Table 4). First, lowland rice production requires considerably less labor input than upland rice cultivation. Roder (2001) reports that the labor input for upland rice cultivation in northern Laos averages almost 300 person-days per year (of which about

Table 5. Number of years of rice shortage according to land ownership.

Years of rice shortage	No. of respondents	Average rice area (ha)	
		Lowland	Upland
0	37	0.54	0.89
1–4	44	0.18	0.74
5–10	12	0.11	0.75

Source: Trösch (2003).

50% is for weed control) compared with about 120-person days per year for lowland rice. The labor saving with the move to lowland rice cultivation allows households to spend more time raising livestock and, to a lesser extent, cultivating alternative cash crops. The second major reason for farmers wanting to expand their lowland paddy area (cited by about 15% of the respondents) is the higher yield and increased sustainability from lowland rice cultivation relative to upland cultivation. Average upland rice yields are 1.5 and 2.0 t ha^{-1}, depending on length of fallow, rainfall, weed competition, etc. Montane lowland rice yields are generally from 3 to 4 t ha^{-1}, and are much more stable than upland yields because water shortages during the cropping season are less of a problem. Furthermore, in areas with access to water during the dry season, there is potential for two rice crops a year.

The main constraints cited by farmers to developing lowland paddies are a lack of suitable land for such development, the steepness of slopes, poor soils, and a lack of water (Trösch 2003).

Effects of paddy land ownership on food security and livelihoods

In discussing rice self-sufficiency, it is recognized that farming households also consume other crops such as maize and root crops (such as cassava) when rice supplies are inadequate. Depending on the household, rice consumption needs may come from upland and/or lowland rice fields. The amount of lowland owned had a direct effect on the food security of individual households. In a survey of Trösch (2003), households with an average lowland rice area of 0.54 ha experienced no rice shortages in the last 10 years, whereas households with an average lowland area of 0.18 ha had between 1 and 4 years with rice shortages; households with an average of 0.11 ha of lowland experienced rice shortages in 5 to 10 of the years (Table 5). These results are similar to those reported for northern Vietnam (Pandey and Minh 1998), where farmers with an average lowland holding size of 309 m^2 per capita experienced only one year or no food shortages in the previous 10-ten year period; however, if the average per capita holding was 154 m^2, they reported rice shortages almost every year.

In the Lao survey of Trösch (2003), farmers reported that, if they have lowland rice fields, in addition to improving their food security, they are able to grow more

Table 6. Effects on livelihood activities of a shift from upland rice to lowland rice cultivation.[a]

Effects	Percentage of respondents
More cash crops are grown	24
Better food security	19
Increased livestock production and fish farming	19
Stopped upland rice cultivation	16
More time for trading	11
Expansion of paper mulberry plantation	8
More time for working as wage labor	3

[a] Responses are from 37 farmers who owned at least some lowland rice area (Trösch 2003).

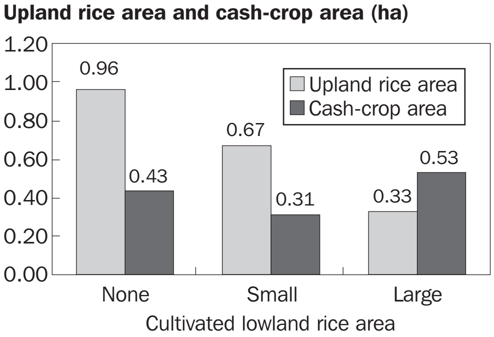

Fig. 3. Upland area used for upland rice and cash crops based on amount of lowland a household cultivates.

cash crops in their upland fields and allocate more time to raising livestock and trading (Table 6). Furthermore, 16% of the respondents reported being able to cease slash-and-burn agricultural practices. In general, the detailed household economic data support these reports. Households that had more than 1 ha of lowland used less than 40% of their upland holdings for rice production; the rest was used for cash crops and gardens (upland farmers refer to a garden as any field that is continuously cropped, i.e., Job's tear garden, teak tree garden, etc.) (Fig. 3). Households with little or no lowland area grew upland rice on almost 70% of their upland fields. Several reasons are possible for farmers in all lowland ownership categories continuing to cultivate upland rice. The main reason is to meet their household consumption needs. This is almost certainly the case for households with a small lowland area. Second, upland rice is usually harvested about one month earlier than lowland rice. Therefore, the cultivation of upland rice provides a supply of rice at a time when household rice stocks

