SLASH-AND-BURN RICE SYSTEMS IN THE HILLS OF NORTHERN LAO PDR: DESCRIPTION, CHALLENGES, AND OPPORTUNITIES

W. RODER

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Cover photo: The effects of slash-and-burn agriculture are readily evident to air travelers between Vientiane and Luang Prabang. Lao PDR (Gene Hettel).

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Contents

Foreword

Over the past decade, the Lao-IRRI Rice Research and Training Project (LIRRTP) has been the principal source of capacity building and technological developments in the rice sector in Lao PDR. From a very low base in 1990, the project has helped develop a functional national rice research system involving more than 120 government officials and technicians.

Research has been conducted in irrigated, rainfed lowland, and upland ecosystems. This publication focuses on efforts in the uplands. Despite significant progress in the uplands, several challenges remain. For example, research has to build on previous component technology research and identify technologies that move away from slash-and-burn shifting cultivation to more stable and more sustainable integrated production systems. Thus, whole-system considerations (e.g., markets and infrastructure) and agroforestry will be important elements. This document brings together much of the previous upland work completed in the LIRRTR We hope that this will form the basis for enhanced efficiency.

William G Padolina
Deputy Director General for Partnerships

Acknowledgments

Working in the Lao upland environment was a tremendously interesting and rewarding experience. It not only provided me with an excellent chance to widen my professional expertise in tropical agriculture but also gave me ample opportunity to gain exposure to disciplines outside agronomy, such as socioeconomics and anthropology.

This work was made possible through the institutional support of IRRI, the financial support of SDC, and the strong commitment and continuous support of the Lao Ministry of Agriculture and the provincial agriculture governments. The provincial agriculture service in Luang Prabang was especially important as the upland component of the Lao-IRRI Project was implemented under its auspices.

The support by the team leader of the Lao-IRRI project. John Schiller, is acknowledged. The friendship and undiminished support by the national director of the Lao-IRRJ Project. Viengsavanh Manivong, in spite of my sometimes unconventional needs and requests, ensured the stability and continuity of the research activities. I owe special thanks to Suvit Pushpavesa, who knew all there was to know about rice and was there whenever advice was needed. Thanks are due to W. Leacock, who introduced me to research methodologies used in social sciences. Of the many colleagues with whom I had the opportunity to work and interact, I would especially like to mention Houmpheng Soukhaphonh, Somphet Phengchanh, Khouanheuane Vannalath, Boonchanh Chathapadith, Soulasith Maniphone, Boonthanh Keobonalapha, and Khamdok Songyikhangsuthor from Luang Prabang Agriculture Service, Somsamut Phongsavath from the Agriculture Service of Oudomxay Province, and Bouakham Phouaravanh from the National Agriculture Research Service. Most importantly, I have to thank the Lao upland farmers who worked with us and were always ready to share their knowledge and to answer our questions.

Introduction

Slash-and-bum agriculture is considered to be one of the oldest land-use systems (Spencer 1966). Although the practice has long disappeared in temperate regions, it is still common in tropical and subtropical areas and is said to be practiced by at least 300 million people, involving up to 30% of the global exploitable soils (Warner 1991).Although production systems vary, most slash-and-bum farmers depend on perennials to suppress weeds and to restore soil fertility during the fallow period. It is generally agreed that slash-and-burn systems are sustainable with long fallows when the population densities are low. Traditional systems have low productivity per unit area, but give high returns to labor, with low energy requirements.

In most countries, slash-and-bum agriculture has regional importance only, but for Lao PDR it is a major land-use practice involving more than 150,000 households or 25% of the rural population (Lao PDR 1999). If all the fallow land is included, shifting cultivation may use upto 80% of the soils used for agriculture. Low population densities, low incomes, and low access to inputs in the past made slash-and-burn agriculture the best land-use option for the rural population in the hilly regions of the country. Today, increasing population pressure, Increasing degradation of the resource base, global awareness of off site effects, and an increasing interdependence between lowland and hill farmers have changed the situation and demand a new approach. It is thus not surprising that the government has given high priority to transforming this perceived harmful system to other agricultural systems. Information on the production system and improved technologies available for extension are limited, mainly because past research and development efforts concentrated on lowland rice production systems, whereas the upland population has often been by-passed. Furthermore, the wide diversity of biophysical and socioeconomic environments provides a major challenge for the research and development process.

An in-depth understanding of the existing production system is required to formulate recommendations for changes. Although the number of publications on slash-and-bum production systems generated over the past two decades is considerable, quantitative data on soil, water, plant, and other biophysical factors of the systems remain limited. It must also be emphasized that long-term solutions to the problems faced by Lao slash-and-bum farmers cannot be found by focusing on their production system in isolation. The problem can only be solved by a holistic approach that takes into consideration the entire economy and social fabric of the country and its neighbors. Interdependencies and linkages in the national economy, especially employment opportunities, market opportunities, access to social institutions, and rules regulating off-site effects, need to be recognized and exploited to optimize benefits for the households that now depend on slash-and-burn agriculture.

In line with government priorities, the Lao-IRRI Project, in collaboration with the Lao National Agriculture Service and the provincial agriculture services, carried out a comprehensive research program focusing on

- Characterizing the production system and environments
- Collecting and characterizing traditional upland rice cultivars
- Selecting rice cultivars for improved drought tolerance

- Developing weed and pest management practices
- Developing production systems that optimize income and conserve the resource base

Most of the collaborators and coauthors had no prior research experience but had a commendable knowledge of the production systems and, most importantly, were keen observers and always ready to learn from slash-and-burn farmers.

Based on the results and observations made from these research activities during 1991-95, this publication describes the land-use system, including many aspects of the biophysical and socioeconomic environment. Investigations on trends, constraints, and possible alternative production systems are documented. Selected additional information generated during 1996-2000 is also included. The resulting qualitative and quantitative data provide (1) inputs to substantiate arguments on slash-and-bum issues in general, (2) baseline data to document trends in the system, (3) technologies for testing with or transmission to slash-and-bum farmers, (4) inputs for further research activities, and (5) information for policymakers and planners.

I hope that the information provided in this publication will be of interest to those working in slash-and-bum production systems in the region, including Lao PDR, Vietnam, Myanmar, and Thailand. At the same time, this publication may make an important contribution to the intensive discussions and consultations on slash-and-bum issues at the global level.

The team of Lao-IRRI upland project in Luang Prabang (1994).

The uplands of Lao PDR

Lao PDR is a landlocked country with an area of about 236,800 km7 and a population of 4.5 million (Lao PDR 1999). Water for hydropower and timber are the principal natural resources. Approximately 3% of the area is used for agriculture with rice as the main crop. Fallow land in slash-and-bum systems may account for another 6-I 0% of the total land area. About 83% of the population is rural and 66% of these people depend on subsistence agriculture.

Rolling hills and rugged mountains dominate the landscape, with peaks rising up to 2,800 m (Fig. 1). Most slash-and-bum cultivation is concentrated on slopes with altitudes ranging from 300 to 800 m. The upper limit for rice cultivation is around 1,500 m. Slope gradients range from 0 to 120% with most of the slopes falling in the range of 15-60%. According to recent statistics (World Hank 1995), 69% of the area used for upland agriculture had a slope gradient of less than 20%.

Sandstone, limestone, and clastic rocks of mesozoic and paleozoic origin are the dominant geological formations found in the hilly areas (ESCAP 1990). Other important geological formations include granite and volcanic rocks. Soils are mainly red-yellow, podzolic, and reddish brown lateritic, leached and acidic with low water-holding capacity.

The climate is tropical with a pronounced rainy season from May through October and a hot dry season in March and April (Fig. 2). The annua] precipitation is above I ,O00 mm for the entire area but fluctuates widely with the highest amounts, 3,700 mm annually, recorded on tbe Boloven Plateau in Champassak Province. In addition to the geographic variations, strong interannual fluctuations in rainfall with abnormal droughts pose major hazards to crop production under upland conditions. Temperature is mainly a function of latitude and elevation. The average temperature declines with increasing elevation at the rate of approximately 0.5 0C per 100-rn altitude change.

Slash-and-bum agriculture is the major production system used in the upland environment. This subsistence system commonly integrates crop production, animal husbandry, and forestry. Only a small percentage of a few select items produced will ever reach the market. Rice is the major upland crop, followed by maize, cassava, and peanuts. Wherever possible, floodplains and valley bottoms are used for lowland rice production. Such fields are usually quite fertile because of the continuous addition of nutrients contained in topsoil lost from the surrounding slopes.

The population is ethnically diverse with more than 60 ethnic groups (Stuart-Fox 1986). Based primarily on ethnic, linguistic, and geographical characteristics, ethnic groups have been divided into three broad categories: Lao Loum (Lao of the lowlands), Lao Theung (Lao of the mountain slopes), and Lao Soung (Lao of the mountain summits). All major ethnic groups of the country depend to some degree on upland agriculture but, in proportion to their total number, Lao Soung and Lao Theung farmers are more likely to live in hilly areas. Although all ethnic groups are engaged in slash-and-bum agriculture, it is very common to hear that it is “the ethnic minorities” (groups others than Lao Loum) or the

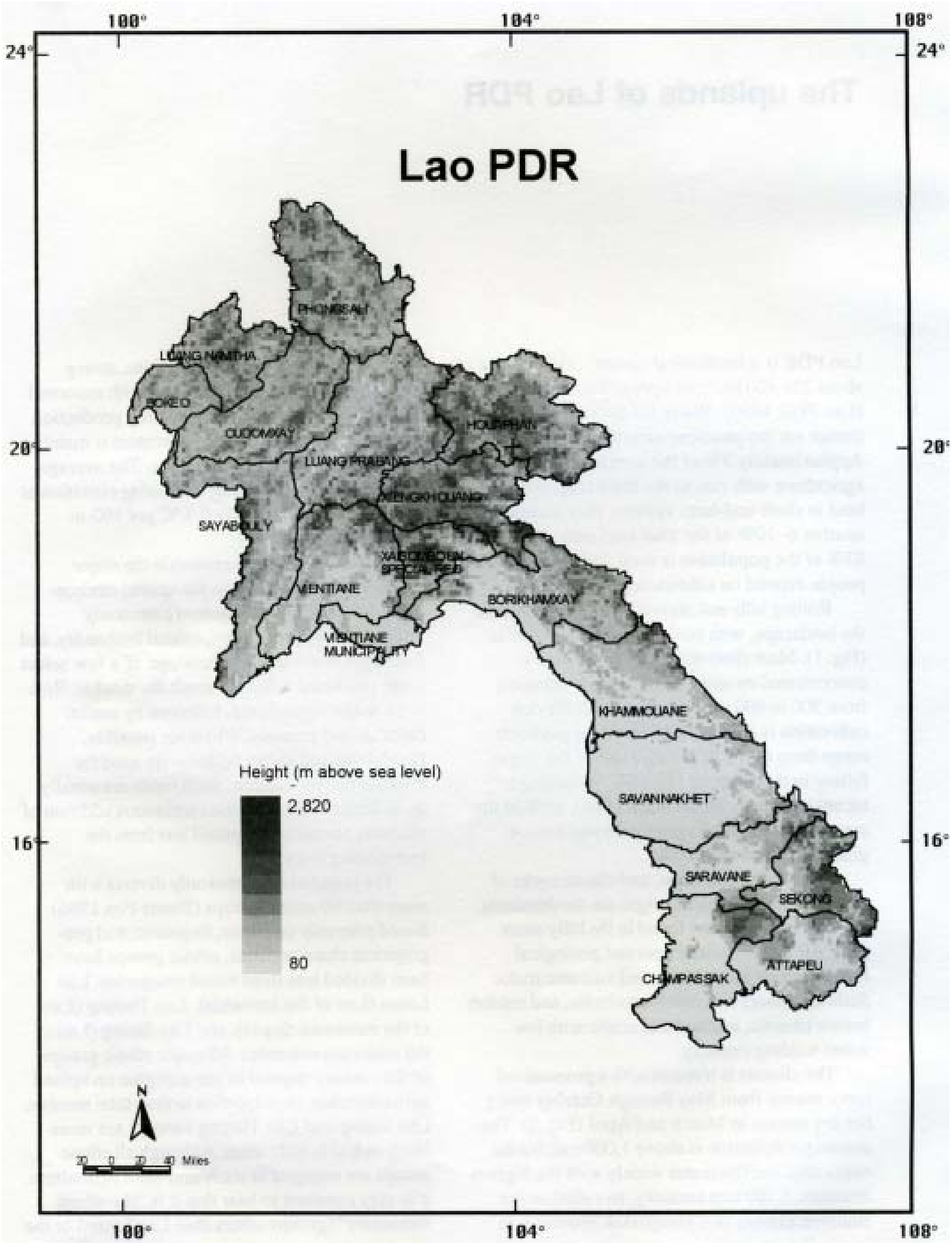


Fig. 1. Topography map of Lao PDR.

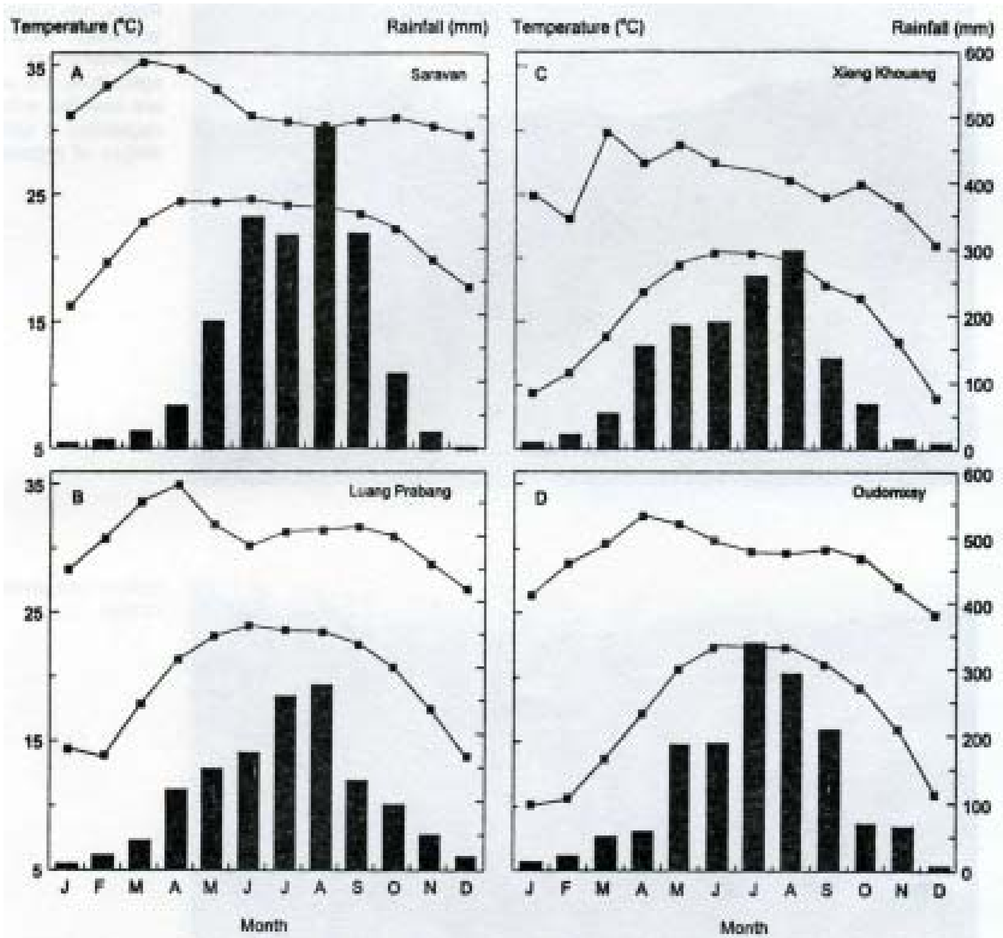


FIg. 2. Monthly average minimum and maximum temperatures (lines) and monthly rainfall (columns) for 1985-98 for (**A**) Saravan (elevation 168 m, longitude 15° 43', annual rainfall, 1.931 mm), (B) Luang Prabang (elevation 300 m, longitude 19° 54', annual rainfall 1,332 mm), (C) Xleng Khouang (elevation 1.050 m, longitude 19°27, annual rainfall 1,385 mm), and (D) Oudomxay (elevation 500 m, longitude 20° 42', annual rainfall 1,467 mm).

"ethnics" that live from slash-and-bum agriculture and destroy the forest. Select ethnic minorities are blamed for causing environmental damage and forest destruction; however, quantitative and qualitative data from the literature and surveys do not support this claim (see information in article included under "Soil and soil fertility"). Variations in land use within the same group are generally larger than between groups.

Rolling hills dominate the landscape. As a result of slash-and-burn agriculture, the slopes are covered with fallow vegetation in various stages of regrowth.

Upland rice grown on slopes.

Wherever possible, floodplains and valley bottoms are used for lowland rice production.

Lao Loum farmer weeding upland rice.

Yuong Hmong boys (Lao Soung group).

Existing slash-and-burn practices and problems and diversity in rice varieties

Land-use systems practiced are dynamic and are influenced by numerous factors, sucb as land availability, land quality, land tenure, population pressure, climate, availability of labor, need for cash, market facilities, past practices, food preferences, ethnicity, past political events, and government policies. Yet, in spite of the great diversity in climate, soil condition, population movements, and ethnicity, the systems used currently have many commonalities and the following generally apply:

- Existing practices have evolved from traditional slash-and-burn systems, which are typical for the subtropical regions of South-east Asia.
- Upland rice is almost always grown in slash-and-bum systems, whereas other crops, as listed below, may be grown as intercrops witb rice or in semipermanent systems.
- Land preparation consists of slashing secondary forest or shrub vegetation in January and February and burning the dry biomass in March or April. The knife, dibbling stick, and a simple blade for weeding are the main implements used and cultivation does not include tillage.
- Rice is planted in bills (10-16 bills nr2) using a dibble stick in late May or early June. The rice varieties used are all traditional varieties.
- Most farmers, except the ilmong and Yao, prefer glutinous rice. Early, medium, and late rice varieties are used to stagger the harvesting date (labor requirement, early consumption) and to reduce risks of weather and pest damage.
- Weed control is the single most important labor requirement, accounting for about 50% of the labor input (Fig. 3). Weeding is often necessary prior to planting. *Chromolaena odorata* is the most common weed. In recent years, fallow cycles have become shorter and weeding requirements have increased substantially.

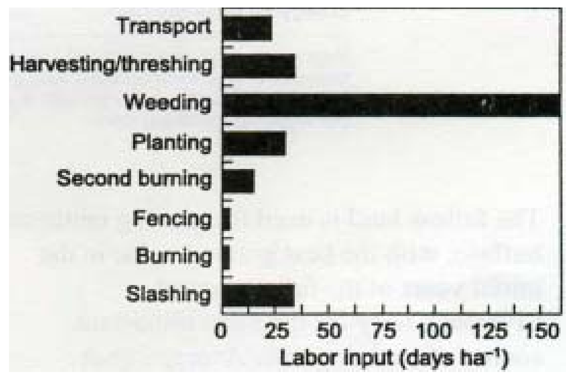


Fig. 3. Labor input for rice production in slash-and-bum systems.

- Labor productivity is comparatively low (Table 1). This is in contrast to the general belief that traditional slash-and—bum systems optimize returns to labor at the cost of using large land resources (Raintree and Warner 1986). Productivity per unit land is extremely low if fallow land is included.
  A single crop of rice is followed by fallow periods of 2-10 years (5-10% of the area is used for successive crops of rice for 2-5 years).
- A variety of other crops are grown in the same plot together with rice. These crops, in order of frequency, include maize, cucumber, pumpkin, taro, cassava, chilies, sesame, smooth loofab, sweet potato, long-bean, peanut, eggplant, Job's tears (*Coix lachryma-jobi*), ginger, angie loofah, sorghum, yambean, pigeonpea, and sun hemp.

Table 1. Labor productivity, energy inputs, yield, and production per area. (Adapted from Ruder St al 1992.)

Parameter	Lao farmer		Farmer in California
	Slash-and-burn	Lowland rice	
Labor input (d ha^{-1})	294	122	3
Input of energy (1,000 kcal hr')	1,143	546	10,958
Labor[a]	882	366	9
Machinery[b]	-	-	7,606
Fertilizers	-	-	2,161
Plant protection	<1	-	460
Seeds	260	180	722
Yield (t ha^{-1})	0.25[c]	1.6	6.5
Labor productivity (kg d^{-1})	5.1	13.1	2,167
Energy output/input ratio	3.9	8.8	1.8

[a]Assuming energy input of 3,000 kcal per labor day
[b]includes energy for machinery, fuel, irrigation, drying, and transport.
[c]Yield of 1.5 t ha^{-1}" in a system with 5 years fallow (used 1.5 1 hr^{-1} for labor productivity and energy output/input ratio).

- The fallow land is used for grazing cattle and buffalo, with the best grazing value in the initial years of the fallow period.
- Livestock is by far the most important source of cash income. Average cash income for families surveyed in 1992 was about US$150 per year, with livestock, crops, off-farm work, handicrafts, loans, and forest products accounting for 44%, 26%, 13%, 7%, 6%, and 1%, respectively (Roder et al 1992).
- Although the land remains national property, farmers can claim ow nership of land improvements and perennial plants on land they have cultivated.

Farmers consider weeds, rodents, insufficient rainfall, and lack of available land (leading to short fallow periods) to be the most important constraints to upland rice production in slash-and-bum systems (Fig. 4). On closer examination, the following factors were seen to be major constraints limiting the economic possibilities of upland families (Roder et al 1992):

- Topography (slash-and-bum systems may be the only sustainablemethod for rice production on slopes with gradients of more than 40%)
- Preference for rice as the staple food and heavy dependence on rice production; maize and cassava would allow for much higher labor productivity and productivity per unit land

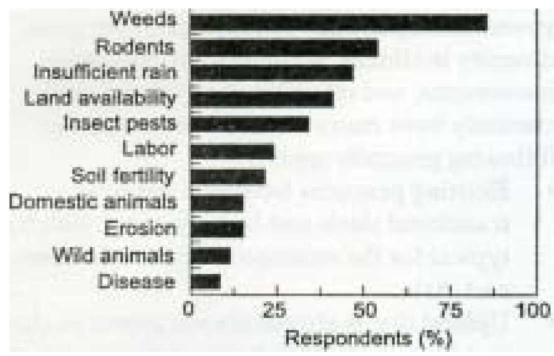


Fig. 4. Constraints to rice production in slash-and-bum systems (household surveys with 129 respondents, land availability includes the constraint "short fallow": insect pests are mostly white grubs)

- Uncertain land tenure
- Difficult communication (road access)
- Uncertain market opportunities
- Lack of alternative employment opportunities
- Poor access to social services, especially education, health, and family planning

The importance of glutinous rice in Lao PDR and the adjoining regions of the neighboring countries and the high diversity in rice varieties is discussed in Roder et al. (1996), a journal article included at the end of this section. This paper was written based on material collected during 1990-94. From 1 996 to 1 998, systematic collection was carried out under the project "Collection and Preservation of Rice Biodiversity in the Lao PDR" (Rac et al 1997a.b). Under this project, 13,192 samples (56% were upland varieties) of cultivated rice and 237 samples of wild rice were collected in an area covering 17 provinces (Rao, unpublished data). The material collected is conserved in long-term storage facilities in Lao PDR (Ministry of Agriculture) and at IRRI (Philippines).

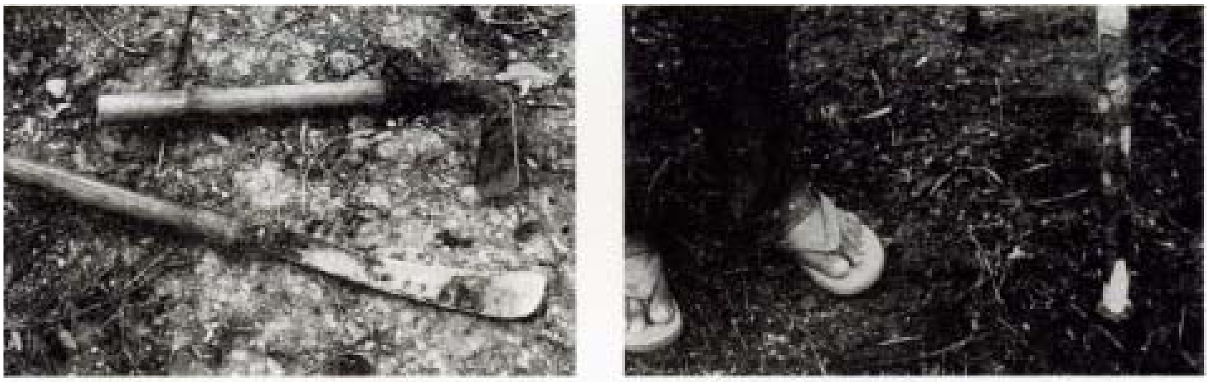
Paper included with this section

Roder W, Keoboulaplia B, Vannalath K, Phouaravanh B. 1996. Glutinous rice and its importance for hill farmers in Laos. Econ. Bot. 50:40 1-408.

In March, dry biomass is burned.

Farmer slashing shrub vegetation in January.

A field immediately after burning.



The only tools required are a knife, a weeding blade, and a dibble stick.

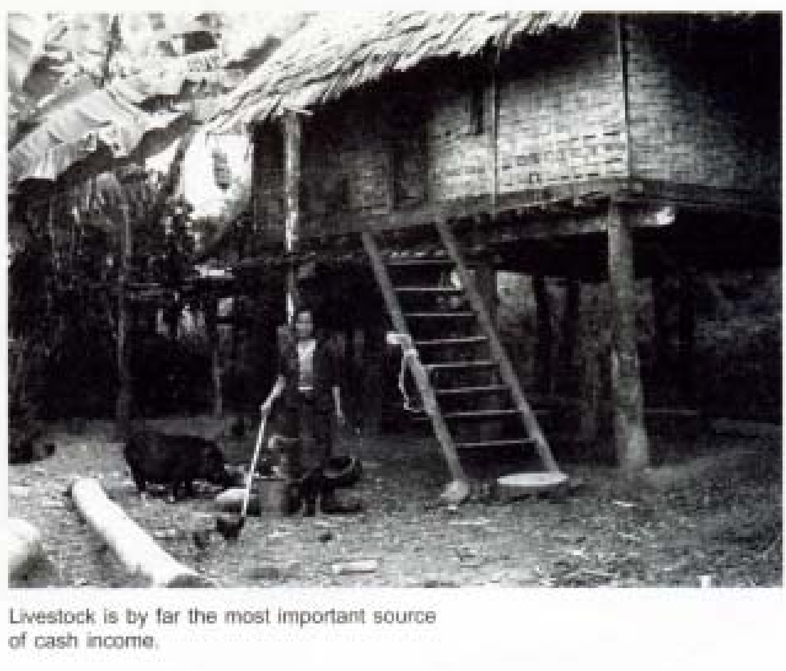
Farmers planting rice.

Harvesting rice by stripping the panicles (Khamu farmer).

Harvesting rice by cutting the panicles with a small blade (Hmong farmer).

Typical temporary rice store located in the rice field.

Cooking sticky rice by steaming.



Livestock is by far the most important source of cash income.

GLUTINOUS RICE AND ITS IMPORTANCE FOR HILL FARMERS IN LAOS[1]

WALTER RODER, BOUNTHANTH KEOBOULAPHA, KLHOUANHEUANE VANNALATH, AND BOUAKI-IAM PHOUARAVANH

Roder-, Walter *(International Rice Research Institute [IRA/f P.O. Box 933, Manila 1099, Philippines. Present address: RNR-RC Jakar, P.O. Jakar, fihutan)* **Bounthanth Keoboulapha, Kiuouanheuane Vannalntb,** and **Bouakham Phounravank** *(LAO IRRI project,P.O. Box 600, Luang Prabang, lAO PDR).GLUTINOUS RICE AND ITS IMPORTANCE FOR HILL FARMERS IN LAOS. Economic Botany, 50(4): 401-408. 1996. Glutinous or wary rice is the most important crop Jbr subsistence fanning economies in the hills of Northern Laos. Hill farmers continue to use traditional varieties only. Geographical and political isolation have contributed towards their preservation. Traditional varieties are mainly of the japonica type, have a good yield potential, are well adapted to the local conditions, and represent a wide genetic diversity. Farmers interviewed prefer varieties with large panicles, planted 2.7 varieties on average, with 17, 30 and S3% of the area planted to early, medium and late varieties, respectively. Out of 544 traditional cultivars 95% flowered within 88-120 days after planting. Crops planted together with rice in order of importance are: maize, cucumber, chili, tarn, and sesame. Farmers reported annual milled rice production of 125 kg per capita and rice selfisufficiency for 8 months for 1992 and 1993. Maize, cassava, and products from the forest are major rice substitutes and food security in remote areas could best be improved by increasing production of maize and cassava in combination with livestock production systems.*

I.e riz gluant et son importance pour les paysan des collines an Laos. *I.e riz gluant est la culture la plus importantce pour les systemes agricoles de subsistence des collines du Nord du Laos. Les paysans montagnards continuent de cultiver uniquement des variétés traditionnelles qui sont préservées par l'isolation geographique et politique. La plupart des variétés traditionnelles sont du type japonica avec de bons rendements potentiels, sont bien adaptées aux conditions locales, et présentent un grande diversité génétique. Les paysans consultés préferent les variétés à grand panicule. Ils ova cultivé en moyenne 2.7 variétés, et 17, 30, et 53% de la surface a été plantée. respectivement avec des variétés précoces, intermédiaires, et tardives. Au moins 95% des 544 cultivars troditionnels ont fleuri entire 88 et 120 jours aprés la plantation. Les cultures plantées avec la riz sont par ordre d'imponance: le mair, le concombre, le chili, le taro et le sésame. les paysans ont enregistre une production annuedle de riz décortiqué de 125 kg per capita ainsi qu 'une autosuffisance en riz pour 8 mois durant les années 1992 et 1993. Les mais, le manioc et les aliments issus de la foret constituent les principaux produits de substitution du riz. La meilleure fafon d amdliorcr Ia sicu rite' alimenta ire des régions reculées serait de combiner sine augmentation de la production de mais et de nzanioc avec des systémes de production animale.*

Key Words: slash-and-bum; sticky rice; waxy rice; traditional varieties; food security.

Laos is the geographic center of an area where farmers and urban dwellers prefer to eat glutnous rice. It is the only country where this specia) type of waxy rice with low amylose content (Juliano 1993:49-59) has distinct national importance. and is consumed by a large majority of the population as the main component of their diet. Glutinous rice is of regional importance in Myanmar, China, Vietnam, Cambodia and Thailand (Golomb 1976), where it is the preferred diet by groups ethnically and/or geographically close to the Laotian population.

Laos is a country with a high degree of genetic diversity in rice, both among cultivars used by the Lao fanners and among wild species occurring scattered iii forested uplands as well as in lowland swamps (Vaughan pen. comm. 1993). The re-

[1]Received 20 September 1995; accepted 22 May 1996.

Economic Botany 50(4) pp 401-408. 1996

markable range in rice cultivars is partly the result of the country's rich cultural and geographical diversity. The population of 4.47 million (National Statistical Center 1993) is made up of over 60 ethmc groups (Stuart-Fox 1986:44-51). Because of geographical and political isolation, upland agriculture practices in 'Laos have changed little, except for a decline in fallow length. No improved, introduced rice varieties have become popular with the hill farmers.

The northern region of the country is an almost continuous succession of rolling hills and rugged mountains with peaks rising to 2800 m. In the traditional, subsistence system. Lao hill farmers have integrated the use of crop, animal husbandry, and forest resources. Because of the limited availability of lowland area, farmers largely depend on upland agriculture (upland refers to fields that are not bounded and usually not leveled). In the past, the hilly topography combined with low population densities, made slash-and-bum the best land use option for upland farmers. Present Government policies, however, give high priority to reducing the area under slash-~and-bum cultivation. Efforts to limit tanners' access to land, combined with rapid population growth, have resulted in shorter fallow cycles and consequently increased weed problems and soil deterioration.

National rice production barely meets the domestic needs and with poor transportation facilities, fluctuations in rice production can lead to localized food deficits. Hilly regions are generally considered to be chronic food-deficit areas, however, little information is available on traditional rice varieties, the importance of rice in the hill farming system, consumption patterns. and rice trading. Various surveys have been carried out by the Lao-IRRI project to characterize the upland fanning system of Northern Laos Concurrently a systematic collection and characterization of upland rice varieties was initiated. Data from these studies and surveys are used to: (1) discuss characteristics of traditional upland rice varieties and (2) evaluate the importance of rice in the fanning system and subsistence economy.

MATERIALS AND METHODS

COLLECTION AND CHARACTERIZATION OF UPLAND VARIETIES

During 1991-I 993 544 upland cultivars were collected from six provinces (Fig. I). These

Fig. 1. Locational map of Northern Laos and provinces were upland rice was collected (dark shading).

were evaluated in observation nurseries at the Houay Khot Station (single plots), and forwarded to IRRI for accession in the global germplasm collection, where they are kept in long-term storage facilities. Duration from planting to flowering, plant height and panicle size are discussed in this paper. Isozyme analysis was done on 318 entries at IRRI Los Banos, using the methods described by Glaszmann (1987).

HOUSEHOLD SURVEY I—LAND USE PRACTICES

A household survey was carried out during the 1992 rice-growing season using a formal questionnaire supplemented by field observations. Villages visited were chosen randomly. The choice of household informants was left to the discretion of the surveyors, and was strongly influenced by advice from the particular village headman. A total of 83 households located in four districts of Luang Prabang Province were included in the survey. The questionnaire focused mainly on land use-related issues. Most of the results from this survey have already been published (Roder et al. 1994). On]y the results relating to rice varieties planted and crops planted in association with rice are discussed in this paper.

TABLE 1. SELECTED CHARACTERISTICS OP TRADITIONAL UPLAND VARIETIES' FROM NORTHERN LAOS (1991-1994).

Variable	Average	Range	Coefficient of variation	Correlation with yield (correlation coefficient)
Days to flowering (no.)	101	81-132	8.9	NS
Plant height (cm)	138	85-185	14.1	0.45***[2]
Panicle/hill	7.5	2-17	26.4	0.16***
Panicle (g)	1.6	0.2-6.9	61.8	0.85***

[1]Total entries were 544
[2]$p<0.001$

HOUSEHOLD SURVEY II-RICE PRODUCTION AND CONSUMPTION PATTERNS

A long-term survey was initiated in 1992 to document trends in rice production and consumption patterns. Five villages each were selected in Xiengnguen and Viengkham districts. In each village 5-10 households were included in the survey (20% for villages with fewer than 50 households and 10% for villages with more than 50 households). Interviews were first conducted at the end of the 1992 harvest season. When the households were revisited in 1993. Chomphet district was included in the survey. The total sample numbers were 62 households in 1992 and 126 in 1993. The formal interview included questions on family size, rice production system and related matters, rice consumption patterns. and source of cash income.

RESULTS AND DISCUSSION

TRADITIONAL RICE VARIETIES

Upland farmers use traditional rice varieties only, and generally prefer varieties with large panicles (high number of spikelets), medium tillering, vigorous early growth, and with glutinous, aromatic grain qualities (Phouaravanh et al. 1994). The traditional upland varieties have a reasonable yield potential. and yields of 4 t ha-' are not unusual in variety trials, and crop cuts yielded up to 4 r ha' (LAO-IRRI 1992). It is. therefore, not surprising that farmers generally did not consider the yield potential of traditional varieties as a major constraint to rice production (Roder et aL 1994).

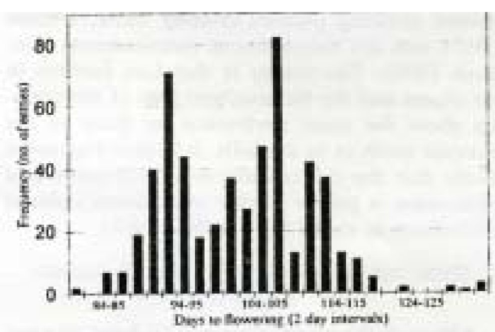


Fig. 2. Frequency distribution for days to flowering for 544 traditional cultivars.

The traditional varieties collected during 1991-93 showed a wide range in characteristics such as plant height, days to flowering, and panide numbers (Table 1, Fig. 2) The number of days required from planting to flowering ranged from 81 to 132 days, but over 95% of all entries observed flowered within 88 to 120 days after planting (Fig 2). Farmers clearly differentiate between early (kan do), medium (kau kang), and late (kau pi) varieties, and most farmers will plant varieties from each group. This allows them to harvest rice for consumption as early as possible, stagger labor requirements for harvest, and spread risks. The extent of yield loss due to climatic constraints (mostly drought), pests and diseases largely depends on plant growth stage at the time of the occurrence of the particular factor Some farmers interviewed planted five different rice varieties. The average number of varieties planted by individual households was 2.7, and the proportion of areas planted with early, medium and late varieties was 17. 30 and 53%, respectively (household survey 1). Mixtures of two or more varieties are sometimes found, but farmers usually try to keep their varieties separate. Beside varieties with distinct maturity characteristics, farmers also have special varieties for religious ceremonies, non-glutinous varieties for noodle making. and varieties with dark grain color for making rice wine. A

TABLE I AREA UNDER VARIOUS CROPS.

Crop	Area under crops (1000 ha)[1]	
	Nationally	Lining Probang
Lowland rice	366 (58)[2]	9 (16)
Upland crops		
Rice	188 (30)	38 (68)
Maize	27 (4)	6 (10)
Roar crops	14 (2)	0.6 (1)
Peanut	8 (1)	1.6 (3)
Others	24 (4)	1 (2)

[1]Source National Statistical Center, 199%
[2]Values ( ) percent of total area cultivate&

TABLE 4. CROPS GROWN TOGETHER WITH RICE.[1]

Crop	Frequency[2] (%)	Area planted (no. of hills)[3]
Cucumber	89	64
Chili and eggplant	79	69
Maize	65	806
Taro	63	42
Sesame	55	<1000
Gourd	44	26
Pumpkin	42	41
Cassava	39	66
Loofah	31	29
Sorghum	20	54
Cowpea	22	25
Peanut	15	230
Sweet potato	9	-[4]
Job's tear	7	-
Yambean	5	-

[1]Basal on the information from household survey (N = 83).
[2] Frequency of households reporting the crap in ricefield.
[3]Average number a[hills or plant5 for farmers having the crop
[4]Samples too small to estimate area.

vious difference in the perceived importance of rice as the main staple food throughout Laos. Rice is the base for every meal, and the term eating food "kin kau" translates to "eating dcc." Often the lack of rice to cover the annual needs of a family is considered as a direct food deficit. Although rice is well adapted to the environment, it is perhaps not the best crop to be used for food production in hilly areas. In the data provided by the National Statistical Center (1993) average yields for upland rice, maize and root crops (mostly cassava), were 1.5, 1.8 and 7.3 t hr^{-1} or 3.9, 4,0 and 7.3 X 10^6 kcal hr^{-1}, respectively (Juliano 1993; Rosling 1987). Rice, although planted on the most fertile land or as the first crop after fallow, provides lower yields and requires higher labor inputs per kilogram of grain produced when compared with maize. Golomb (1976) speculated that ethnic groups settied in the lowlands may have introduced the hill Canners to rice to make them dependent on lowland societies producing rice surpldses. Conversely Watabe and co-workers (1970) suggested that rice varieties used in Central Thailand progressed from glutinous upland varieties to glutinous lowland varieties and were finally replaced by non-glutinous lowland varieties.