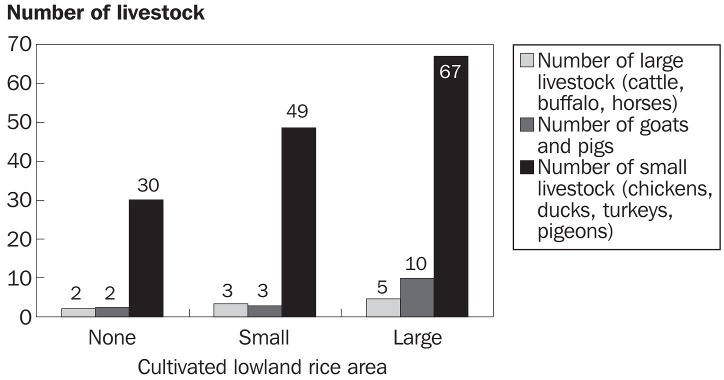

Fig. 4. Average number of livestock being raised by farmers with differing amounts of lowland rice area.

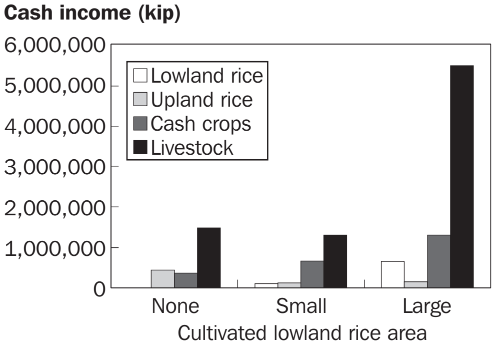

Fig. 5. Average cash income by source shown by the cultivated lowland rice area. This calculation includes only sold products. Small lowland area = >0 and <1 ha, large lowland area = ^{3}1 ha. US$1 = 10,560 kip.

have usually been depleted, as well as allowing farmers to spread labor demand during the period of the rice harvest. Third, upland rice is generally considered to be of higher quality than lowland rice, taste better, and, when sold, retail at a higher market price than lowland rice. Finally, upland rice is a good cash crop. Upland rice prices are stable and farmers are familiar with the crop. Other cash crops that are grown in upland areas of northern Laos include Job's tears, sesame, maize, chili, and cotton.

One of the most striking differences among the three lowland ownership categories was that farmers with areas of lowland rice had, on average, more small and large livestock than households that had no lowland (Fig. 4). The number of livestock per household also increased with larger holdings of lowland. In addition, these livestock became the most important source of household cash income (Fig. 5).

Benefit-cost analysis of paddy development

Paddy development requires terracing fields. On flat valley bottoms, this requires relatively little work; however, as the slope increases, more soil has to be moved to make flat-terraced paddies (Photo 25.2). In addition to developing the terraces, canals and weirs need to be constructed to carry water to the paddies (Photos 25.3 and 25.4). In some cases, canals may be required to carry water for a couple of kilometers. Weirs are often constructed of wooden logs, which are used to dam a stream. Although these irrigation systems can be simple and based on the use of local materials and labor, an opportunity cost is associated with their development. This cost is incurred in the initial years when the terraces are constructed. Subsequently, an annual cost is usually associated with the stabilization and maintenance of the system.

For an economic assessment of paddy development, it is necessary to account for the incremental costs and benefits that are realized, over several years. Costs of paddy development are incurred in the first few years, whereas the benefits accrue in the future. As the immediate benefit is valued more highly than the same benefit at some time in the future, the later benefits and costs need to be suitably discounted to make them comparable.

The major benefits from the conversion of sloping upland fields into terraced paddy land are the savings in labor input for rice production, together with the improved yield and increased frequency of cropping over time. The labor released associated with the move to increased lowland rice cultivation may, in turn, be used for income generation activities or for supporting other livelihood activities.