Upland rice is almost always produced in slash-and-burn systems. Land preparation consists of slashing secondary forest or shrub vegetation in January/February and burning the dry biomass in March or April. Rice is planted in hills using a dibble stick in late May or early June. A single crop of rice is usually followed by fallow periods of 2-8 years. A small number of Farmers cultivate rice for 2 or more successive years. *Chromolaena odorata*, an introduced species, dominates the weed population during the cropping and the initial fallow phase. Weeding is the single most important labor requirement. accounting for approximately 50% of the total labor inputs of about 200-300 days ha^{-1} $year^{-1}$ (Roder et al. 1994). Because of the high labor input for weeding, the return on labor from upland rice production is much lower than that in lowland rice production systems (Roder et al. 1994). In another study carried our in Luang Prabang Province, Leacock and co-workers (1993) reported labor inputs of 268, 205 and 194 days ha-' or returns on labor of 4.3, &6 and 13.3 kg grain labor day-' for upland rice, lowland rice and maize production, respectively.

As expected, the major staple food is also the most important crop in the farming systems and occupies over 70% of the area cultivated by most upland farmers (Table 3). A wide variety of other species is planted in association with rice (Table 4). Cucumber, chili, maize, taro. and sesame are planted most frequently. The area planted for each species depends largely on the needs of the family and is usually small. Only maize grown for pig feed and human consumption and crops planted for the market, such as sesame, are cultivated more extensively. The number of hills used for individual crops (Table 4), is only a rough indication of their relative importance as the area per bill varies widely between crop and field. Only the most frequently planted species are listed in table 4. Other crops found in farmers' fields include: pigeon pea. sun hemp. tobacco, mucuna (*Mucuna* sp.), mung-bean, *Phaseolus* bean, watermelon, spices and ornamental flowers.

Various crops are often planted in specific niches: cucumbers and yam bean climbing on short tree trunks; loofah species climbing on trees that were too difficult to cut; cowpea in areas with poor rice stands; maize, Job's tears (*Coix lachryma-jobi*). and cassava along paths and boundaries; chi-Ii, pigeon pea. and various spices and ornamentals near the temporary field hut.

RICE THE MAJOR STAPLE AND AN IMPORTANT SOURCE FOR CASH

According to our survey data about 125 kg per capita of milled rice was produced in both years, with additional net inflow of rice. The quantities of rice available are only slightly lower when compared with major rice-consuming countries such as Indonesia and Bangladesh (Iuliano 1993:20). There could be some doubt in the reliability of the figures, because farmers tend to report lower areas and production figures as until recently they were taxed on the basis of the area of rice cultivated. The differences in rice trading observed between the samples of 1992 and 1993 are largely an effect of the additional district included with a relatively large number of households. The volume of rice trading is dependent prinarily on transport possibilities. Most households buying or selling rice are located in villages that are close to the road.

In spite of the relatively large quantities available, tanners report rice deficit periods of almost 4 months on average. This apparent deficit may rcsult from a combination of factors including: localized shortages, inclusion of households with other major sources of income, and farmers optimizing rice usage to avoid losses- Increasing storage losses over 'time, absence of a market, and availability of other food sources may make it more attractive for the family to produce and store rice for 8-10 months only, rather than having large surpluses. The occasional shortages of rice are certainly not a recent phenomenon (Gourou 1942: 355; Wall 1975:29). About 50 years ago Gourou (1942) made the following observations: "The rice and maize harvested is used for daily consumption or transformed to alcohol and it is rare that the farmncrs have sufficient reserves until the next harvest- The rice stores are usually empty in July forcing farmers families to rely on hunting and gathering for provisions.

TABLE 5. REASONS CITED FOR NOT HAVING SUFFICIENT RICE.[1]

Reason	1992	1993
Lack of rain	39	50
Pests	35	25
Illness in family	7	5
Lack of labor or too much weed	7	8
Sold or exchanged	7	4

[1] Sample size was 64 and 126 households in 1992 and 1993. respectively.

Upland farmers, especially those living in remote areas, have little incentive to produce surplus rice. Already 100 years ago the lack of a market was considered the main deterrent to higher rice production in Laos (Pavie 1901: 197). Without surplus rice production, small fluctuations in yield caused by climate, pest problems. or labor shortages immediately lead to rice shortages.

Although farmers usually agree that weeds are the main constraint to rice production (Roder et aL 1994), lack of rain or poor rainfall distribution was the main cause mentioned by them for rice shortages in 1992 and 1993 (Table 5). Rainfall for Luang Prabang for the same years was 96 and 93% of the long term average. The annual rainfall in the region is quite low with a long-term average (1950-1994) of 1282mm for Luang Prabang. It is therefore quite possible that localized drought stress may have had significant effects on some fanns. Drought stress as a main cause of rice shortages in an average rainfall year clearly shows how vulnerable the systern really is. Years with unusually low rainfall since 1950 were 1954, 1956. 1957. 1958, 1959, 1962, 1967, 1968 and 1987 with rainfall totals of only 78. 80, 38. 68. 80, 79. 79, 76, and 81% of the long-term average.

In spite of the limited access to market, because of poor road communication and lack of proper market mechanisms, rice has become an important source of cash, especially for farmers with limited cash income from livestock (Table 6). Having no alternative but to sell rice for ready cash was cited as the main reason for not having sufficient rice by 7% of the respondents in 1992 and 4% in 1991 Unfortunately most

TABLE 6. SOURCES OF CASH INCOME'.

	Households (%)		Cash income (US $)	
	1992	1993	1992	1993
Rice	28	26	15	5
Livestock	67	57	76	59
Forest products	18	47	3	10
Other crops	23	18	3	5
Wages and off farm	32	30	15	8

[1]Sample size was 63 and 126 households in 1992 and 1993 respectively.
[2]Figures refer to the calendar year (nor consistent with table 6, where harvest of a particular year was used)

tanners are forced to sell their rice before (on advance payment) or shortly after harvest, at a time when rice prices are low.

It may be predicted that rice trading will in crease rapidly with improved market access and that upland tanners will gradually become more dependent on rice produced in lowland environments. Yet with the growing economic power of the urban population, and their preference for aromatic glutinous rice, there is an increasing market for rice produced under upland conditions and sold at premium prices.

Maize and tuber crops are planted primarily to be used as livestock feed but also are used widely as rice substitutes, especially in the months before the new rice harvest. Planting larger areas to these crops would greatly improve the food security of remote areas, without the problems associated with fluctuation in production because surpluses would be directly absorbed by the producers through conversion into animal products. If indeed drought is the main cause of food deficits, systems guaranteeing food security for remote areas will only be found by using less drought-susceptible crops other than rice. Unfortunately the consumption of maize and tuber crops is associated with low social status, and with increased availability of cash, rice purchased from the market has become the most important food source in periods when rice produced by the family is not sufficient (Table 7, 8).

Upland farmers have traditionally used a variety of products from forest and fallow land, including tubers, bamboo shoots, greens, fruits, insects and animals, and some were confident that they could survive without rice for periods of up to a year (Izikowitz 1951).

TABLE 7. IMPORTANCE OF RICE' IN INDIVIDUAL HOUSEHOLDS (HH).

Parameter	1992:	1993
Rice production		
Rice produced per family (kg year')	1289	1214
Rice produced per capita (kg year-')	179	179
Rice outflow		
Households selling rice before harvest (%)	2	8
Average quantity said before harvest (kg hh^{-1})	10 (640) [3]	15 (192)
Households selling rice after harvest (%)	39	21
Average quantity sold after harvest (kg hh^{-1})	191 (489)	36 (176)
Rice inflow		
Households buying rice (%)	44	25
Average quantity bought (kg hh^{-1})	313 (715)	68 (268)
Households borrowing rice (%)	20	2
Average quantity borrowed (kg hh^{-1})	68 (332)	1.4 (60)
Households exchanging goods for rice (%)	17	17
Average quantity acquired by exchange (kg hh^{-1})	32 (187)	16 (96)
Rice consumption		
Rice self-sufficiency (month year')	7.9	8.1
Net inflow (kg hh^{-1})	212	34
Net inflow (kg per capita)	29	5

[1]all figures in unhusked rice, approximate recovery For milled rice is 70%
[2] Sample size was 64 and 126 households in 1992 and 1993. respectively.
[3]Quantity 4) average for households selling or buying rice.

TABLE 8. OTHER STAPLE FOODS FARMERS EAT WHEN THEY DO NOT HAVE SUFFICIENT RICE)

	Used as a major rice substitute by farmers(%)	
Staple bed	1992	1993
Purchased rice	54	85
cassava	39	7
Maize	32	12
Taro	19	10

[1]Sample size was 64 and 126 households in 1992 and 1993, respeclively

SUMMARY AND CONCLUSIONS

Traditional upland rice varieties represent a wide genetic diversity but are largely of the japonica type. In spite of environmental constraints, rice is and will remain the most important crop for the bill population. Farmers are ready to invest most of their labor in rice production to produce a high-quality glutinous rice for home consumption. Improved access to markets will probably increase the dependency on rice as a staple food, but at the same time will result in a partial replacement of home-produced rice by rice brought. from outside. Policies emphasizing food security through rice production are not likely to help the farmer through the transition period from subsistence slash-and-burn systems to market oriented, land use systems with permanent cultivation When formulating development strategies and policies the following facts must be recognized:

1. Traditionally upland farmers were never solely dependent on rice for their food requirements;
2. Rice deficits of 1-3 months are not a new phenomenon;
3. Upland farmers are often forced to sell rice in order to find cash for urgent purchases;
4. Real food security in remote regions may only be achieved/maintained by focusing on crops other than rice, such as maize and cassava in association with livestock production

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Research methodology

Slash-and-burn environments are generally very heterogeneous as a result of past land use, variations in climate, and the soil formation process. Heterogeneity increases rapidly with an increase in ruggedness of the topography because of an interaction of the factors mentioned above with elevation, slope gradient, and exposure. Furthermore, in the absence of tillage, short-range variability can be extremely high and is influenced by the fallow vegetation cover, uneven deposits of ash during burning, and the activities of termites and other soil organisms. Because of this variability, the number of locations or repetitions required for conventional experimental designs can become unrealistically high (Nokoe and Olufowote 1990).

The frustration faced by researchers was aptly described by a reviewer commenting on one of our first soil-related papers submitted for publication. The anonymous reviewer wrote: "The older I get, the less patience I have with the unfounded hope that knowing how much variability there is out there will in some manner solve the problem. I'll admit that knowing a site is reasonably uniform is a comfort if one is determined to treat the area uniformly. But knowing how many subsamples thoroughly mixed are required to wipe out evidence of 100 termite mounds, 200 ash spots, 25 root wads, and one abandoned outhouse does not get us anywhere, except to ask the question 'so what'?"

The inherent heterogeneity of the environmental factors of slash-and-bum environments requires special attention from the researcher. Although suitable methods can be found for most situations by modifying and adapting conventional methods, there is a need to develop tools and methodologies for specific situations. Experiences generated in the various field investigations may provide inputs for the planning of future activities and for refining specific research tools and methods.

Participatory research methodologies

The initial research activities focused on characterizing the production system and its environment and collecting and describing rice varieties. In these efforts, farmers' participation was largely in the form of providing information. In the second phase, when efforts gradually shifted toward developing appropriate weed management practices and developing alternative production systems, farmers' participation became increasingly important. The level of participation varied based on the objective of the individual studies.

Exploiting heterogeneity

Although heterogeneity in the environment, especially in soil conditions, is a major obstacle to implementing field experiments, it can also be used to the researchers' advantage. The wide range of soil fertility or soil moisture conditions within one field or region, for example, can be exploited in fertility and moisture studies and their interaction. Instead of a design with applied treatments or with the inclusion of many sites, a research project could use the existing range of conditions. We used the opportunities provided by the heterogeneous conditions in our efforts to describe weed, pest, and soil conditions and their effects on rice yield.

Measurements for soil movements

Two methods, plastic-lined ditches and pins, were used to estimate soil movements. With the pin method, metal rods (1 m long, 8-12 mm diameter) were inserted in the ground and changes in soil height measured at certain time intervals. This method is suitable only for situations in which extremely large quantities of soil movement are expected, as a 1-mm change in soil height corresponds to a soil quantity of about 100 t ha-'. For most situations, the use of pins was not suitable because the soil movements were too small. Furthermore, small changes in the soil surface, such as changes due to soil shrinking and swelling or the effects of weeding, can strongly affect the measurements.

The method using plastic-lined ditches at the lower end of the observation plot was found to be the most suitable method for short-term observation plots (<3 years) where an installation with permanent structures was not justified (Roder et al 1995). The soil accumulated in the ditches was collected and removed at monthly intervals. It was found to be important to use a plastic that was resistant to ultraviolet radiation. Termite damage and drainage of runoff water were factors that had to be given special attention.

Minimizing plot-to-plot interactions

Experimental plots on sloping land are exposed to runoff water and soil movements. Treatment effects of plots in the upper part of the slope may affect plots located below. To minimize these effects, a system of erosion barriers, mostly Brachiaria brizantha or vetiver grass (Vetiveria zizanjoides), and drainage was used for the on-station research area. To minimize plot-to-plot interactions, vetiver grass was also routinely planted along the plot borders (around each individual experimental unit) of long-term experiments and runoff water removed through a combination of these grass strips with drainage ducts. This method was also found to be excellent for demonstrating the problem of erosion and soil movements.

In on-farm studies, plots were generally laid out in a way to have only one line of plots along the contours of the slope. Plot-to-plot interactions were further minimized by drainage furrows between plots. In long-term on-farm studies, vetiver grass or B. brizantha was generally used as erosion barriers and to minimize plot-to-plot interactions.

Vegetation measurements for weeds, fallow vegetation, or improved fallow

The methods used to measure weed cover, weed species composition, and vegetation cover during the fallow period were largely borrowed from methodologies used for ecological studies, especially for vegetation assessment in rangeland systems (Cook and Stubbenclieck 1986, Kent and Coker 1992). Covet; density, frequency, and biomass yield were the most widely used measurements. Cover was usually based cii visual assessment. Frequency and density were measured from quadrates ranging in size from 0.04 to I in2. Density is a count of numbers of a given species per unit area. The presence of a species in the quadrate provided an estimate of its frequency in plots of the particular size (Kent and Coker 1992).

A modified transect method was used for the observations of weed populations in farmers' fields. A 10-m measuring tape was placed above the rice crop canopy and weed cover directly underneath the measuring tape was recorded for individual species in 1-rn intervals. These observations provided an estimate of weed cover (in cm) and frequency (based on presence or absence of a particular species in 1-rn intervals).

Annual changes in the biomass of the vegetation in long-term fallow monitoring plots were estimated from samples taken outside the monitoring plots. Similarly, a double-sampling method was used to estimate yields in some studies to reduce labor requirements. In this method, only a fraction of the observation quadrates are clipped and measured to calibrate visual observations made in the other plots (Cook and Stubbendieck J 986).

Variation in parameters measured

For proper planning of field experiments, it is necessary to know the expected variation of parameters to be observed. The coefficients of variation (CVs) for rice yield and other parameters measured in experiments carried out during 1991-94 are shown in Table 2 and Figure 5. The variation in rice yield increases with decreasing yield for both on-station and on4arm experiments. Fallow vegetation has a strong influence on the variation. When the previous crop was

Table 2. Range and average coefficient of variation (CV) observed in field trials carried out during 1991-94A

	Number of trials	CV range	CV average
Yield on-station	28	11-70	24.9
Yield on-farm after fallow	9	15-49	322
Yield on-farm after rice	5	5-34	15.4
Plant height	10	5.7-1 3.3	7.2
Panicle number	8	10-17	13.6
Grain weight	3	2.3-3.2	2.8
Days to flowering	1	-	1.7

[a]Based on Lao-IRRI Annual Reports 1991,1992. 1993, and 1994 (unpublished).

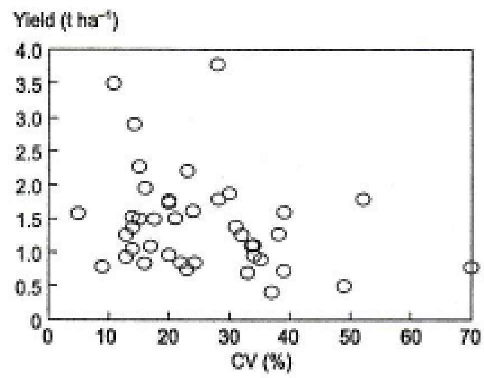

Fig. 5. The relationship between coefficient of variation CV (%) in field experiments and yield (based on Lao-IRRI Annual Reports 1991, 1992, 1993, and 1994, unpublished).

rice, the CV in on-farm studies was substantially lower than for experiments conducted in fields after fallow. The high variation is often due to nutrient stress or white grub damage. If the influence of these factors can be minimized, CVs below 10% can be expected. The variation for yield components such as particle number, grain weight, and days to flowering is much lower than for grain yield.

The results from a study estimating short-range variability for selected soil parameters were published in Roder et al (1995), included at the end of this section.

Additional experiments were carried out in 1995 to compare variability (within fields and between fields) of potential parameters to be used for soil-water-weed interaction studies. The studies were carried out in Xiengngeun District, Luang Prabang Province. Fields were selected in April, after farmers had burned the slashed fallow biomass. Areas with apparent irregularities (trees, bamboo stumps, termite mounds) were excluded. Planting of the traditional glutinous rice variety Vieng was done following the traditional method, placing approximately 8-10 seeds treated with carbaryl in 3-5-cm-deep holes made with a dibble stick. Planting boles were spaced at 20 x 25 cm.

Methods for study I, variation within field. One field each, with a reasonably uniform soil surface, was selected at Houayhia (site A) and at Beusam (site B). Slope gradients ranged from 5% to 30% at site A and from 5% to 35% at site B. At each site, 30 individual plots of 5 x 3 m were delineated with a distance of at least 4 m between plots. Rice was planted on 17 May at site A and on 18 May at site B. Soil samples, eight subsamples per plot, were collected with an Oakfield probe at depths of 0-15 and 15-30cm at planting, at panicle initiation (0-15 cm only), and at harvest. Leaf chlorophyll content was measured with a chlorophyll meter (Minolta SPAD-502) monthly three times with intervals of 1 month starting on 5 July at site A and on 4 July at Site B. Measurements were taken from 10 fully expanded uppermost leaves per plot. White grub damage was assessed by counting hills affected in July and August. Root samples from five hills per plot were collected after flowering to quantify root-knot nematode (*Meloidogyne graminicola*) density on the crop root, following methods described by Prot and Matias (1995). At maturity, 20 hills were harvested randomly from each plot to measure panicle number per hill and rice yield.

Methods for study. 2, variability between fields and the effect of N application. Nine fields were selected. In each field, an experiment was laid out with three replicates and three treatments: (1) control, (2) 30 kg N applied at panicle initiation, and (3) 20 kg N at panicle initiation and 20 kg N at flowering. Plot size was 25 m^2. Planting was done at all sites between 2 and 7 June. Leaf chlorophyll content was measured in August. The methods used to measure chlorophyll and root-knot nematodes were the same as those described above. At maturity, panicle numbers were recorded from 10 hills per plot and rice yield was measured from the entire plot after removing border rows.

The results were similar for the two sites (Table 3). The highest variability was observed for pest and weed observations, with a CV of 334-544% for nematocle density. Both nematode and weed observations do not usually follow a normal distribution and transformations are frequently used for statistical analysis. Plant observations also showed high variation, except

Table 3. Variation within individual fields for plant, soil, and pest parameters (30 individual plots each for site A and site 8). CV = coefficient of variation.