A full-fledged assessment of the economic value of paddy development requires accounting for all changes in the farming systems and labor use in nonfarm activities that are induced by the availability of paddies. Such a complete assessment is outside the scope of this chapter. Instead, a somewhat "partial" analysis is conducted by considering only the major changes in the farming system that are likely to be observed.

The estimates of the various parameters needed for a benefit-cost analysis are presented in Table 7. Most of these parameters were obtained from farm surveys.

Development of terraces involves considerable movement and relocation of surface and subsurface soil. As a result, it takes several years for rice yields to stabilize in a developed terrace. In the economic analysis, rice yield has been assumed to increase linearly from 1.5 t ha^{-1} in the first year to 3.4 t ha^{-1} in the third year. Lowland rice yields in northern Laos are typically 3 to 4 t ha^{-1} (Linquist et al 1998).

The economic performance of paddy development was measured in terms of the internal rate of return (IRR), net present value (NPV), and number of years required to recoup the cost of paddy development (or the break-even period). The IRR is the average return earned by the investment made. If the IRR is higher than the going interest rate at which farmers can secure a loan, the investment can be considered to be profitable. The NPV measures the total gain from investment made over the planning horizon. It is calculated by netting out all costs from the benefit streams and suitably discounting these streams for a different time value of money. For an investment to be profitable, the NPV must be greater than zero, with a higher NPV

Table 7. Values of parameters used for the base run.

Parameter	Values used in the base run
Discount rate (%)	10
Yield of upland rice (t ha^{-1})	1.7[a]
Yield of paddy rice (t ha^{-1})	3.4[a]
Cash cost of production of upland rice (\$ ha^{-1})	10[b]
Cash cost of production of paddy rice (\$ ha^{-1})	20[b]
Farm-gate price of rice (\$ t^{-1})	70[b]
Cost of constructing terraces, weirs, and irrigation canals (\$ ha^{-1})	300[c]
Frequency of rice cultivation in paddies	Once per year
Frequency of rice cultivation in uplands	Once every third year, with fallow in between
Planning horizon (years)	25
Loss of rice area because of terrace construction (%)	10
Number of years needed for the rice yield in paddies to reach the assumed yield	3[c]
Labor savings in rice production (person-days) per household	280[d]

[a]Data source: MAF (2002). Yield data are for northern region. [b]From survey data. [c]From survey data reported in Trösch (2003). [d]Assuming the average household size of six members and per capita rice requirement of 350 kg per year, the total production needed to meet the household requirement is 2.1 t. Given the assumed rice yields, the upland and lowland rice area required to produce this amount is 1.2 ha and 0.6 ha, respectively. The corresponding savings in labor, using labor use per ha from Roder (2001), is thus approximately 280 person-days (calculated as 1.2 × 294 – 0.6 × 122).

indicating greater gains. The break-even period is an intuitive indicator of the profitability of paddy development. It measures the number of years needed for the initial investment in paddy development to break even. The shorter the break-even period, the more attractive the investment will be.

The estimated NPV measures the net gain in present value of switching the production of household rice needs from upland to lowland conditions by constructing terraces. Over the 25 years considered for the exercise, farmers have the potential to gain a total of \$690 per ha after deducting all costs associated with terrace development (Table 8). The IRR indicates that the investment will yield an annual return of around 51%. By most commercial standards, an annual rate of return of 51% is considered to be good.

A more intuitive interpretation of the profitability is provided by the estimated break-even period. It takes approximately 4 years for farmers to recoup the cost of investment through higher rice yields and gains from savings in labor input. Farmers who have a planning horizon shorter than 4 years may not consider the construction of terraces a rewarding proposition under the assumptions of the economic exercise.

Table 8. Base run results.

Parameter	Resulting value
Net present value	\$690 ha^{-1}
Internal rate of return	51%
Break-even period	4 years

The results are sensitive to the opportunity cost of the labor released as a result of terrace construction. The profitability of terrace construction increases rapidly with the increase in the opportunity cost of labor released. Thus, farmers who have a high opportunity cost of labor are likely to find rice production in paddies a more viable economic proposition than those whose opportunity cost of labor is low. The cost of developing a terrace is the major investment cost. The results of terrace construction can therefore be expected to be sensitive to this parameter. If the cost is half the amount assumed in the exercise (only \$150 ha^{-1}), the IRR jumps to 98%.