Parameter	Site A			Site B		
	Av	Range	CV	Av	Range	CV
Crop						
Biomass at PI[a](fresh gm^{-2})	296	120-500	30	552	190-940	36
Grain yield (g hill-1)	24	13.1-35.3	27	37	16.9-64.9	37
Soil						
Moisture at harvest 0-15 cm (%)	21	15.3-25.5	10	26	20.8-30.7	9.7
Moisture at harvest, 15-30 cm (%)	22	18.9-25.2	7.7	27	22.3-31.4	9.0
Bulk density, 0-15cm	1.2	1.14-1.31	3.6	1.1	0.97-1.18	4.4
Bulk density, 15-30 cm	1.3	1.20-1.40	4,2	1.2	1.13-1.36	4+1
Sand, 0-15 cm (%)	33	24.9-38.9	10	33	26.9-40.9	12
Sand, 15-30 cm (%)	28	20.9-34.9	14	27	20.9-34.9	13
Organic C, 0-15 cm (%)	1.9	1.44-2.68	14	1.5	1.2-1.8	12
Organic C, 15-30cm (%)	1.1	0.76-2.04	24	0.86	064-1.28	16
Total N, 0-15 cm (%)	0.19	0.15-0.25	12	0.21	0.14-0.29	18
Total N, 15-30cm (%)	0.14	0.11-0.18	12	0.16	0.13-0.20	13
Available P, 0-15cm (mg kg^{-1})[b]	16	6.3-40	41	18	8.8-70	64
Available P, 15-30cm (mg kg^{-1})	4.9	2.5-12	41	79	2.8-75	163
CEC,0-lScm	3.6	1.94-6+2	26	6.8	3.14-9.41	25
CEC, 15-30cm	1.9	1.26-3.56	32	4.4	2.29-7.64	31
N supply						
SPAD July	35	31.9-37.8	4.7	35.0	31.8-37.8	3.9
SPAD September	35	30.6-40.6	8.0	34.2	2&7-432	13.4
N at planting (kg ha^{-1})	63	37-111	23	71	48-1 08	20
N at harvest (kg ha^{-1})	43	17-69	32	81	40-1 32	38
Weeds						
Weed biomass at P1 (fresh g m^2)	133	3-415	83.2	79.5	18-313	94.7
Ageratum density (plants m^2)	5	0-16	89.0	43.4	10-1 20	53.0
Pests						
White grub (hills damaged m^{-2})	0.13	0-0.6	97.7	0.13	0-0.67	133.8
Helicotylenchus sp (no. g^{-1} root)	4.58	0-21	134.6	0.61	0-11	343.6
Meloidogyne graminicola (no. g^{-1} root)	0.07	0-2	544.8	7.7	0.-136	334.9

[a] PI = panicle initiation CEC = cation exchange capacity
[b]Olsen extraction.

Table 4. Variation in yield and other parameters for individual sites[a] CV = coefficient of variation.

Site	Previous crop Ct ha^{-1})	Grain yield Average Ct ha^{-1})	Range (%)	CV P1	CV (%) of other parameters Blomass at	Panicles (no hill^{-1})	SPAD[b]	Nematodes
H. Khot1	Rice	1.21	0.88-1.65	13	27	8.4	5.8	297
H. Khot2	Rice	0.92	0.57-1.28	30	23	22	4.6	167
Beusaml	Fallow	2.38	2.08-2.71	5,5	25	n.a.[c]	4.9	270
Beusam2	Fallow	0.95	0.38-2.12	32	54	21	2.9	159
Pakto1	Rice	0.21	0.03-0.32	60	n.a.	40	3.6	279
Pakto2	Rice	0.54	0.26-1.00	22	n.a.	27	3.2	n.a.
Nakha	Rice	0.97	0.38-1.45	14	n.a.	17	6.4	n.a.
Houayhia1	Rice	2.43	1.42-3.12	19	8	17	3.3	157
Houayhia2	Rice	2.36	1.75-2.97	1.5	n.a.	16	3.7	n.a.

[a] Results from a fertilizer trial carried out at nine sites (on-farm) with three replicates and three treatments.
[b] Panicle initiation stage.
[c] n.a. = data not available.

for the SPAD measurements. The CV for rice yield from individual sites in the fertilizer study ranged from 1.5% to 60% (Table 4). The high variation at some sites was largely due to white grub or root-knot nematode damage. The variation observed for soil parameters was similar to that observed earlier (Roder et al 1995, article included at the end of this section) with CVs <20% for organic C and total N and CVs >50% for available P. Soil physical measurements, such as bulk density and moisture, had lower CVs, generally <10%.

The earlier study (Roder et al 1995) compared the variation between individual soil samples collected in a grid system, whereas in this study composite samples from eight subsamples per plot were used. Thus, the earlie study compared variation between individual points, whereas the latter compared variation between plots. The high CV for yield measurements observed in both experiments demonstrates the need for researchers to be prepared to work with lower confidence levels, high numbers of sites or replicates, or larger treatment effects.

<u>Paper included with this section</u>

Roder W, Pbengchanh WS, Soukbaphonh H. 1995. Estimates of variation for measurements of selected soil parameters on slash-and-bum fields in Northern Laos. Commun. Soil Sci. Plant Anal. 26:2361-2368.

Ditches lined with plastic were used to estimate soil movements.

Hills of rice affected by white grub damage.

Collecting soil samples in a slash-and-burn field with the Oakfield probe.

Long-term research plots with borders of vetiver grass (*Vetiveria zizanioides*).

COMMUN. SOIL SCI. PLANT ANAL., 26(15&16), 2361-2368 (1995)

ESTIMATES OF VARIATION FOR MEASUREMENTS OF SELECTED SOIL PARAMETERS ON SLASH-AND-BURN FIELDS IN NORTHERN LAOS

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ABSTRACT: Monitoring changes in soil fertility is an important component in the evaluation of land-use systems. This research was undertaken to estimate short-range soil variability of selected soil parameters in slash-and-bum systems of. Northern Laos as a prerequisite for planning long-term experiments. Coefficient of variation for the top interval (0-3 cm) was 10.4, 8.7, 20.7, 12.8, 75.8, and 44.8% for pH, total nitrogen (N), organic carbon (C), total phosphorus. (P), available F, and available potassium (K), respectively (averaged over two sites). Variation generally decreased with increasing depth of soil interval, except for soil organic matter, where coefficient of variation was 14.1, 13.4, 14.6, 18.2, and 26.9% for intervals of 340, 10-25, 25-50, 50-75, and 75-100 cm, respectively. The number of sub-samples required to document changes in available P and K will be unrealistically high if high confidence levels are required. Correlation between pH and available P and K was high for the 0-3 cm interval.

INTRODUCTION

Slash-and-bum agriculture with upland rice as the major crop is the predominant land-use system in the hilly areas of Northern Laos. With low population densities and moderate expectations, this system may have been ecologically sound and adapted to the resources available. The government presently gives high priority to reducing the area under slash-and-bum agriculture. These interventions, along with fast population growth, have resulted in shorter fallow cycles and consequently increased weed problems and soil deterioration (Fujisaka. 1991).

Research evaluating the effects of increased cropping intensity, improved fallow, and/or green manure crops on soil fertility in slash-and—burn systems of Northern Laos has been accorded high priority (Fujisaka, 1991). Although little information: is available on Laos, literature about changes in soil fertility during cropping and fallow periods of slash-and-bum systems in Asia, Africa, and South America abound (Andriesse and Schelhaas, 1987; Nyc and Greenland, 1960; Sanchez, 1987).

Influenced by a variable vegetation cover, uneven distribution of ash deposits, and activities of termites and other soil organisms, soil variability within an individual field jg generally very high. Several authors have made reference to the high variability of soil fertility parameters in slash-and-bum soils (Isbell, 1987; Pushparajah, 1989; Chancy and McGarity, 1978), but estimates of the magnitude are scarce. Andriesse and Schelhaas (1987) cite coefficients of variation (CV) up to 50 and 100% for available P in slash-and-bum soils in Sarawak and Thailand, respectively. Pusbparajah and Chan (1987) have presented data from rubber plantation soils showing CY's of 20.6, 18.6, 67.5, and 55% for C, N, nitrate (NO~), and available P, respectively. Coefficients for organic C ranged from 29 to 52% for Rendosols in Belize (Brubacher et al.; 1989). These estimates of soil variability are generally limited to the topsoil interval of 0-10 or 0-15 cm. Fournier et al. (1994) described short-range variability in three forest covered acid soils in Canada and discussed the results of similar studies.

This study was undertaken to: (i) estimate short-range variation in key soil parameters under typical slash-and-bum conditions of Northern Laos, and (ii) determine the appropriate number of subsamples to be taken for cropping systems and nutrient dynamic studies.

MATERIALS AND METHODS

Soil samples were collected from 200 in2 plots at two shifting cultivation sites in the Xiengnguen District of Luang Prabang Province (Table 1). Sites selected have representative soils for slash-and-bum areas of Northern Laos were of uniform slope, had undergone several fallow/cultivation cycles, and were free of large termite mounds or large root wads. Following traditional practices earlier described by Fujisaka (1991), vegetation was slashed in February and burned in late March of 1991. Sampling was carried out in May, 15 days after planting rice. Samples were collected in a grid pattern using 4x5 m distances. At each site. 10

Table I: Description of (he two sample sites

	Banlong-O	Ban 1O
Elevation (in)	460	350
Slope (96)	35	30
Soil type1)	Dystric Cambisol	Ferric Alisol
Years cropped	1	2
Years fallow	6	8

1) Soil Survey Department. Ministry of Agriculture and Forestry, LAO-PDR, Vientiane

individual samples were collected at depth intervals of 0-3, 3-10, 10-25, 25-50, 50-75, and 75-100 cm using an Qakfield core sampler (20-mm diameter). Samples were air-dried and sent to the laboratory of the Lands Development Department in Bangkok for determination of pH, and organic matter (Walkley-Black acid dichromate digestion), total N (semimicro Kjeldahl), total P (x-ray fluorescence), available P (Bray P2), and available K (extraction with 1N NI-140Ac) contents (Page et al, 1982).

The number of samples (n) necessary to estimate the mean of a particular parameter within a certain range (D) was estimated using the equation:

$$n = t_{.}^{2} s^{2} / D^{2} \qquad [1]$$

where: ta = Student's 't' with (n-i) degrees of freedom for the desired confidence level and s^2 = variance (Petersen and Calvin, 1986). The relationship between the different parameters measured was evaluated using correlation estimates.

RESULTS AND DISCUSSION

Nutrient concentrations were greatest in the top 0-3 cm interval (Table 2). This is largely the result of litter turnover, humus accumulation, and ash deposits as has been documented in various environments (Andriesse and Scbelhaas, 1987; Nye and Greenland, 1960). While a decrease in magnitude with increase in depth was fairly gradual for most nutrients, available P content dropped abruptly. The concentration of available P at the 3-40 cm depth interval was only 23% of its concentration in the top interval.

Table 2: Average value, range and coefficient of variation (CV) for soil parameters at 2 sites

Parameter/depth	banlong-O			ban 10		
	Average	Range	CV (%)	Average	Range	CV (%)
pH						
0- 3cm	5.82	5.2-7.0	11.6	5.74	5.2-67	9.2
3 - 10cm	4.83	4.5-i6	6.4	4.97	4.7-5.5	5.5
10- 25 cm	4.56	4.0-4.7	4.6	4.67	4.6-4.8	1.5
25 - 50cm	415	4.6-4.9	2.0	4.75	4.6-4.9	1.8
50-75 cm	4.88	4.8-5.0	1.6	416	4.7-5.0	2.0
75 ‘100cm	5.03	49-5.1	1.6	4.94	4.7-5!	2A
Total N	**kg soil^{-1}**			**kg soil^{-1}**		
0- 3 cm	2.56	2.2-3.2	12.9	2.98	2.81.2	4.4
3- 10cm	2.14	l.9-2A	6	2.45	2.3-2.6	4.1
10-25cm	1-91	11-2.2	16.2	21.3	1.9-2.1	3.9
25-50cm	1.89	1.8-2.1	5.3	1.79	1.7-1.9	3.4
50-75cm	138	1-5-2.0	9.0	169	1.6-1.8	4.1
75 -100cm	1.65	1.4-2.1	12.7	1.55	1.5-1.7	41
Organic matter	**kg soil^{-1}**			**kg soil^{-1}**		
0- 3cm	491	37-90	31.6	64.1	54-77	9.7
3-10cm	29.8	24-37	15.0	42.4	37-52	13.1
10-25cm	22.5	18-29	17.5	26.2	23-31	9.3
25-50cm	16.8	14-20	12.5	19.6	17- 28	16.8
50-75cm	141	9-19	24.0	14.5	12-I8	12.3
75-100cm	12.0	8-fl	33.5	11.1	9-16	20.3
Total P	**mg kg soil^{-1}**			**mg kg soil^{-1}**		
0- 3cm	651	565.785	12.3	852	304-880	13.3
3- 10cm	515	495-565	4.3	663	620-710	4.7
10- 25 cm	468	445-495	3.9	561	520-595	4.1
25 - 50 cm	433	395-460	5.4	497	445-520	45
50 - 75 cm	404	385-435	3-9	454	430-485	3.2
75-100cm	418	375-475	7.2	438	410-465	4.2
Available P	**mg kg soil^{-1}**			**mg kg soil^{-1}**		
0- 3cm	371	12-116	82.6	38.0	11 87	689
3 - 10cm	71	1.2-22	763	91	4.0- 14	35.4
10-25cm	5,8	2.9-13	51.7	7.3	1.9- 17	60.5
25 - 50cm	41	2.5-7.1	31.0	61)	2.8- 12	43.5
50-75cm	5.5	3.3-8-5	33.7	6.5	2.7- 10	31.9
75-100cm	41	2.2-7.8	38.4	7.4	2.5- 15	50.7
Available K	**mg kg soil^{-1}**			**mg kg soil^{-1}**		
0- 3cm	330	198-796	53.1	474	304-880	36.4
3 - 10cm	126	61-384	75.8	179	78-320	44.8
10-25cm	80	55-170	43.5	88	65-138	24.5
25-50cm	57	43-80	20.0	60	46-74	13.6
50-75cm	SI	34-65	19.1	49	41-59	10.6
75- 100cm	41	35-55	14.7	48	40-59	14.4

As expected (Petersen and Calvin, 1986), the variation in measured soil properties was highest among samples of the top interval, except for organic matter content. Probably influenced by the non-uniforn root distribution of the fallow vegetation, variation in organic matter content remained high or increased with depth. The differences in magnitude of variation observed between the two fields could be due to differences in soil type, slope, effect of cultivation, previous cropping-fallow cycles, or other factors.

The CV estimates for total N, organic matter, available P. and available IC contents presented in this study are comparable with values reported by others (Andriesse and Schelhaas, 1987; Pushparajah and Chan, 1987; Brubacher et al., 1989), but are generally higher when compared to temperate forest soils (Fournier et al. 1994), or cultivated tropical soils (Dhillon et al. 1994). The moderate variation in pH, total N, and total P makes 15 subsamples sufficient to document changes of 10% with a confidence level of 95% on a 200 in2 plot. Similarly, 20 subsamples would be enough to document changes of 10% in soil organic matter Content. High variation in available P and K, however, necessitates a much higher sample number for these parameters. The number of subsamples required to document changes of 10% at a confidence level of 95% for the Banlong-O soil would be 348, 297, 137, 49, 58, and 75 for available P content and 144, 294, 96, 20, 19 and 11 for available K content for depths of 0-3, 3'l0, 10-25, 2$50, 50-75, and 75-100 cm, respectively. Collecting such a high number of subsamples is unrealistic for most situations; therefore, lower confidence levels will have to be accepted or other sampling methods devised. Sampling from smaller subplots at fixed locations [as used by Cassman et al. (1992)] could help reduce variation in studies that monitor nutrient changes over time. For both soils, the lowest depth interval had the highest variation in organic matter content. Organic matter is likely to be a key parameter in monitoring studies. Considering the high variation in organic matter at lower depths, it may be necessary to collect large numbers of samples for all depth intervals.

Correlation between various soil parameters decreased with depth, thus only the estimates for the top three intervals are shown (Table 3). Organic matter, N, P, and K pools in the topsoil are strongly linked to the vegetation dynamics and its resulting litter turnover and accumulation. Ash deposits from the burned biomass directly influenced ph, total P, available P, and available K content in the 0-3 cm soil interval, resulting in high correlation coefficients. Also for the second depth

Table 3: Correlation matrix for the 3 top intervals (Averaged over both sites)

Parameter	pH matter	N	Organic	Total P	Available P
Depth 0-3 cm					
N	-	-	0.89***	0.58***	-
Organic matter	-	0.89***	-	-	-
Total P	0.42*	0.58***	0.57***	-	0.57***
Avail P	0.88***	-	-	0.57***	-
Avail K	0,73*	-	-	0.67**	0.81***
Depth 3-10 cm					
N	0.51**	-	0.81***	0.81***	-
Organic matter	0.43*	0.81***	-	0.80***	0.44*
Total P	0.44*	0.8l***	0.80***	-	039*
Available P	-	-	0.44*	039*	-
Available K	0.50**	-	0.42*	046**	0.69***
Depth 10-25 cm					
N	-	-	0.69**	-	-
Organic matter	-	0.69**	-	0.54**	-
Total P	-	-	0.54**	-	-
Available P	-	-	-	-	-
Available K	-	-	-	-	-

*,**,***indicate significant correlation or P<0.1, P<0.05 and P<0.0l, respectively

interval. (3-10 cm), some relationship between pH and total P and available K content was observed. At the same time there was a strong relationship between organic matter and the same parameters in the 3-10 cm interval. Total P was related to organic matter for the following depth intervals: 0-3, 3-10, 10-25, and 25-50 cm. Organic matter and total N were related at all depths except at the 25-50 interval.

Following the results of this study, it will be feasible to document effects of cropping system treatments on sail fertility parameters in slash-and-bum sails. Depending on objectives and treatments, organic matter is likely to be the most suitable parameter to be monitored and has lower variation than available P and K. Soil physical parameters, such as water infiltration and bulk density, may offer additional important tools to document and explain the treatment effects.

ACKNOWLEGEMENT
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Soil and soil fertility

Soil infertility is frequently cited as a constraint to crop production in the tropics in general and for slash-and-burn systems in particular (Sanchez 1987, Warner 1991). Gupta and O'Toole (1986) suggested that almost all upland rice soils have low N supply capacity and that most are deficient in P. Parent material, rainfall pattern, topography, vegetation, and cultivation practices are the main determinants of soil quality and fertility. It is generally agreed that soil organic matter plays a key role in achieving and maintaining a certain fertility level (Roder et al 1997). Soil organic matter is not only a pool of plant nutrients; it also affects soil physical, chemical, and biological properties.

In slash-and-burn systems, the accumulation of soil organic matter during the fallow period and ash deposits from the burned biomass are major factors contributing to increased soil fertility at the end of the fallow period. Mineralization of soil organic matter after burning is an important source of N for cultivated crops.

Soil fertility is no doubt an important factor affecting rice yields in Lao shifting cultivation systems. Soils are generally poor, mainly red-yellow, podzolic, and reddish brown lateritic, leached and acidic, with low water-holding capacity. Most references on slash-and-bum agriculture in Lao PDR cite soil fertility as a major constraint. Yet, extensive investigations focusing on subrelated factors that may affect rice, yield failed to show a conclusive relationship between conventional soil, fertility parameters and crop yields. The results of these studies Were summarized in the papers included at the end of this section.

Similarly, in a study carried out in 1995 (methods described in study 2 in the section "Research methodology"), rice yield showed little association with soil parameters measured except for the relationship between yield and chlorophyll (SPAD) measurements (Table 5, Fig. 6). This association was especially strong for SPAD measurements taken in September, at the time of flowering. Other soil parameters measured, besides those listed in Table 5, were texture, pH, CEC, and available P.