The profitability of terrace construction is also determined by the number of years needed for the full development of the productive capacity of terraces after the initial soil disturbance. The faster the productive capacity of the paddy fields is stabilized, the shorter the break-even period will be. Thus, farmers are likely to find construction of terraces more attractive on the gentler slopes that require less soil disturbance. Alternatively, better technologies for terrace construction and stabilization to quickly achieve the yield potential of a fully developed terrace would be desirable.

Research issues and progress

Why conduct research on montane lowland systems?

Rice-based research on the montane lowland system in Laos is important for several reasons. First, poverty levels are greatest in the more mountainous areas (ADB 2001) and the provinces with the greatest levels of poverty are in the mountainous north. A clear association has been shown between the incidence of poverty and level of household rice sufficiency (ADB 2001). Yields of rice, farmers' staple crop, are declining in upland fields of the north, further aggravating rice deficits. Because of poor infrastructure, it is not cost-effective to transport rice from areas of rice surplus in central and southern Laos to these remote mountainous areas. Lowland rice systems exist in these mountainous areas but grain yields in these systems are generally low and variable.

Improving the productivity of lowland rice or increasing the area of lowland rice in montane areas can reduce the pressure on rice cultivation in upland areas, thereby allowing farmers to have the opportunity of implementing more sustainable cropping strategies in their upland fields. Farmers with greater areas of lowland rice are also more likely to diversify into other crops in their upland fields.

An important theoretical exercise is to estimate the potential reduction in upland rice cultivation that might accompany a move to greater lowland production in mon-

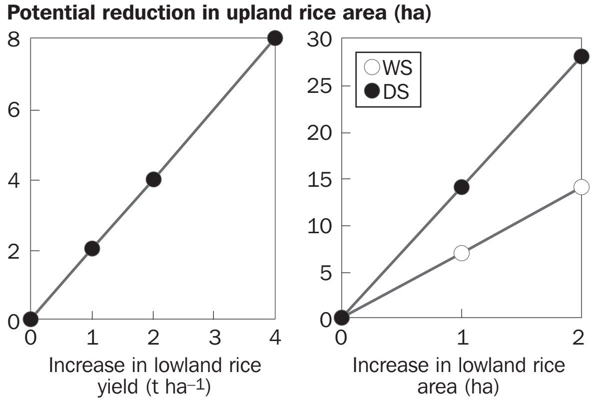

Fig. 6. The potential effect of increased lowland rice productivity or increasing lowland rice area on upland rice area.

tane areas. Assuming that upland rice yields average about 1.5 t ha^{-1} and that there is a 3-year cropping cycle with rice being grown after 2 years of fallow, an upland field would have a theoretical production potential of 0.5 t ha^{-1} per year. Lowland rice, on the other hand, can produce an average of 3.5 t ha^{-1} per year (or possibly as much as 7.0 t ha^{-1} per year if irrigation is available to allow double cropping). Using these assumptions, if rice yields from existing lowland fields can be increased by an average of 1 t ha^{-1} per year, this increased lowland production has the potential of replacing 2 ha of upland rice, which might then be allocated to the cultivation of other upland crops. When the increased lowland rice production comes from the development of new paddy areas, using the above assumptions, for every hectare of lowland developed, the upland rice area could potentially be reduced by 7 ha if rice is grown only in the wet season in the lowland area, or by 14 ha if dry-season rice production is also possible (Fig. 6). This exercise assumes that farmers grow rice only for subsistence purposes. However, Trösch (2003) reports that lowland farmers still grow upland rice as a cash crop even when they own large areas of lowland. Until good markets develop for other upland crops, it can be anticipated that upland rice will continue to be grown even by households that are able to meet their rice requirements through lowland cultivation.