In a fertilizer study carried out across nine locations (methods described in the section "Research methodology"), rice yield showed significant associations (P<O.O5) with SPAD readings for two sites and with panicle numbers for five sites (Table 6), whereas N application increased yields at two sites only.

Table 5. Correlation between yield and selected parameters (30 individual plots for each site).

Parameter	Correlation with yield	
	Site A	Site B
Soil		
Bulk density, 0-15 cm	0.20	-0.39**[a]
Bulk density, 15-30 cm	0.15	-0.35*
TotalN,0-lScm	0.21	-0.17
Total N, 15-30 cm	0.34**	0.05
Organic 0, 0-15 cm	0.29	-0.21
Organic C, 15-30 cm	0-27	-0.14
N supply		
Chlorophyll July	0.44**	0.49***
Chlorophyll August	0.31*	0.75***
Chlorophyll September	0.76***	0.78***
N at planting (NH_4 + NO_3), 0-30cm	-0.01	-0.02
N at harvest (NH_4+ NO_3), 0-30cm	-0.12	0.03

[a]* , **, ***Indicate significant correlation at P<0.1, P<0.05, and P<0.01, respectively

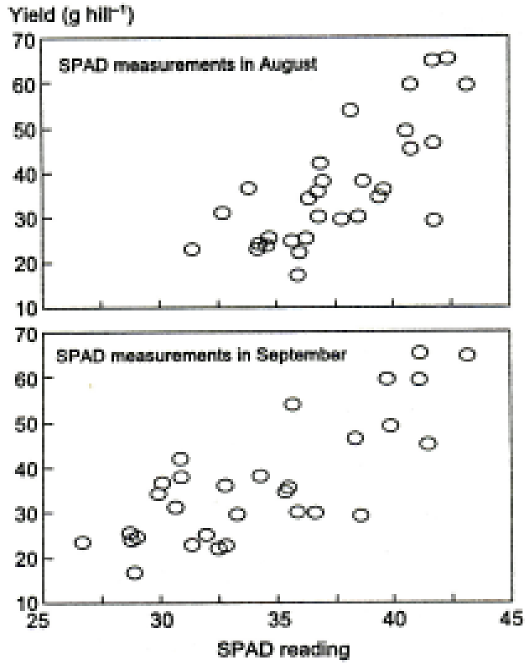

Fig. 6. Relationship between chlorophyll measurements (SPAD) and grain yield (measurements pooled from two sites with 30 plots each).

Table 6. Yield and correlation coefficients between yield and other parameters. [a]

Site	Yield (t hr1)	Yield increase with N (%)		Correlation of yield with	
		1 N application	2 N applications	SPAD	Panicle no.
Houay Khot 1	1.21	3	25	0.42	0.35
Houay Khot 2	0.92	0	0	-0.29	0.58*[b]
Beusam 1	2.38	6	0	0.27	n.a.[c]
Beusam 2	0.95	0	0	0.83	0.65
Paktol	0.21	56	17	0.03	0.83***
Pakto2	0.54	0	0	0.14	0.79**
Nakha	0.97	39	69**	-0.21	n.a.
Houayhia 1	2.43	15	45	0.56	0.77**
Houayhia 2	2.36	6***	0	0.33	0.09

[a]Fertilizer trial carried out at nine sites (on-farm) with three replicates per site and three fertilizer treatments: (1) control, (2) 30 kg N at panicle initiation stage, and (3) 20 kg N at panicle Initiation stage and 20 kg at flowering stage.

[b]*,**,*** indicate significant correlation or treatment effect at P.cO.1, P.cO.05, and P41.01, respectively.

[c]n.a. = data not available.

During 1990-95, a wide range of fertilizer studies were conducted (Tables 7 and 8). Although the results of fertilizer trials are not conclusive, the data indicate that N limits rice yield. The results also imply that N stress is more pronounced in the later part of the growing season, with a higher response to N observed for split applications in which some of the N was applied after panicle initiation or at the time of flowering. Application of P resulted in increased P uptake of 38% but had no consistent effect on grain yield (Table 8).

With a gradual decline in the level of organic matter because of shorter fallow cycles, it is

Table 7. Results of fertilizer studies.[a]

Parameters studied	effect on rice yield	References[b]
Application of N during early phase	0-20	1, 2, 3
Application of N during booting stage	0-40	2, 3
Application of N after flowering	0-40	3
Application of N in 2 splits	0-69	4
Application of N in 3 splits	0-SO	3, 4
Application of P fertilizer	0-15	3
Mulching of pigeonpea residue	57	2
Mulching with C. odorata (fresh)	0	2, 3

[a]For each parameter, all studies reported were included. For most of the N studios. no P and K was applied.
[b] references: 1 = LAO-IRRI annual report 1992; 2 LAQIFIRI annual report 1993. 3 = LAO-IRRI annual report 1994, 4 unpublished data, 1995.

Table 8. Phosphorus uptake by traditional upland rice In response to near-non-limiting applications of P with and without NK (average of three locations on-farm).

Treatment	P uptake (kg ha^{-1})	Grain yield (t ha^{-1})	Biomass yield (t ha^{-1})
No fertilizer	6.8	1.4	3.0
P,Sokg ha^1	9.4	1.4	3.1
F', 50kg, N 100 kg, and K 50 kg ha^{-1}	10.7	2.0	4.5
LSDa (0.05)	2.4	0.5	1.0

[a]LSD= least significant difference.

expected that N stress may become more accentuated and increasingly limit rice yields in the near future.

In many of the fertilizer studies, N was applied at the time of planting or in the early phase of rice development without taking the soil N dynamics and plant requirements into consideration. Mineralization of organic matter, the major N source, accelerates after burning with increasing moisture and temperature and the pool of available N is highest at the time of rice planting (Roder et al 1995). The challenges for the future are to

- limit N and organic matter losses through soil conservation, especially by practices that emphasize residue management;
- provide sufficient N during the critical stages of the rice crop (1) through N-rich residues of forages/crops grown in rotation, (2) timing N supply with N stress, or (3) application of slow-release N.

Many references on Lao slash-and-bum agriculture link poor soil management with ethnicity of the slash-and-bum fanner (Halpern 1961, Win 1959). Extensive quantitative and qualitative data generated from various surveys and from the literature do not corroborate these generalized conclusions. Variations in land use within the same group are generally larger than between groups (see additional information in the articles included at the end of this section).

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RoderW, Pbengcbanh S. Keoboulapha H. 1995. Relationships between soil, fallow period, weeds, and rice yield in slash-and-bum systems of Laos. Plant Soil 176:27-36.
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Monitoring plot after rice harvest.

Monitoring plot with one-year-old fallow vegetation.

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Rice with contour strip of vetiver grass (*Vetiveria zizanioides*).

Plan: and Soil 176: 27-36, 1995.

Relationships between soil, fallow period, weeds and rice yield in slash-and-burn systems of Laos*

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Abstract

Decline in soil fertility accelerated by shorter fallow periods was expected to be a major constraint in slash-and-bum rice production systems in northem Laos. In this paper we describe relationships between fallow period, soil fertility parameters, weeds and rice yield. Soil infertility is not perceived a major yield constraint by the farmers. Of the various soil parameters observed only soil organic matter showed consistent association with rice yield (r =0.42, p<0.01). Fallow period and rice yield showed no association and the relationship between fallow and organic matter was very weak (r=0.16, p<0.01). Rice yield was negatively related to densities of Ageratum conyzoides and Lygodium flexuosum. Soil loss during the cropping period ranged from 300-29.300 kg ha^{-1}. For the same period organic matter, total N, available P and available K content in the top 0-3 cm decreased by 11,12,17, and 17%, respectively, and loss of total N for the soil depth of 0-25 cm was estimated at 400 kg ha^{-1}. Soil physical properties, moisture stress and available N are the most likely detriments to rice yields. Further attempts to relate soil properties to rice yield should include repeated measurements during the cropping season and observations on soil physical properties.

Introduction

Soil infertility is frequently cited as a constraint to crop production in the tropics in general and for slash-and-bum systems in particular (Jordan. 1985; Sanchez and Logan, 1992; Wamer. 1991). Although low fertility limits agricultural production in some tropical areas it is not an universal problem and often other constraints may be confused with soil fertility. Weed competition, rather than soil fertility, is frequently the obvious reason for slash-and-bum farmers to move to a new field (Moody. 1974; Nye and Greenland. 1960; Sanchez, 1976; Wamer, 1991).

Declining soil fertility is often associated with a decline in soil organic matter. Organic matter dynamics under shifting cultivation systems have been well documented (Brubacher et al., 1989; Nye and Greenland, 1960, 1964), and most authors agree that organic matter and nutrient content in soil increase with increasing years under bush or tree fallow (Lugo and Brown, 1993). The biomass of the fallow vegetation generally represents the major pool for potassium, calcium and magnesium (Andriesse and Schelhaas, 1987; Nye and Greenland, 1960; Sanchez, 1987). Most of the nitrogen and phosphorus, is however, located in the soil (Andriesse and Schelhaas, 1987; Sanchez, 1987).

Slash-and-bum agriculture with upland rice as the major crop is the predominant land use system in the hilly areas of northem Laos. With low population density and moderate material expectations of the rural population, this system may perhaps have been in balance with nature. Present government policies give high priority to reducing the area under slash and-bum agriculture. These interventions, along with rapid pop-

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ulation growth, have resulted in shorter fallow cycles and consequently increased weed problems and soil deterioration (Fujisaka, 1991; Roder et al., 1994). Average fallow periods have been reduced from over 30 years to periods of about 5 years.

Most documents discussing the potential of upland agriculture in Laos make reference to soil fertility as a major constraint (Fujisaka, 1991; Gourou, 1942; Lovelace, 1991; Rural micro-projects, 1992; SUAN 1990). Quantitative data to support these generalized observations are, however, nonexistent. From 1991 to 1993 the LAO-IRRI project has collected various data from slash-and-burn fields relating to land use practices, soil fertility and rice production. The available data are summarized with the objective 1) to discuss relationships between land use practices. soil fertility parameters and rice yield, and 2) to identify soil conditions which may affect rice yield.

Materials and methods

General description of the area and the farming System

The studies were carried out in the Provinces of Luang Prabang and Oudomxay in Northern Laos. These two provinces have the highest proportion of upland rice cultivation in the country. Upland rice is generally cultivated on sloping land using slash-and-burn methods without tillage and inputs of fertilizers. Rice is planted in hills with the help of a dibble stick. A single crop of rice is followed by fallow periods of 2-10 years.

The average rainfall for Luang Prabang town was 1340 mm for 1961-90-. Sandstone. limestone, and clastic rocks of Mesozoic and Paleozoic origin are the dominant geological formations in the region (ESCAP, 1990). Other important geological formations include granite and volcanic rocks. Information on soil conditions is sparse. The only soil map of the area classifies most of the upland soils as Orthic Acrisols (FAO/LTNESCO, 1974). Soils are generally reddish-brown and moderately acidic (Roder et al, 1992).

Description of individual studies

Characterization of existing land use systems was the overall objective of the various studies. Findings discussing weed distribution, land use, use of perennial crops, and traditional rice varieties have been reported separately (Roder et al., 1994, 1995a; Phouaravanh et al., 1994). This paper summarizes results relating to soil properties and rice yield. Objectives and location for the individual studies listed below are given in Table 1.

Household survey

Surveys were carried out during the rice-growing seasons using a formal questionnaire supplemented by field observations (Table 1). Villages visited were chosen randomly. The choice of household informants was left to the discretion of the surveyors and was strongly influenced by advice of particular village headmen. A total of 129 households located in 3 districts of Oudomxay (all in 1991) and in 4 districts of Luang Prabang Provinces (mostly in 1992) were included. The survey questionnaire focused largely on land use-related issues. Respondents were asked to rate a list of possible constraints and enumerate the constraints they considered the most important.

During the survey in 1991, soil samples were collected (10-15 subsamples of 0-15 cm depth) from: a) fields currently under upland rice (slashed-and-burned in the same year); and b) fields that farmers expected to slash and use for cultivation in the coming year (last year of fallow). Additional observations taken for fields visited included: slope gradient, cropping period and fallow period.

Crop cut measurements

Two randomly selected 2 x 5m plots were harvested each from 50 fields visited (100 plots). From each plot a composite soil sample of 5-8 subsamples from 0-10 cm depth was collected and analyzed (Table 1). Hills per area and panicles per hill were counted from a subsample of 1 x 1m. Slope gradients and fallow, periods were recorded.

Yield-soil- weed survey

Fifty-five fields were selected, covering fallow periods ranging from 2 to 20 years (Table 1). Five plots of 1 x 1m each were randomly selected in areas where the rice crop visually looked better and areas where the crop looked poor. The following observations were made for each plot:

- Visually estimate rice yield, and biomass of weeds and tree seedlings or coppices.
- Count the number of rice hills and the number of plants of the major weed species *Chrornolne-*

Table 1. Main objectives, location of studies, and details for soil analysis

Study and main objective	Location (Province/districts)	Soil analysis
Household survey (1991/92) ● Characterization of landuse systems ● Identify constraints to rice production	Luang Prabang (Vieng-iham and Xaengnguen districts) Oudomxay (Houn, Say, Beng. and Namo districts)	*Laboratory 1 (L1)*[a] 0M[b]. pH. exchangeable Al, Total N, Total P. EXPC. ExK[d]
Crop cut (1991) ● Estimate rice yield ● Relate yield level to soil parameters	Luang Prabang (Xiengnguen. Vieng-kham and Pongsay districts)	*Laboratory 2 (12)* 0M, pH, total N, Total P, ExP, ExK, Texture
Yield-soil-weed survey (1993) ● Identify relationships between rice yield, weed, and soil parameters	Luang Prabang (Xiengnguen district)	*Laborarory 2* OM.,pH, Total N, Total P, ExP, ExK, NO_3, HN_4, exchangeable AVMg/Ca. CEC, Texture,
Soil changes and soil loss in the cropping period (1992) ● Document changes in soil fertility during cropping period ● Relate changes to soil loss	Luang Prabang (Xiegnguen district)	*Laboratory 1* 014 pH. exchangeable Al, Total N. Total P. ExP, ExK, extractable N($NI1_4$ + NO_3 + NO_2)

[a] L1=Department of Land Development. Bangkok, Thailand; L2 Dongdok, Department of Agriculture and Extension, Vientiane, Lao PDR.
[b] OM - Organic matter.
[c]ExP = extractable P.
[d] ExK = extractable K.

na odorata. Ageratum conyzoides and Lygodium flexuosum.

- Collect soil samples (6 subsamples m2) from 0-15 cm depth for analysis of soil parameters.

Measurements of soil changes and soil loss in the rice cropping period

A monitoring area of 20 x 20m was marked at five sites (S1-S5) in March (Table 1). Sites selected have soils representative of the region, were uniform in slope, had undergone several fallow/crop cycles and were free of large termite mounds or large root wads. Barriers made of bamboo and soil were build around the plot perimeter to avoid runoff interaction from the surrounding areas. Soil samples were collected before burning (Al) (S 1 only), immediately after burning (March, A2), after planting rice (late May to early June, A3), 60 days after planting rice (A4), and at the time of rice harvest (A5). At each site, a composite sample consisting of 20 subsamples 'was collected with an Oakfield core sampler (20 mm diameter). Subsamples were collected from depths of 0-3, 3-10, and 10-25 cm at points on a grid pattern of 4 >c 5 m distances. During the same period soil loss was measured at three sites (S2, 53 and S4) in collection ditches dug below the monitoring plots (20 m long) and lined with plastic. Soil accumulated in the ditches was measured and removed monthly from May to October. An air-dried subsample from each month was retained for laboratory analysis.

Processing of soil samples and chemical analysis

All soil samples were air dried and forwarded for chemical analysis to the Department of Land Development

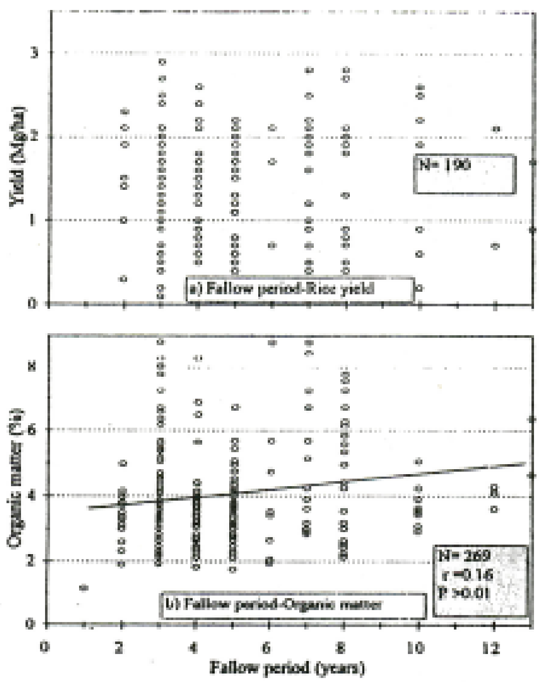

Fig. 1. Relationship between fallow period and a) rice yield and b) soil organic matter.

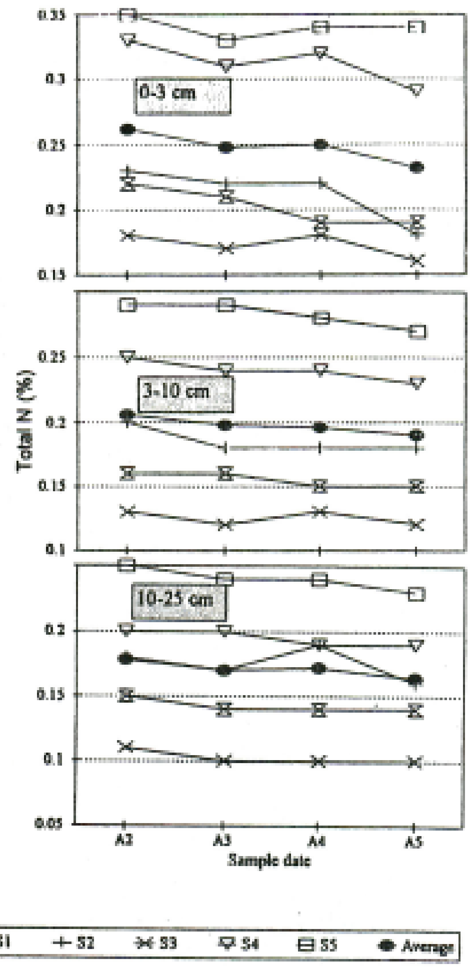

Fig. 2. Total soil-N (%) from samples collected at five sites in Xiengnguen district (1992). A2) after burning, A3) after planting rice, A4) 60 days after planting, and A5) at time of rice harvest. Sampling depths were 0–3, 3–10, and 10–25 cm.

(DLD, Bangkok, Thailand) or Soil Survey and Soil Classification Laboratory (SLC) Dongdok. Department of Agriculture and Extension (Vientiane, Laos) (Table 1). Analytical methods used by the DLD were Waildey-Black for organic matter, 1:1 soil water ratio for pH, micro Kjeldahl for total N, x-ray fluorescence method for total P, potassium chloride extraction for exchangeable Al, Bray-2 for extractable F; ammorn-urn acetate extraction for extractable K, and magnesium oxide-Devarda alloy stem distillation method for available N (Soil Survey Methods Manual, DLD 1992 unpubl.; Page et al., 1982). Analytical methods used by the SLC were wet combustion with K2Cr2O7 in H2S04 for soil organic matter, 1:2.5 soil water ratio for pH, Olsen for extractable F, acetic acid extraction for extractable K, ammonium acetate extraction for CEC, exchangeable Mg, and exchangeable Ca, potassium chloride extraction for exchangeable Al (SLC Laboratory manual, unpubl-; Page et al., 1982).