A further reason for improving food security and rice productivity in montane areas is that 14% of Laos has been set aside as National Biodiversity Conservation Areas (NBCA). There are 20 such parks and most are located in mountainous areas with farmers living in and around them. Poverty and declining productivity of upland fields are forcing many of these farmers into foraging and using the conservation areas in an unsustainable manner. Ensuring food security in these areas by increasing the productivity from associated montane lowland areas may help protect these valuable conservation areas from overuse.

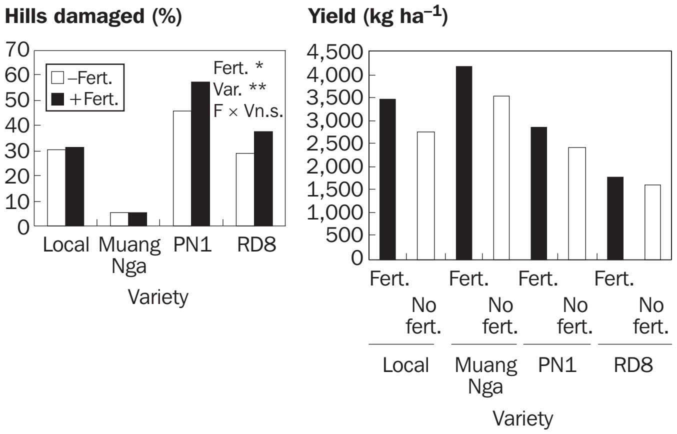

Fig. 7. Percentage of tillers damaged by gall midge and rice yields as affected by variety and fertilizer treatments. ns = nonsignificant.

Constraints to montane lowland rice productivity

Montane lowland rice yields in northern Laos are potentially higher than yields on the large plains of southern and central Laos because the lowland soils are generally more fertile in the north than in central and southern Laos (Linquist et al 1998). However, there are opportunities for increasing yields, stabilizing yields across years, and increasing paddy productivity; these issues form the basis of the research being conducted. In the wet season, gall midge is a major pest and, in some years, can cause severe reductions in rice yields. In the dry season, limited water for irrigation is the main constraint to growing lowland rice; however, there are opportunities for crop diversification where water supplies are available but inadequate for lowland rice. At high altitudes, cold temperature is a major potential constraint. Each of these issues is being examined, with the related progress being summarized in the following sections.

Gall midge. Traditional rice varieties perform well in lowland areas of the north, and can yield up to 4 t ha^{-1} in favorable years. However, yield fluctuations can be substantial from year to year. A major factor contributing to yield variability is the incidence of damage caused by the Asian rice gall midge (*Orseolia oryzae* Wood-Mason) (see Chapter 17). Gall midge damage is the most frequently cited constraint to production by lowland farmers in northern Laos. The damage is encountered only during the wet season, and is greatest in very wet years.

Increasing montane paddy productivity will require the use of improved varieties and better fertility management. However, the currently available improved varieties are highly susceptible to gall midge damage (Fig. 7). Furthermore, improving soil fertility increases gall midge problems (Fig. 7). Therefore, unless improved varieties with gall midge resistance are developed and introduced, substantial improvements in lowland rice yields in the montane lowland areas of northern Laos will probably not be feasible.

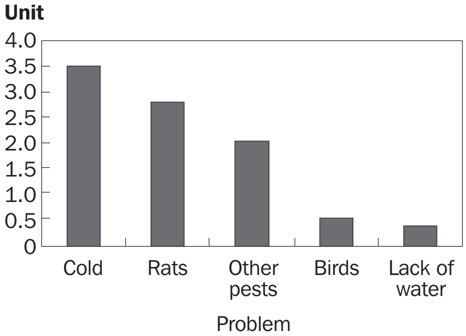

Fig. 8. Farmer-perceived problems to dry-season lowland rice cropping at high elevation. The higher the number, the greater the problem.

Two local varieties (Muang Nga and Mak Nge) have been identified as having resistance to gall midge. Muang Nga has been tested in the north with good results in terms of yield potential, while also confirming its gall midge resistance (Fig. 7). Muang Nga is a late-maturing wet-season variety that is proving to be popular in villages where farmers use late-maturing varieties. However, in villages where there is a preference for early- and medium-maturity varieties, crops of the later-maturing Muang Nga are targeted by pests after the harvest of earlier-maturing varieties. Mak Nge, a medium-duration variety, is currently still being evaluated by farmers. The breeding program is also focusing on the crossing of Muang Nga with improved popular early- and medium-duration varieties such as Thadokkham-1 (TDK1) and TDK5, in an attempt to produce a variety that combines the qualities of earlier maturity, fertilizer responsiveness, and resistance to gall midge.

Dry-season low temperatures. Low temperature is a constraint for farmers attempting dry-season lowland rice cultivation at high altitudes in northern Laos (Fig. 8). Temperature is related to elevation. Analysis of historical temperature data from meteorological stations throughout Laos show that, in the north, during November to January, there is, on average, a 0.92 °C decrease in mean minimum temperature for every 100 m increase in elevation (Table 9) (Chanphengxai et al 2003). While these data are average monthly mean temperatures, daily minimum temperatures can go lower than 4 °C. For example, in 1999, minimum temperatures in Xieng Khouang reached below freezing during the same period (December 1999) and minimum temperatures dropped to only 2 °C in Luang Prabang (about 300 m elevation). The establishment phase of the rice crop during November to January is most vulnerable to low-temperature damage. Low temperatures result in poor seed germination and poor seedling growth. In December and January, the coldest months (Fig. 9), mean monthly temperatures in some northern provinces (e.g., Xieng Khouang) can be as low as 7 °C. Research on improving rice production at high elevations has focused on three main areas.

Table 9. Estimated mean minimum temperature (ºC) for November, December, and January for 100–1,500 m elevation in northern Laos.

Elevation	November	December	January
100	20.1	16.7	17.1
200	19.1	15.8	16.2
300	18.1	14.8	15.4
400	17.1	13.9	14.5
500	16.1	13.0	13.7
600	15.1	12.1	12.9
700	14.1	11.1	12.0
800	13.1	10.2	11.2
900	12.1	9.3	10.3
1,000	11.1	8.4	9.5
1,100	10.1	7.4	8.7
1,200	9.1	6.5	7.8
1,300	8.1	5.6	7.0
1,400	7.1	4.7	6.1
1,500	6.1	3.7	5.3

Source: ACIAR (2002, 2003).

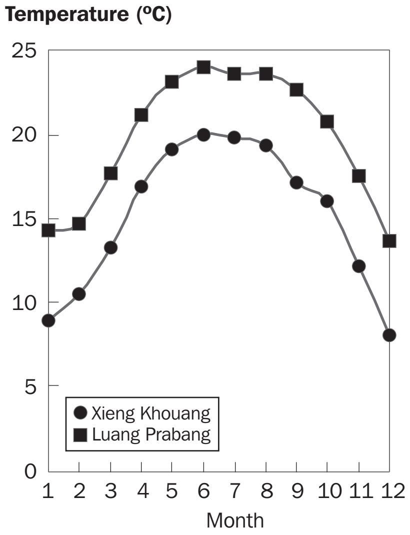

Fig. 9. Mean monthly minimum temperatures for Luang Prabang (300 m) and Xieng Khouang (1,100 m). Data are means from 1985 to 1997.

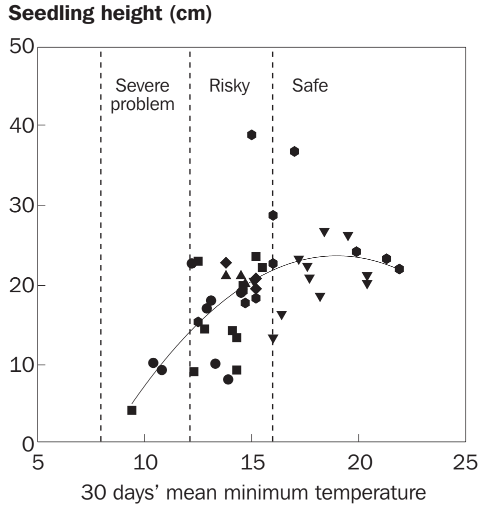

Fig. 10. Effect of 30 days' mean temperature on seedling height at Xieng Khoung.