Data analysis

Results were checked for normality. Weed density data, not following a normal distribution pattern, were transformed for all statistical calculations by the formula $(x + 0.5)^{1/2}$. Regression analysis. principal component analysis. and t-test were used to relate crop yield with other parameters and to evaluate land use effects on selected parameters.

Results mud discussion

Farmers: perception of constraints to rice production

Weed competition was considered the single most important constraint to upland rice production (Table 2). Some of the other important constraints listed, such as land availability (or short fallow) and labor, can be

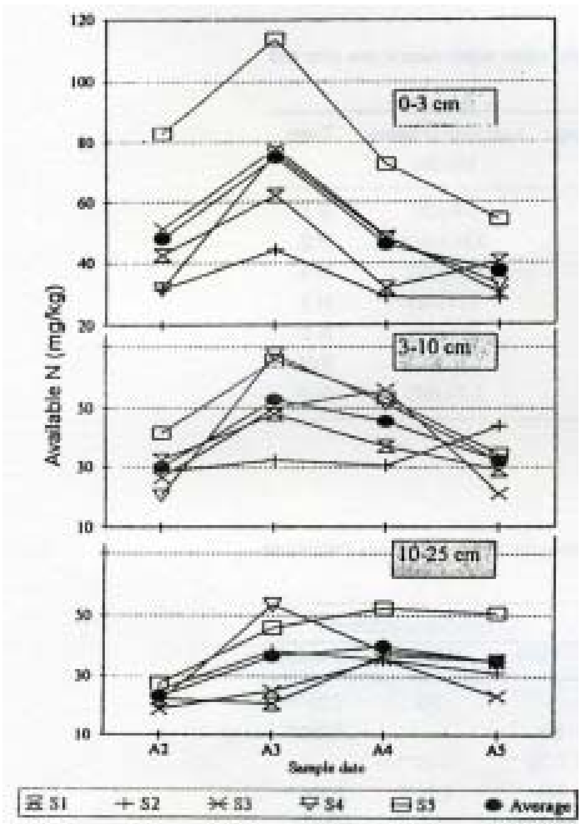

Fig 3 Available N (NH_4. NO_3, and NO_2, mg kg $^{-1}$)from sample collected at five sites in Ximgnguen district (1992), A2) after burning, A_3) after planting rice. A_4) 60 days after planting, and A_5)- time of rice harvest. Sampling depths were 0-3. 3-10, and 10-2 cm.

Table 2. Major constraints to upland rice production indicated by slash and burn farmers of Luang Prabang and Oudomxay provinces

Constraint	Frequency (% of respondents)
Weeds	85
Rodents	54
insufficient rainfall	47
Land availability	41
insects[c]	34
Labor	24
Soil suitability for rice production	21
Erosion	15
Domestic animals	15
Wild animals	11
Disease	8

[a]sample size was 129 households.
[b]Also included the constraint “short fallow period”
[c]Mostly white grub.

directly related to weeding requirements. Most farmers considered their soil resources as adequate for rice production and did not perceive soil erosion as major constraints and it is obvious that the reduction in fallow lengths has had a stronger effect on weed pressure than on soil fertility levels (Roder et al., 1994).

Farmers customarily provide adequate weed control, and weeds are therefore not a direct yield constraint but a constraint to labor productivity. Weed control in upland rice production requires about 150-200 days ha1 or 40-50% of the total labor input (koder et at., 1994). Considering the extremely high labor inputs for weed control the farmers rating is realistic. As a result of shorter fallow periods, labor requirements for weeding have increased substantially over the last few decades.

Relationship between fallow period, soil organic matter and other soil fertility parameters

Soil organic matter and N content was similar for soil samples taken from fields with a rice crop (slashed-.an& burned a ‘few months earlier) and from fields in the last year of the fallow period (Table 3). The average fallow period in the region is presently about 5 years (Roder et at. 1994), and an organic matter buildup during the fallow period was expected to partially replace the organic matter lost during the cropping period (Lugo and Brown, 1993).

Several authors have shown an increase in the organic matter content immediately after burning (Andriesse and Schelhaas, 1987; Kyuma et al., 1985; Nye and Greenland, 1960). Kyuma et al. (1985) suggested that this increase could be attributed to unburned litter and partly to carbonized litter The lack of differences in soil organic matter content between samples taken from fields in the crop phase and fields in the last stage of the fallow phase could be the result of an mm tial increase after burning. Soil samples were collected 3-4 month after the burning.

Soil pH and extractable K were generally higher for fields that were subjected to a recent burning (present rice crop) when compared to fields in the last stage of the fallow, although high variability for extractable K precluded statistical significance for the differences. The increase in soil pI-! and extractable K as a result of burning has been well documented (Andriesse and Schelhaas,1987; Kyuma et at, 1985; Pushparajah and Bachik, 1985). These changes are partly attributed to the ash deposits.

Therefore only the results of simple correlation analysis are used in the discussion. The only parameters that showed a weak association with rice yield over a large sampling area were soil organic matter ($r = 0.42$, $p<0.01$) and density of Ageratum conyzoides and Lygodium flexuosuin (negative relationship, Table 4 and 5). In the yield-soil-weed survey rice yield was related to NO_3 (r=0.23) and NH_4 (r=0.29). Ammomum and NO_3 were not measured from the crop cut samples. The level of available N fluctuates substantially over the growing season, with a peak during the period after planting coinciding with the beginning of the raining season (Fig. 3).

The positive association between soil organic matter and rice yield could largely be due to its effect on soil physical properties. Unfortunately our investigations did not include soil physical measurement& With an annual rainfall average of 1300 mm, soil moisture is likely to be limiting rice yields in some years. Fanners also considered insufficient rainfall as a more important constraint to rice production than soil properties. Moisture retention, water infiltration, and water holding capacity would therefore all be important properties of the soil to be considered.

From all the survey conducted regression analysis did not show any associations between yield and extractable P. extractable K, or soil ph. Similarly no association could be found between rice yield and density of the major weed *C. odorata* (Table 5). Measurements from the yield-weed survey, however, showed most soil fertility parameters to be inferior from sites with poor rice yield. The difference was 6, 9,11, 11 and 16% for organic matter, total N, NO3, extractable P, and extractable K, respectively (Table 6).

Ageratum conyzoides and *L. fiexuosum* were positively relatcd to extractable K (r = 0.25 and 0.21) and negatively to total N (r = -0.26 and -020). Furthermore, *L. fiexuosum* appears to be favored by low Ca (r= -0.38) and Mg (rz -0.27) availability and a low pH level (r= -0.30).

Soil dynamics during the cropping period

Burning increased the extractable P and K in the topsoil interval (0-3 cm) of site S1 by 76 and 60%, respectively. Similarly soil ph was increased from 14 to 5.8. This effect is mainly caused by ash deposits. After burning the average value for organic matter, total N, available P. available K and pH all decreased over the season (Table 7, Fig. 2)- Nitrogen and organic matter losses were substantial for all three intervals measured, whereas changes for other parameters were generally limited to the 0-3cm interval. Changes in nitrogen content are less variable than changes observed in organic matter content. This is consistent with earlier studies (Roder et al., 1995b), where similar soils under the same conditions had coefficients of variation of 8.6, 5.1, and 10.1 for total N and 20.7, 14.0, and 13.4 for organic matter contents at depths of 0-3, 3-10 and 10-25 cm, respectively.

The decrease in organic matter and N was accompanied by a substantial increase in available forms of N (NH_4, NO_3 and NO_2, Fig. 3) During the period from the time of burning to the planting of rice the average levels for these forms of N increased by 56, 77 and 60% for depths of 0-3, 3-10 and 10-25 cm, respectively (assuming bulk density of 0.9, 1,0 and 1.] for soil depth intervals of 0-3, 3-lO, and 10-25 cm, respectively). Mineralization of organic matter is the main source of N for the rice crop. As a result of N uptake by the rice crop and N losses, the pool of available N started to drop 30-60 days after rice planting The total quantity of available N in the top 0-25 cm of soil was 72, 118,110 and 92 from soil samples collected after burning, at the time of planting, 60 days after planting, and at rice harvest, respectively. Visible N stress in the form of yellowish appearance of rice crops can frequently be seen. Nitrogen may be a key soil nutrient limiting yield in some instances. In a fertilizer trial (unpubl. data by authors) application of 30 kg N, 30 days after planting rice resulted in yield Increases of up to 75%.

Nitrogen fertilizer was considered the most important factor contributing to an increase in rice yields in northern Thailand (Hoey, pers. commun, Thai-Australian project). While it will be impractical and uneconomical for most Lao upland farmers to use nitrogen fertilizers, the use of nitrogen-fixing legumes may be a key to increased rice yields.

The quantity of organic matter and N lost from the time after burning till rice harvest for the top 0-25 cm of soil was about 10,000 and 400 kg ha^{-1}, respectively During the same period the quantity of organic matter and N lost in the runoff soil at the three sites measured was 970 and 50kg ha^{-1}, respectively. Tulaphitak et al.. (1985) estimated a loss of 13,000 kg of organic matter ha' in the first year afterburning for slash-and-burn systems in northern Thailand.

Soil loss varied substantially between sites (Table 8). The differences observed are probably caused by the combined effect of soil physical (texture, clay type, water infiltration) and biological differences. Soil loss

Table 5. Yield and weed density relationships (correlation coefficients. 560 samples)

	Range	Correlation coefficients				
		Yield	Hills	*C. odorata*	*A. conyzoides*	*L. flexuosurn*
Yield(MT ha^{-1})	0.02-3	-	0.32***[a]	NS	-0.12**	-0.19***
Hills ($no.m^{-2}$)	1-23	0.32***	-	-0.10**	NS	-0.19~
C.odorata (no. m^{-2})[b]	0-45	NS	-0.14	-	NS	NS
A.convzoides(no. m^{-2})	0-115	-0.12**	NS	NS	-	0.20***
L flexuosum($no.m^{-2}$)	0-8	-0.19***	-0.20~	O.16***	0.23***	-
Tree biomass(g m^{-2})	0-300	NS	NS	O.19***	NS	NS

[a]PR>F: *<0.05 **<0.01,<0.001.
[b]Observations for weed densities were transformed by $(x+O.5)^{1/2}$ for statistical analysis.

Table 6. Soil and plant parameters for samples taken from field portions with good (above field average) and poor yield (below field average)

Parameter	Yield level		T-test
	Good	Poor	PR>F
a) Soil samples[a]			
Soil organic matter (%)	3.18 (22)[b]	2.98 (23)	0.02
NO3 (mg kg^{-1})	5.75 (42)	5.11(38)	0-05
Total N (%)	0.22 (16)	0.20 (19)	<0.01
Total P(mg kg^{-1})	816 (20)	770 (18)	<0.01
Extractable P (mg kg^{-1}) [c]	4.10(4!)	3.64 (43)	<1101
Extractable IC (mg kg^{-1})	211(33)	177 (35)	<0.0)
CEC (meq $100g^{-1}$ soil)	60.4 (31)	56-3 (35)	c001
Ca(meq $100g^{-1}$ soil)	6.8 (78)	6.1 (90)	<0.01
pH	5.66(9)	5.60(10)	(105
At (meq 100^{-1} soil)	0.38 (189)	0.55 (154)	<0.01
b) Field observation			
C. odorata (no. m^{-2})[d]	7.7 (54)	9.) (51)	<0.01
A. conyzoides ($no.m^{-2}$)	25.1 (84)	29.8 (82)	0.02
L.flexuosum ($no.m^{-2}$)	01(42)	13(50)	<0.01
Plant density (hills m^{-2})	13.6 (21)	12.0 (26)	<0.01
Rice yield (Mt ha^{-1})	1.5 (28)	116 (40)	<0.01

[a] Number of samples per yield level were: a) soil samples 55, b) field observations 280.
[b] Coefficient of variation for mean (for weed density the CV. for the transformed data is given).
[c] Olsen.
[d] Observations for weed densities were transformed by $(x+05)^{1/2}$ for statistical analysis.

at site 54 with a slope of 40% was insignificant. At the other two sites the soil loss observed, although high, was still within the limits generally accepted for agricultural land. The nutrient quantities lost in the runoff soil are small. Only 10 and 12% of the loss of organic matter and total N, respectively, could be accounted for by the run off material collected.

Table 7. Average values for soil parameters measured after burning (March) and at the time of rice harvest (November) 1992 (5 sites)

Parameter	Soil depth 0-3 cm			Soil depth 3-10 cm		
	A[a]	B	T-test	A	B	T-rest
pH	5.8	5-6	0.07	5.1	54	NS
Organic matter(%)	513	4.45	<0.01	3.42	313	0.06
Total N (%)	0.262	0.232	0.01	0.206	0.190	<0.01
Total P (mg^{-1} kg)	772	736	NS	625	641	NS
Extractable P (mg^{-1} kg)[b]	26.4	22.0	0.09	10.1	10.5	NS
Extractable K (mg^{-1} kg)	356	297	<O.01	173	157	NS

[a] = sample taken after burning (April), B sample taken at the rime of rice harvest (November).

[b] Bray 2.

Table 8. Soil loss horn 3 sites in Xiengnguen district during the 1992 cropping season (measured from May to October)

Sire	Slope (%)	Soil loss	O.matter	Nitrogen	Total P	Available P	Available K
		Run off losses in kg ha^{-1}					
S2	40	29’300	1500	67	30	2.1	15
S3	55	26000	1400	71	27	1.0	11
S4	40	300	2	1	<1	<0.1	<1
			Average concentration (mg 100g soil -1)a				
Eroded soil			4830	265	78	2.6	38
Top soil (0-3 cm, July)			5719	282	101	4.9	42

[a]From soil accumulated in collection ditches (eroded soil, May to October) and soil samples collected from the top 0-3 cm in July (Top soil)

Summary and conclusions

The relatively extensive soil and rice yield measurements did not reveal strong associations between soil parameters and rice yield. The soil conditions prevailing in die area studied are extremely heterogeneous, influenced by the hilly topography, microclimate and landuse. Interactions between soil parameters, landuse, and crop yield under these conditions are very complex and difficult to explain. Attempts to characterize effects of landuse practices on soil parameters are further complicated by:

- Farmers adaptation to existing soil conditions, such as choosing shorter fallow periods for soils with higher fertility;
- Cumulative effects of previous cropping and fallow cycles. In our investigations we could only consider the last fallow period;
- Timing of soil sampling. Rapid changes in parameters measured can occur over a period of few weeks (Tulaphitak et aL, 1985).

Soil organic matter is the only soil characteristic that consistently showed some relationship with yield, whereas available P is consistent in the absence of any relationship. The fact that most parameters such as available P, available K, and CEC generally used to describe soil fertility did not show any relationship with rice yield is, however, no proof that soil fertility is not limiting rice production. Soil measurements in the crop cut and the survey evaluating weed and soil effects on rice yield were taken late in the growing season of the rice crop. It is well documented that earlier stages, especially tillering and panicle initiation, most strongly respond to nutrient availability. The losses of N and organic matter are high. The fast mineralization rate of organic matter is an important source for N and other plant nutrients, yet systems aiming at longer cropping periods will need to include strategies that reduce the speed of organic matter mineralization.

Crop yields are the result of a multitude of factors interacting throughout the growing season. Soil fertility constraints are likely to be interacting with other constraints such as rainfall and disease prevalence (especially blast). It appears' that we have presently no simple method to measure 'soil effects on rice yield under upland conditions. Future attempts to identify constraints to upland rice production under the given conditions need to incorporate observations on soil physical properties, and should include repeated measurements during critical periods of the growing season such as panicle initiation and flowering periods.

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GEODERMA

Dynamics of soil and vegetation during crop and fallow period in slash-and-burn fields of northern Laos

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Abstract

Slash-and-bum rice production systems in northern Laos are undergoing dramatic changes. Increased population pressure and regulations limiting access to land have resulted in shorter fallow periods. Limited information is available on nutrient dynamics in slash-and-bum systems of Southeast Asia in general and particularly on effects of reduced fallow length. Crop and fallow effects on soil parameters and fallow vegetation were quantified in slash-and-bum fields in Luang Prabang, northern Laos from 1991 to 1994. Over the cropping season from May to October declines of 8, 7, and 3% organic C and 33, 40, and 53% extractable P. were observed for the depth. intervals of 0-3, 3-10 and 10-25 cm, respectively. Over the same period extractable K declined by 34% in the 0-3 cm interval and increased by 15 and 17% in the 3-10 and 10-25 cm intervals. The declining trend continued over the 3 year crop-fallow cycle with losses (depth 0-100 cm) of 29±7.6 t organic C ha^{-1}, 2.0 ± 1.1 t total N ha^{-1}, and 0.7+0.81 extractable K ha^{-1}. At the end of the fallow period the above ground biomass contained 100 kg N hat 5 kg P ha^{-1}, and 140 kg K ha^{-1}. The fallow vegetation was dominated by Chronzolaena odorata with a gradual succession towards tree and bamboo species. The nutrients in the above ground fallow vegetation represent only a small fraction of the N and C lost due to mineralization and leaching. With the present no-till system, mineralization losses are far more serious than losses due to soil erosion. Short fallows will result in a fast decline and low equilibrium of soil organic C levels, reducing the potential for rice yields and limiting farmers choice for other land use options which may become available with better market access.

Keywords: shifting cultivation; rice; soil fertility; C-loss

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1. Introduction

Slash-and-bum agriculture remains a dominant land use system in many parts of the tropics. Although systems vary, most slash-and-burn farmers depend on perennials to suppress weeds and recover soil fertility during the fallow period. Observers generally agree that slash-and-bum systems are sustainable with long fallows, but many caution that the systems will collapse due to insufficient restoration of soil fertility levels if fallows are reduced (Jordan, 1985; Sanchez and Logan, 1992; Warner, 1991). Accumulation of soil organic matter during the fallow period and ash deposits from the burned biomass are the main factors contributing to increased soil fertility at the end of the fallow period. The biomass of the fallow vegetation is generally a major pool for potassium. calcium and magnesium (Andriesse and Schelhaas, 1987; Jordan, 1985; Nye and Greenland,' 1960; Sanchez, 1987). However, most of the nitrogen and phosphorus, is located in the soil and the additions from the burned biomass are less important.

Mineralization of organic matter, occurring at high rates after the initial burning of die plant biornass, is an important source for N and other plant nutrients. Tulaphitak et al.(1985) estimated a loss of 13 t organic matter ha^{-1} ,in the first year after burning for slash-and-bum systems in northern Thailand. Similarly, organic matter losses of 10 ha^{-1}, during the cropping period after burning were reported from a study conducted in northern Laos (Roder et a)., I 995a). Organic matter and nutrient dynamics under shifting cultivation systems have been described for African, Asian, and South American conditions (Brubacher et at, 1989; Nakano, 1978; Nye and Greenland, 1960; Nye and Greenland, 1964; Sanchez Ct al., 1983; Tulaphitak et al., 1985; Van Reuler and Janssen, 1993a; Zinke et al., 1970) yet, quantitative data for nutrient pools are limited to information obtained by measurements taken at one point in time, and few investigations have quantified nutrient dynamics over an entire cropping and fallow cycle. Furthermore, several authors have emphasized a lack of soil fertility data relating to slash-and-burn agriculture in the hilly regions of Southeast Asia (Nalcano, 1978; Sanchez, 1976).

Slash-and-burn agriculture with upland rice as the major crop is the predominant land use system in the hilly areas of northern Laos. Over the last 20 years. average fallow periods have been reduced drastically (Roder et at, 1994). Although farmers consider labor requirements for weeding as a far more important constraint to upland rice production than soil fertility, there is a growing concern about the environmental as well as agronomic effect of reduced fallow length and there is an urgent need to quantify trends in soil fertility and weeds under the reduced fallow periods Soil nutrients and fallow vegetation were, therefore, measured in 4 slash-and-burn fields in 1991 to 1994 to document dynamics of soil fertility parameters and fallow vegetation during the cropping and the fallow cycle and to quantify major nutrient pools. The findings from this study are expected to (1) substantiate statements associating soil fertility trends with fallow period, (2) provide base line data to quantify future fertility trends, and (3) help optimize future use of land resources in the hills of Laos.

2. Materials and methods

2.1. General description of area, firming system, and monitoring sites

The studies were carried out in the Xiengnguen District in the Province of Luang Prabang in northern Laos (190N). Approximately 25% of the total upland rice area of the country is in this province. Upland rice is generally cultivated on sloping land using slash-and-bum methods without tillage and without inputs of fertilizers. Slopes can range from 0 to over 100%, but over 70% of the upland cultivation is limited to slopes in the class O~-30% (World Bank, 1995> Rice is planted in hills with the help of a dibble stick A single crop of rice is followed by fallow periods of 2-10 years.

The climate is dominated by the monsoon with a dry period from October to April and moderate to high rainfall from May to September. The average rainfall for Luang Prabang town was 1340 mm for 1961-90 and ranged from 1064 to 1406 mm in 1991-94. Sandstone, limestone, and clastic rocks of Mesozoic and Paleozoic origin are the dominant geological formations in the region (ESCAP. 1990). Other important geological formations include granite and volcanic rocks. Upland soils were classified as Orthic Acrisols (FAO/UNESCO, 1974) and are generally reddish brown and moderately acidic.

Four monitoring areas (SI -S4) of 20 X 20 m were selected and delineated in April 1991 after farmers had burned the dry, above ground biomass (Table 1). Sites 1 and 2 were located close to Ban Lorig-O and sites 3 and 4 close to Ban Phonthong. The 2 villages are about 25 km apart. Sites selected had soils representative of the region, were uniform in slope, had undergone several fallow/crop cycles, and were free of large termite mounds or large root wads. The fallow periods prior to the burning ranged from 6 to 8 years. All plots were located inside existing fields and farmers followed the same practices in the monitored plots as in the surrounding field. Rice was planted in May 1991 at densities of 8-12 hills m2 Weeding was done manually 3 times during the season. After the rice harvest in November 1991, fields were left fallow for 2 or more years The cultivators of site S1 and S2 decided to plant rice again after 2 years of fallow. The average fallow length in the district observed in a 1991 survey was 4 years (Roder et al., 1994).

Table 1
Description of slash-and-bum fields used in the study [a]

	S1	S2	S3	S4
Elevation Un)	460	450	540	520
Slope (%)	35	45	28	45
Soil type [b]	Dystric Cainbisol	Dystric Cambisol	Ferric Alisol	Ferric
Alisol				
Years falIow	6	6	8	8

[a] Sites were located in the Xiengrguen District. Luang Prabang Province, Laos (Si and 52 near Ran Long-O. S3 and S4 near Ban Phonthong).
[b] Soil Sorvey and Soil Classification Laboratory Dongdok. Department of Agriculture and Extension. Vientiane.

Short range variation at SI and a second location (not included in the monitoring study) was quantified in 1991 using an Oakfield core sampler (20 mm diameter) and 20 individual samples per plot (Roder et al., 1995bY Coefficients of variation for the top interval (0-3 cm) averaged over 2 sites were 10.4% for p1-I, 8.7% for total N, 20.7% for organic C, 12t% for total P. 75.8% for extractable P, and 44.8% for extractable K. Variation generally decreased with increasing depth of soil, except for soil organic C. Following this preliminary study the number of subsamples required to estimate changes of 10% at a confidence level of 95% was less than 15 for all variables measured, except for extractable P and K.

22. Soil sampling

Twenty subsamples per plot were collected in a grid pattern using an Oakfield core sampler (20 mm diameter). Sampling depths were 0-3, 3-10, 10-25, 25-50, 50-75, and 75-100 cm. Sampling was done in May 1991, 1992, 1993, and 1994 (S1 and S2 before burning). Additional samples from the 3 top intervals were collected from all sites after rice harvest in 1991 and from plots S1 and S2 after slashing (March), burning (May), and rice planting (May) in 1994. Soil bulk density was measured in 1994 taking 5 subsamples per site with the Oakfield core sampler.

2.3. Soil loss

Attempts were made to measure soil loss by placing 20 steel pins (80 cm) in each site before the onset of the rainy season in 1991. Due to moderate erosion, no height differences could be observed at the end of the 1991 cropping season. The method was presumed unsuitable and no further measurements were made.

2.4. Processing of soil samples and chemical analysis

Samples were air-dried and sent to the laboratory of the Lands Development Department in Bangkok for analysis of pH, organic C (Walkiey-Riack acid dichromate digestion), total N (semimicro Kjeldahl), extractable P (Bray 2), extractable K (extraction with I N NH_4OAc), Al (KCl extraction), and CEC (extraction with I NH_4OAc at pH 7, DLD, 1992; Page et al., 1982).

2.5 Plant sampling

Above ground biomass was measured at the time of rice harvest in October/November 1991 and after 1 and 2 years of fallow in December 1992 and 1993. In 1991, all plant biomass was harvested from 10 randomly placed I x I m frames- In 1992 and 1993, plant dry matter was estimated by cutting and weighing the above ground biomass from a representative area of 9 m2 adjacent to the monitoring plot. Plant material was measured separately for the most important species Dry matter was calculated based on a moisture content of 12% for the air-dried subsamples. Litter fall was measured during the second year of fallow (1993). Four wooden boxes of 0.25 X 0.25 m, with a bottom of 2 mm wire mesh screen were placed randomly in each plot and the material accumulated was removed at monthly intervals.

Plant samples for the major species from the 1991 and 1992 plant measurements (one combined sample for all the sites) were analyzed for N, K, F, and Ca content by the Soil Survey and Soil Classification Laboratory (SLC) Dongdok, Department of Agriculture and Extension (Vientiane, Laos). Nitrogen, K, P, and Ca content of different plant pans analyzed were reported earlier (Roder et al., 1995c). Litter samples were analyzed separately for each month and each site,

2.6. Presentation of results

Except for an overall budget of organic C, N, extractable F, and extractable K, all soil data are discussed relative to soil mass. Soil bulk density was measured in 1994 only. Various studies have shown that bulk density changes during the course of the fallow and cropping period but these changes are generally small (Brown and Lugo, 1990; Nye and Greenland, 1964). hi a study by Nye and Greenland (1964) with forest cover as original vegetation, burning and 2 years of cropping resulted in less than 2% change in bulk density in the top 25 cm soil interval. Authors were aware of the impact of bulk density changes on the original sample depth, but given the soil type, the relative short fallow period, and the absence of tillage, the changes are not expected to affect the results significantly.

Most studies monitoring soil or vegetation dynamics in slash and burn systems are limited to one site (Andriesse and Schelhaas, 1987; Seubert et al., 1977; Tulaphitak et at, 1985). Because of extreme variation, the results from studies encompassing more than one site are usually discussed separately for individual sites (Sanchez et at, 1983; Van Reuler and Jaussen, I 993a). In our discussion we present average data for the four sites, along with a measurement of variation. While this way of presentation does not obscure any of the trends, changes observed (even if consistent across sites) are often not significant because of the high variations between sites.

3. Results and discussion

3.1. Soil observations

Our observations documenting an initial increase after burning and subsequent decrease for most soil nutrient status parameters are consistent with those reported by others (Nye and Greenland, 1964; Sanchez et al., 1983; Seubert et al., 1977; Tulaphitak et al., 1985). Due to the previous depletion of soil organic C because of repeated cycles of short fallows and the limited quantities of above ground biomass present at the time of burning, the magnitude of the changes are comparatively small in our study (Table 2, Figs. 1-3). The effects of biomass burning on soil pH, and extractable nutrients are, to a large extent, the result of ash deposits (Van Reuler and Janssen, 1993b) and therefore depended on the available biomass quantity and its composition. Biomass quantities in our studies (not measured) were estimated at <25 t ha^{-1}, compared with 30-80

Table 2
Average values for soil parameters measured in four slash-and-bum fields in northern Laos after burning (A) and at the time of rice harvest (B) 1991

Parameter	Soil depth 0-3cm			Soil depth 3-10 cm			Soil depth 10-25 cm		
	Aa	B	T-test [b]	A	B	F-test	A	B	F-test
pH	5.5	5.3	023	4.7	48	0.32	4.5	4.6	0.08
Al (meq 100 g^{-1})	0.3	0.5	036	2.9	2.4	0.02	4.2	3.5	<0.01
Organic C (%)	3.3	3.0	0.20	2.3	2.1	0.20	1.6	1.5	0.66
Extractable P (mg kg^{-1}) [c]	24	16	0.06	7.9	4.7	0.09	4.3	2.0	<0.01
Extractable K bug kg^{-1})	347	229	0.06	127	146	0.09	83	97	0.22
CEC (meq 100 g^{-1})	15	16	0.29	13	13	0.22	11	12	<0.01
Exch. Mg(meq 100 g^{-1})	3.0	2.4	0.06	1.1	1.2	0.50	0-6	0.7	039
Exch.Ca(meq 100g^{-1})	3.8	4.5	0.33	11	3.0	<0.01	0-7	2A	<0.01

[a] A = sample taken after burning (May). B = sample taken at the rime of rice harvest (November).
[b] Probability level of T-test.
[c] Bray Z

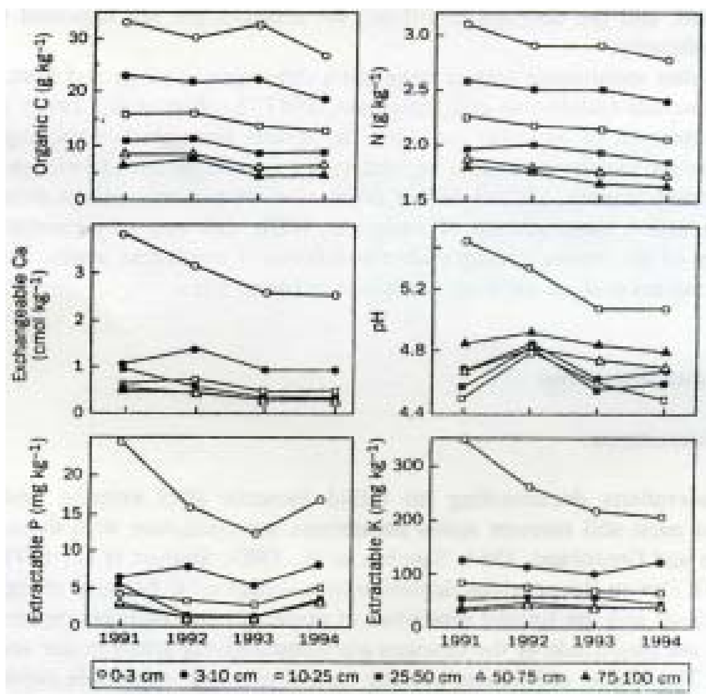

Fig 1. Average trends in selected nutrient status parameters during the cropping (1991) and fallow period (1992-94) for the depth intervals of 0-3, 3-10, 10-25. 25-50. 50-75 and 75-100 cm observed in 4 slash-and-burn fields in northern Laos (ANOVA summary in Table 3).

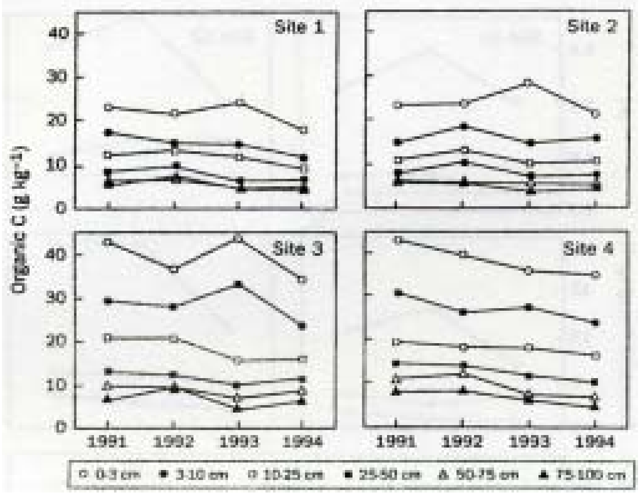

Fig. 1 Trends in organic C during the cropping (1991) and fallow period (1992-94) for the depth intervals of 0-3, 3-lO. 10-25. 25-50, 50-75 and 75-100 cm observed in 4 slash-and-bum fields (sites 1-4) in northern Laos (ANOVA summary in Table 3)

reported by Andriesse and Schelhaas (1987), 160-180 by Greenland and Kowal (1960), and 194 t h^{-1} by Kyuma et al. (1985). Because of ash deposit and the effect of heat, the most dramatic changes in the upper soil layers occur at the time of burning and the period immediately after burning (Sanchez et al., 1983; Seubert et al., 1977; Tulaphitak et al, 1985). In our study, this effect was observed at the end of the monitoring period when two sites were changed to rice after a fallow period of 2 years.

3.1.1. Cropping period (1991)

From the time of planting in May to rice harvest in October, organic C and extractable P decreased in all 3 depths monitored, although high variation precluded significance for organic C (Table 2). Extractable K decreased by 34% in the top interval (0-3 cm) and ‘increased by 15% and 17% in the 3-10 and 10-25 cm soil intervals. Similarly, the downward movement of elements released from above ground biomass burning resulted in an increase of pH. CEC, and exchangeable Ca in the 10-25 cm depth interval. The rainfall from May to September was 947 mm and leaching is likely to occur.

3.1.2. Fallow period (1991-1994)

The most important observation is the continuous downward trend over the entire cropping and fallow period in the soil N and organic C contents (Figs. 1 and 2, Table 3) with substantial losses of C and N to the atmosphere. On average, losses over the period or 3 years represented 20% of the total soil organic C and 8% of the nitrogen content in the 1 m profile (Table 4). While the loss in the initial year occurred largely in the top soil layer, it was more significant at lower layers in the following years. Sites 3 and 4 had a substantially higher level of organic C but the trends were similar for all sites (Fig.

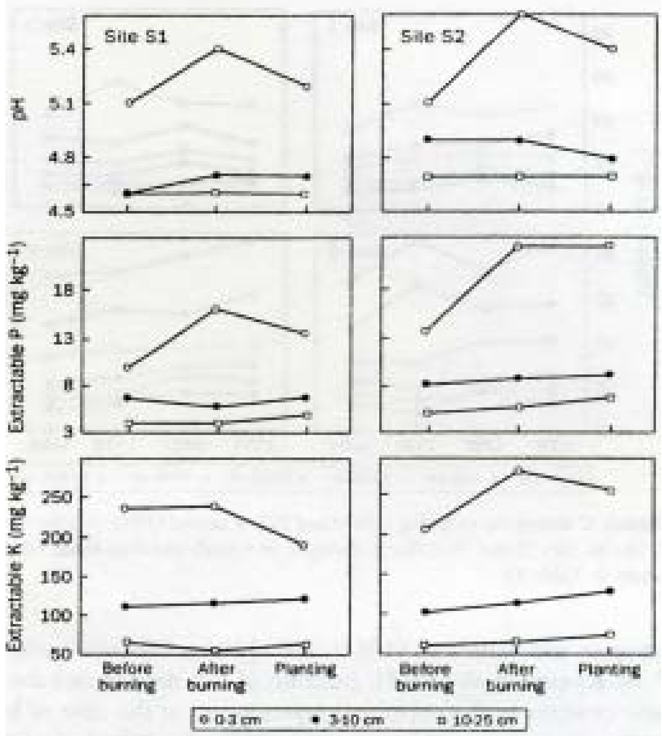

Fig. 3. Changes in pH, extractable P and extractable K observed at two slash-and-born fields (sites 1 and 2) in northern Laos from samples collected before burning (March), after burning (April) and at the time of rice planting (May).

2) with total C losses over the 25 t ha^{-1} for site 1, 13 for site 2, 26 for site 3, and 49 for site 4.

Zinke et al.(1970) and Nakano (1978) have shown that total N and C in slash-and-bum systems in northern Thailand reached their lowest levels in the middle of the fallow period of 4-5 years. Tulaphitak et al. (1985) reported organic matter loses, of' 8.8% annually and estimated that 240 kg N, 20 kg P, and 80 kg K would be released during the first year after burning due to the mineralization of soil organic matter. Estimates of P, K, Mg, and Ca are probably influenced by organic matter mineralization. Cations released through mineralization may reduce or magnify changes expected due to leaching. Soil pH and extractable bases showed a fast decline in the topmost soil layer in the first year after burning, with a simultaneous increase in the lower soil. layers. Extractable P and K increased towards the end of the fallow period. But even when accounting for the K stored in the vegetation, the overall balance for K is still negative (Tables 4 and'6).

Many observations on soil changes under slash-and-bum agriculture were limited to measurements in the upper 0-15 or 0-30 cm top layer, (Nye and Greenland. 1964; Sanchez et a!., 1983; Tulaphitak et al., 1985). Brown and Lugo (1990) have shown that

Table 3
Summary cable for ANOVA of soil parameters (mean values arc shown in Fig. 2) observed in four slash-and-bum fields in northern Laos during 1991-94

	pH	Exchangeable Ca	Total N	Organic C	Extractable P	Extractable K
0-3 *cm*						
PR> F [a]	0.02	0.08	NS	0.02	0.10	0.09
Contrast [b]	(1) <0.01	(1) 0.02	-	(3) 0.04	(2) 0.06	(1) 0.02
CV (%)	14	22.7	7.9	78	310	28.5
.3-10 *cm*						
PR>F	0.07	NS	NS	010	NS	NS
Contrast	(3) 0.02	-	-	(1)0.04	-	-
CV (%)	23	32.3	6.1	10.9	24.3	16.0
10-25 *cm*						
PR> F	0.01	NS	NS	0.01	<aci	NS
Contrast	(3) 0.04	-	-	(1) <001	(2) <0,01	-
CV (%)	2.4	35.7	64	8.4	20.5	25.6
25-50 *cm*						
PR>F	0.02	0.05	0.10	<0.01	0:10	003
Contrast	(3) <0.01	(1) 0.02	(1) 0.05	(3) 0.01	(2) 0.03	(2) <0.01
CV (%)	23	32.8	3.9	9.3	833	11.6
50-75 *cm*						
PR>F	NS	NS	0.04	<0.01	<0.01	0.01
Contrast	-	-	(1) <0.01	(3)<0.02	(2)<0.01	(3) 0.04
CV (90	2.8	41.0	3.6	12.9	36.3	10.0
75-100*cm*						
PR> F	NS	NS	0.08	<0.01	<0.01	0.03
Contrast	-	-.	(1) 0.02	(3) <0,01	(2) <0.01	(2) 0.02
CV (90	2.0	36.5	5.6	14.3	20.8	7.5

[a] PR > F for change of parameter over time.
[b] Orthogonal contrasts, only PR> F value given for the highest order still significant: numbers indicate (1) linear, (2) quadratic, and (3) cubic

Table 4
Average organic C, nitrogen. P and K changes from the lime of planting (May 1991) to the end of the fallow period (May 1994) observed in four slash-and-burn fields in northern Laos

Depth	Organic C		Nitrogen		Extractable P		Extractable K	
	(t ha-1)	(%)	(t ha-1)	(%)	(kg ha-1)	(%)	(kg ha-1)	(%)
0-25 cm	9+2.6 a	18	0.57±0.44	9	04±16	0.2	606±628	20
25-50cm	7±2.3	18	0.31 ±0.21	5	5.9±7.6	3.3	290± 192	17
50-75cm	7±2.2	24	048±0.14	8	(+)b0.5±2.3	(+)0.4	(4)50±53	(+)4
75-100cm	6-4-23	26	0.59±0.27	9	(4)3.0±1.3	(+)3.3	(+)165±102	(+)14
Total (0-100 cm)	29±74	20	1.96±1.1	8	2.8±13.7	0.5	681±766	9.4

a Mean ± standard error.
b Accumulation of element.