1. *Identification of the critical mean monthly temperature for optimal sowing time*. Measurements of germination percentage and seedling growth indicate that the mean minimum temperature during the seedbed period needs to be at least 12 °C. When the mean minimum temperature is 12 °C during the period of seeding and early seedling growth, seedlings of the improved glutinous variety TDK5 can achieve a height of about 12 cm within 30 days after sowing; seedling growth and height increase rapidly with increasing temperature (Fig. 10). Using this critical temperature and the relationship between temperature and elevation described above, areas and periods have been identified where lowland rice production is risky. For example, at elevations above 900 m (as is common in Xieng Khouang), it is considered too risky to seed rice in November (Sihathep et al 2001).
2. *Improved nursery management to protect seedlings using plastic covers*. Covering the rice seedbed with plastic raises temperatures and results in improved seedling germination and growth (Photo 25.5). Two systems have been tested (Fukai et al 2003): the use of a plastic sheet to cover the seedbed, with the plastic being removed when the seedlings are about 5 cm tall; and covering the seedbed with a plastic dome until seedlings are sufficiently tall for transplanting. Nighttime temperatures inside the dome have been measured and are about 4 °C higher than the external ambient temperature, resulting in improved germination and seedling growth (Fig. 11). In areas where dry-season rice cropping can be affected by low temperature during the seedbed stage, the use of plastic domes in on-farm studies has been shown to increase yields by an average of over 0.5 t ha^{-1} (Table 10). An additional

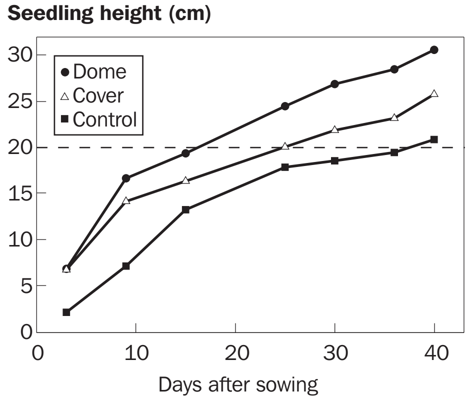

Fig. 11. Effects of nursery management practices on seedling height at Xieng Khoung.

Table 10. On-farm evaluation in Nam Bak (350 m), La (620 m), Namtha (550 m), and Sing (650 m) districts comparing the plastic dome with the traditional farmers' practice.

Province	District	No. of farmers testing	Treatment	Grain yield[a] (kg ha^{-1})
Luang Prabang	Nam Bak	3	Farmers' practice	2,020
			Plastic dome	2,416
Oudomxay	La	3	Farmers' practice	2,562
			Plastic dome	3,349
Luang Namtha	Namtha	2	Farmers' practice	2,951
			Plastic dome	3,483
Luang Namtha	Sing	2	Farmers' practice	2,463
			Plastic dome	2,973
Mean			Farmers' practice	2,458
			Plastic dome	3,021
			$P > 0.05$	0.0000

[a] The grain yield is the mean of farmers (2 or 3 replications) in each district. Statistics were obtained using each farmer (10 in total) as a replication.

benefit of the use of plastic domes that has been reported by farmers is that they help protect the seedlings in the nursery from rat damage.

3. *Improved crop management*. Good management with the use of appropriate varieties is needed to reduce the time the dry-season rice crop is in the field to allow time for field preparation for the main wet-season crop. Ideally, farmers would like to harvest their crop in April. However, low temperatures combined with late-duration varieties often result in farmers having to harvest in May or June (and sometimes even as late as July). Using plastic covers or

Table 11. Average number of days to flowering (TDK6) when 30-day-old and 45-day-old seedlings (grown under three nursery treatments) were transplanted in Xieng Khouang (Kham District) during the 2003-04 dry season.

Treatment	Age of seedlings		
	30 days	45 days	Av
Conventional	138	144	142
Plastic cover	134	136	135
Plastic dome	133	136	134
Mean	135	139	137

domes can shorten the time the rice crop is in the field by 4 to 8 days (Table 11). Improved varieties specifically adapted to the lowland conditions of northern Laos have yet to be developed. From among varieties developed for the main rice-growing areas in the central and southern regions, the variety best suited to high-altitude dry-season cropping on account of its relatively short maturity time and yield potential is TDK5.

Crop diversification in montane areas. Rice was grown on about 6,000 ha in the 2003 dry season. About 75% of this area was in the three provinces of Luang Prabang, Sayabouly, and Houaphanh (MAF 2003). The dry-season rice area is limited primarily as a result of inadequate water. The water requirement for rice cropping is much higher than for other crops. Studies are currently under way by the National Agriculture and Forestry Research Institute and its collaborators to identify alternative nonrice cropping options for lowland paddies that do not have adequate water for lowland rice cropping but may have enough water for other crops (such as vegetables, maize, soybean, and tobacco).

Expansion of the montane paddy area. Most of the large flat areas in northern Laos with easy water access have been developed for rice production through government and development programs. Increasingly, farmers are terracing hillsides for lowland rice cultivation. However, the potential for an expansion of lowland rice area in this manner has not been determined. Apart from socioeconomic factors such as the cost of developing terraces, social issues such as understanding how water is viewed as a community resource are also important considerations. For example, if a village upstream diverts water to develop paddy land, what are the effects on downstream villages? Other considerations include the socioeconomic conditions that make paddy development possible and attractive for farmers, and equity issues, particularly with respect to considerations of whether all farmers can be involved rather than only the more wealthy farmers in a community.

The expansion of paddy area also depends on the biophysical environment, particularly topography and water availability. Further research is necessary to help district- and village-level planners identify suitable areas for paddy development. The potential also probably exists for improvements in water-use efficiency (canals are often dug along hillsides with high potential for water loss) and in paddies, thereby allowing the potential for an expansion of irrigated area within the limits of water availability.

A further area of research that may allow more efficient use of limited water resources, while at the same time increasing yield potential, is that relating to aerobic rice cultivation. Aerobic rice can be grown under either flooded (anaerobic) or non-flooded (aerobic) conditions, and produce high yields. In some areas of Laos (such as in Luang Prabang), farmers already grow upland rice varieties in terraced paddies where water is not available for continual flooding. When the water supply is good, they keep the fields flooded, but when water availability is limited, they only irrigate the lower terraced fields. Research has begun in Laos to identify suitable varieties that are responsive to inputs and give high yields in such systems. A major potential production constraint in this system will come from weed competition, as weeds are much more difficult to control in nonflooded fields.

Conclusions

The development of montane lowland paddies and research to improve the productivity of these paddies offer good opportunities to improve food security and reduce poverty in the more mountainous areas of Laos. Furthermore, an expansion of lowland rice cultivation in montane areas also provides a basis for farmers being able to reduce rice production in associated upland areas, and adopt more sustainable agricultural practices in this environment. There has already been a recent expansion of paddy area in northern Laos in response to land allocation policies that have led to shorter fallows, under which upland rice cultivation is no longer sustainable. Furthermore, some data already suggest that farmers, if they have an adequate lowland area for rice cultivation, will adopt more sustainable agricultural practices in their upland fields.

Improved rice production in the montane environment will need to involve the use of improved varieties and the adoption of improved management practices. While some of the technologies developed by the Lao National Rice Research Program for improving lowland rice production in the central and southern regions have relevance for the montane lowland environment, a need remains for ongoing research to better understand and develop production systems specifically suited to helping alleviate some of the production constraints specific to the montane lowlands of Laos.

Despite the development of the larger valley bottoms for lowland rice cultivation in more mountainous northern areas having already been undertaken, opportunities remain for improving lowland rice production in these areas. Where the opportunity exists for the development of irrigation, improved yields might be achieved with wet-season crops through the use of supplementary irrigation, while second-cropping opportunities for dry-season cropping can be investigated where water supplies are adequate. In addition, expansion of lowland paddy area in some areas can take place through the development of additional rice terraces. However, additional research is necessary to determine the potential area that might be further developed, taking into account water flows, rainfall, water requirements of paddy rice, economic considerations, and topography. Research will also be required at the community level to develop appropriate water user rights, and on ways to develop paddy areas that are compatible with these rights.

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Notes

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