Table 5
Average above ground biomass in four slash-and-burn fields in northern Laos during the rice crop (1991) and cwn subsequent years of fallow (1992-93)

Species	Plant biomass (t ha^{-1})		
	1991	1992	1993
Chronwloena odorala	0.23 ± 0.07[a]	4.8 ± 0.7	4.5 ± 1.4
Lygodiurn flexuoswn	0.14 ± 0.03	0.6 ± 0.4	0.1 ± 0.05
Orhcrbroad leaf species	0.17±0.03	0.5±0,3	1.3t0.9
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 [C]	1-4±0-13	9.8±1.1	15.5±1.9

[a] Mean ± standard error.
[b] Not available.
[c] Rice grain harvested, and rice stem in 1991 was 1.1 and 1.2 t/ha.

changes in soil C and N occurred throughout the profile. While N and organic matter losses at depths below 30 cm may have limited agronomic significance they are important for the overall C and N cycle, especially the C contribution to the atmosphere.

3.1.3. Effect of burning (1994)

At two sites the vegetation was slashed and burned in early 1994 and rice was planted in May. Soil samples taken before and after burning did show the distinct burning effects manifested by an initial increase and subsequent drop for pH and extractable bases as shown by others (Fig. 3). The magnitude was, however, small when compared to other studies (Nye and Greenland, 1964, Sanchez et al, 1983; Tulaphitak et al., 1985) and no response to burning was observed for N and organic C content. This poor response is largely due to the short fallow and low biomass quantities as discussed above.

3.2. Plant observations

The average above ground biomass at four monitoring sites was 1.4 t ha $^{-1}$ at rice harvest in 1991 and increased to 9.8 t ha>' at the end of 1992 (1 year fallow) and 15.5 t ha $^{-1}$, in 1993. At rice harvest, tree and bamboo species contributed 61% to the total biomass (Table 5). Their development is, however, 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. *Chromolaena odorara*, the most important weed and fallow species contributed 16% to the total above ground biomass in 1991, 49 in 4992, and 29 in 1993. With progressing fallow period, bamboo and tree species gradually replace *C. odorata* (Roder et al., 1995c). *Chromolaena odorata* introduced in the 1950s has become the most important weed and fallow species in most slash-and-bum areas of the country. The contribution of grass species to the weed and fallow biomass is generally small, and

Table 6
Average N, P. K, and Ca stored in the above ground vegetation [a] observed in four slash-and-burn fields in northern Laos during the rice crop (1991) and two subsequent years of fallow (1992-93)

	C. odorata	Others	Bamboo	Tree	Rice straw	Total
N (kg ha^{-1})						
1991	0.9	1.5	1.0	2.2	3.5	92
1992	32.6	5.5	12.6	9.8		60.5
1993	30.1	7.9	24,0	34.5		97.0
P(kg ha^{-1})						
1991	04	0.4	0.2	0.8	1.0	2.7
1992	2.4	0.8	0.4	0.3		3.9
1993	2.3	0.6	0.8	1.1		4.6
K (kg ha^{-1})						
1991	0.6	0.7	1.0	0.6	2.5	5.4
1992	52.8	4.7	27.1	7.7		92.2
1993	49.5	9.2	51.6	27.0		137
Ca (kg ha^{-1})						
1991	1.1	1.8	0.7	5.9	4.0	13.5
1992	14.4	41	2.9	5.4		26.9
1993	13.5	4.9	5.6	19.1		43.1

[a] Calculated based on N, P. K, and Ca conrern of average plant samples from 1991 and 1992 measurements. Content for 1992 measurements, reported for individual plant parts by Roder et al. (1995c) were used to calculate 1993 quantities.

in contrast with some other slash-and-bum systems in Asia, *Imperata cylindrica.* although present, is rarely dominant.

The nutrient quantities stored in the above ground biomass were modest for P. but substantial for K (Table 6). Upon burning, most of the P, K, and Ca present in the plant biomass are expected to become available for the crops. In addition to the nutrients present in he above ground biomass, there is a gradual accumulation in the topsoil through litter fall. The total litter quantity produced during the second year of fallow was 1.2 t ha^{-1}, with peak of litter fall occurring towards the end of the dry season, when *Chromolaena odorata* sheds its leaves (Table 7, Fig. 4). The amounts of plant nutrients

Table 7
Average biomass and N, P, and K content of litter collected in four slash-and-bum fields in northern Laos during the second year of fallow (1993)

Parameter	
Dry matter(t ha^{-1})	1.2±0.07[a]
N(kg ha^{-1})	16±1.9
P (kg $^{-1}$)	1.6±0.1
K(kg $^{-1}$)	5.0±0.3

[a] Mean ± standard error.

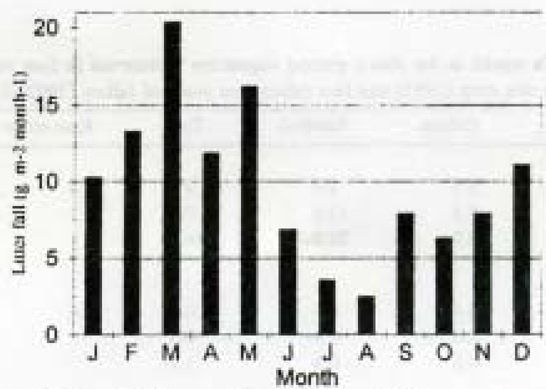

Fig. 4. Average monthly litter fall (means of 4 sites) observed in the second year of fallow (1993).

added through the litter are modest and the N and K quantities of litter and above ground biomass combined are much lower compared to those lost from the soil.

4. Summary and conclusions

The sail pools of organic C and total N were reduced substantially during the cropping and the short fallow period- Only a small proportion of the over 28 t of organic C and 2 t of N losses can be attributed to erosion. Soil loss during the cropping period was too low to be measured by the pin method. In a separate study, carried out under similar conditions, soil loss over the cropping period ranged from 0.3 to 30 t ha^{-1} accounting for about 10% of the N and C losses (Roder et al., 1995a).

The fallow period of 2 years was too short to reverse the downward trend and soil organic C and N levels are expected. to decrease further with subsequent cropping-fallow cycles until an equilibrium has been reached. Similarly, the fallow periods of 10-15 years reported during the 1950s were not sufficient to restore soil organic C to levels present before burning. The C pools present at the beginning of the study were therefore undoubtedly very different when compared to the soil under natural. vegetation. Brown - and Lugo (1990) suggested that the time for recovery of soil C during succession would be about 40—50 years. The amount of C, N, and K present in the above ground plant biomass represent only about 20, 5, and 20% of the quantities lost from the soil pool during the short fallow period. Any discussion on the contribution of slash-and-bum agriculture towards the atmospheric C needs .to include the C-dynamics of the soil pool. The C released from the soil through mineralization after burning is generally higher than the C released from the burning of the above ground biomass.

The reduction in fallow period has substantially increased the labor requirement for weeding and farmers generally attribute more importance to effects of fallow on weeds than upon soil fertility (Roder et al., 1995a). in recent studies, soil organic matter has shown only a weak or no association with rice yield, while fallow length has no effect at all. The absence of a measurable correlation between yield decline and changes in soil fertility parameters in slash-and-bum fields has been reported by Sanchez (1976) and Nakano (1978). They suggested that too much emphasis should not be placed on the recovery of fertility in the fallow period. The importance of organic C for the maintenance of soil physical, chemical, and biological properties is, however, well established and a decline below a critical limit will lead to yield declines. Studies with additional N-fertilizer inputs have already demonstrated substantial yield increases, indicating that the mineralization of soil organic matter is insufficient to provide the N requirements of the rice crop. Furthermore, the tremendous reduction in soil organic C levels will strongly limit the farmers' choice for other land use options which may become available with better access to markets.

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RELATIONSHIP BETWEEN ETHNIC GROUP AND LAND USE IN THE HILLY AREAS OF LAOS

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ABSTRACT
Slash-and-bum agriculture, with upland rice as the major crop, is the predominant land use system in the hilly areas of Laos. The hill population is comprised of a large number of different ethnic groups and distinct positive and negative slash-and-burn practices have been ascribed to particular groups. Select "ethnic minorities" are blamed for causing environmental damage and forest destruction; however, quantitative and qualitative data from literature and surveys do not support this claim. Variations in land use within the same group are generally larger than between groups. Practices used today are largely a function of land capability, climate, population pressures, and past political events. A large number of members of so called "lowland ethnic groups" are found to be fully or partially dependent on bill agriculture. Fallow periods have declined and cropping length increased for all groups. Farm typology using socio-economic indicators rather than ethnic identity should be used in discussion, for policy formulation, and in the planning and execution of development activities focusing on hill areas. Future changes in land use will be driven by economic incentives rather than by long-term ecological concern by the individual farmer and economic incentives promoting ecological sustainability need to be devised.

Key words: Ethnic group, land use, Lao PDR, Slash-and-burn, Upland rice.

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INTRODUCTION

Upland environments, specially those with hilly topography, are inherently fragile and require a careful approach if used for agricultural production. Resource limitations in lowland environments and the growing population in the hills put high pressure on hill areas. As this process can easily offset the fragile equilibrium and cause irreparable damage with major offside effects, we find a fast-growing interest group at regional, national, and international levels attempting to enforce rules and regulations on the upland farmer. Customarily all the blame for environmental problems in the hills and their downstream effects is linked to the hill population, or segments of it. Hill farmers are often at a serious disadvantage when compared with populations or farmers living in adjacent lowland areas. Furthermore populations in remote bill areas frequently belong to ethnic minorities and the problems associated with cultural differences further magnify the socioeconomic constraints related to geography (Vienne, 1989). Poor communication, limited access to socio-economic benefits and markets, poor representation in government bodies, lack of understanding by other groups — all contribute to maintain or increase the existing disparity.

The northern and eastern regions of Laos are an almost continuous succession of rolling hills and rugged mountains with peaks rising up to 2800 m (Stuart-Fox, 1986). Where possible, floodplains and valley, bottoms are used for lowland (lowland refers to fields that are bunded and level) rice production. Due to limited area of lowland available, farmers depend to a large extent on upland agriculture (upland refers to fields that are not banded and usually not level). Hilly topography combined with low population densities made slash-anch-bum the best land use option for upland farmers. Rice is the major upland crop, followed by maize, cassava, and peanut (National Statistical Center, 1993). Following the 1993 statistics, upland rice accounted for 35% of the national rice area and for 23% of the annual rice production. Present government policies give high priority to reducing the area under slash-and-bum agriculture. Efforts to limit farmers' access to land combined with fast population growth have resulted in shorter fallow cycles and consequently increased weed problems and soil deterioration. Many recent documents discussing the potential of upland agriculture in Laos make reference to soil fertility as a major constraint (Fujisaka, 1991; Lovelace, 1991; SUAN 1990). Relatively extensive soil and rice yield measurements did, however, not reveal strong associations between soil parameters and rice yield and soil infertility is not perceived a major yield constraint by the farmers (Roder I 995a).

The population of Laos is made up of more than 60 ethnic groups (Stuart-Fox, 1986). Based on ethnicity, linguistics, and geographical characteristics, the ethnic groups are divided into three broad categories: Lao Loum (Lao of the lowlands), Lao Theung (Lao of the mountain slopes), and Lao Sung (Lao of the mountain summits, Table I). The terms used give emphasis to the geographic distribution, which is largely arbitrary and violates accepted anthropological theories on environment and human interactions (Ellen. 1982). Nevertheless this classification is widely used by government and nongovernment agencies and individuals at international, national and regional levels when describing the rural population of Laos. This classification system strongly enforces the bias that farmers belonging to the classes of "slope" or "mountain summit" dwellers would depend exclusively on slash-and-burn agriculture because of ethnic preference. In spite of the fact that all ethnic groups are engaged in slash-and-burn agriculture, it is very common to hear the label that it is "the ethnic minorities" (groups others than Lao Loum) or the "ethnics' that live from slash-and-burn agriculture and destroy the forest. Some of the ethnic groups may have been traditional slash-and-burn farmers, while others have been pushed from the lowland into the hillsby an increasing population (Halpern. 1961; Izikowitz, 1951). More recent immigrants, largely members of the Lao Sung category.. simply did not have any choice but to settle in the more remote, hilly areas.

As stated by Kunstadter and Chapman (1978), assumptions concerning ethnic categories and their relationship to environment, economy, and social structure have important implications for public policies. Generalization and accusations do not provide a fruitful base for the ongoing discussions on slash-and-burn agriculture and its associated problems, constraints, and potentials. There is an urgent need for quantitative data to support or refute popular conceptions about the relationship between ethnic identity and slash-and-burn agriculture. In this paper we use references available on land use by hill farmers and data obtained from recent surveys to I) discuss popular presumptions relating land use and ethnic groups, 2) review quantitative data describing land use in the past, and 3) describe present land use practices prevailing in northern Laos with special attention to ethnic identify.

MATERIALS AND METHODS

Review of literature and technical reports
Publications and technical reports discussing slash-and-burn practices, upland agriculture, or socioeconomic aspects of the hill population were reviewed for quantitative and qualitative information relating to upland agriculture practices and ethnicity.

information on land use practices
Data from household surveys, crop cut measurements, and a yield-soil-weed survey carried out in parts of the Luang Prabang, Oudomxay, and Bokeo provinces during 199 1-94 were combined to compare land use, cropping periods, fallow periods, elevation, slope gradient, density of major weeds, crop yield, and soil parameters for the individual ethnic groups. The methods of these surveys were outlined previously (Table 2).

RESULTS AND DISCUSSION

Popular presumptions
Phommasthit (1975) wrote: “In the northern part of Laos bill tribes grow upland rice and depend totally on it. The Lao government is very disappointed about deforestation for upland rice, because the hill tribes leave the area after two or three years’ This is a very commonly made statement and it is understood that “hill tribes” and “ethnic minorities’ refer to ethnic groups belonging to the Lao Theung and Lao Sung category (Table 1). The use of this terminology in Laos is probably influenced by the terms used in northern Thailand, although unlike in Thailand, some of the groups concerned are certainly not minorities. Various authors describing slash-and-burn systems have distinguished between pioneer and rotational systems. Eased on the relationship between cultivation and fallow periods, Kunstadter and Chapman (1978) used three categories: 1) short cultivation-short fallow, 2) short cultivation-long fallow, and 3) long cultivation-very long fallow to describe the systems used in northern Thailand. Northern Thai, Karen, and Hmong were listed as examples of ethnic groups using systems 1-3. respectively. At the same time, the authors were, however, careful to caution against associating land use with ethnic categories. Many recent observers of the Lao upland agriculture system have apparently mistaken the “Kunstadter and Chapman classification” as a classification of Lao Loum (northern Thai). Lao Theung. and Lao Sung (Hmong) agriculture. Repeated citing of the same narrow reference base without follow-up in the field has resulted in the widespread acceptance of a preconceived but largely unrealistic association of !and use with ethnic categories.

Similarly as in Thailand (Vienne, 1989), the terms hill tribes or ethnic minorities often imply negative connotations such as lack of understanding for the Lao culture (Yananda and

Nonwakorn, 1925), backwardness (Boudene, 1913), destructive land use (Hakangard et aL, 1990; IUCN, 1988; Phommasthit, 1975; Wirtz, 1959), and being intellectually inferior (Dessaint, 1981; Yananda and Nonwakorn, 1925). While there is absolutely no basis for these disparaging observations, there is no doubt that non-Lao speaking groups are at a serious disadvantage in a system where they need to use an unfamiliar language to get access to education and other government services. Furthermore, hill farmers require a far higher labor input for rice production compared with lowland farmers and are thus at a very strong economic disadvantage (Roder et al. 1994).

What groups are practicing slash-and-burn agriculture

There is little information available on the land use practices of the early inhabitants of Laos. Halpern (1961) suggested that some groups of Lao Theung traditionally used slash-and-bum cultivation. According to Boudene (1913), Lao Theung farmers in Attopeu used to grow small areas of lowland rice almost 100 years ago. Following Yananda and Nonwakorn (1925) the Yao (Lao Sung) originated from Nangking and were traditionally growing lowland rice. Similarly, Kunstadter and Chapman (1978) provide examples of Hmong (Lao Sung) farmers adopting lowland rice and plow-cultivation and subsequently changing back to slash-and-bum systems depending on the opportunities for either form of cultivation. These examples indicate that the available options ultimately determined the agricultural methods adapted. It is quite likely that many of the early inhabitants may have used both, lowland and upland rice cultivation. Increasing economic and political power of the Lao Loum, however, may have forced the other groups into more remote areas with limited options but to grow rice on the hill slopes (Halpern, 1961). With increasing population, even some of the. Lao Loum themselves were later forced to change to upland rice cultivation.

Survey data from Luang Prabang and Oudomxay provinces indicate that all ethnic groups are engaged in slash-and-burn upland agriculture (Table 3). All Lao Loum villages surveyed had upland rice cultivation and the contribution from lowland areas to total rice production was small. Most Lao Loum families in the hilly regions had no lowland, others may have some but relatively small areas. Similarly, if conditions allow, Lao Theung or Lao Sung farmers may also have lowland ricefields. In a survey carried out in Nonghet District (Xiengkhouang Province), none of the Lao Loum and Lao Theung families interviewed had lowland rice, while the Lao Sung families had 024 hectare on an average (Table 4). It is, however, not disputed that groups in the Lao Theung and Lao Sung categories are more concentrated in the hilly areas and thus more dependent on upland agriculture. How far this is the result of being forced out of the lowland or to take refuge in remote hills and how far it is cultural preference will remain open for further debate.

Systems diversity: crops, livestock, and trees

There are distinct differences between ethnic categories in crop diversity and livestock numbers. Lao Sung farmers have’ much higher areas of maize cultivation than the other categories for all the regions where quantitative data are available (Tables 3 and 4) and they generally have a higher diversity in the number of vegetable, crop, and perennial species (data not shown) per family Apparent ethnic differences in choice and importance of perennial species used are largely a result of environment and available resources. Mango and coconut are the most important species for Lao Loum, while banana and papaya are more important for Lao Sung farmers (Roder et al. 1995b). This is clearly influenced by climatic conditions, since mango and coconut are not suited to the high elevations generally inhabited by the Lao Sung farmers. Age of settlement may be another factor affecting choice of species. Banana and papaya can both be harvested within one year after planting and may therefore be the preferred species in newer settlements. The number of timber species, especially teak, planted by individual families could be related to the wealth and the availability of lowland area of a particular household (Roder et al. 1995b).

Several authors have credited Khamu (Lao Theung) farmers for their appreciation of trees and the environment (Hakangard et al. 1990; Tayanin 1992) and claimed that unlike others, they would influence the fallow vegetation by encouraging the survival of certain species or refrain from cutting preferred species at the time of slashing. No evidence of such practices could be found by any of the farmers visited and interviewed. Trees which are too large (Dessaint, 1981) or otherwise too difficult to cut are sometimes left standing and used as support for various gourd species. Species of economic interest are left in (he field by all upland farmers irrespective of ethnic group. Examples of such species include Styrax sp. (for benzoin production), wild banana, wild yam, and trumpet flower (*Oraxylum indicum*) (Roder et al., I 995b).

Lao Loum farmers have generally higher numbers of buffalo, while Lao Sung farmers have more cattle, pigs, and horses. Livestock is the most important source of cash for all categories and the number of livestock owned is generally an indication of the material wealth of a household. On an average, the number of large livestock units owned was 2.6, 1.9, and 4.2 for Lao Loum, Lao Theung, and Lao Sung, respectively (Table 3, buffalo, cattle and horses taken as I unit, pigs as 0.2 unit). This indicates that the Lao Sung farmers are probably wealthier than those in the other categories.

Choice of location, altitude

Remote villages at higher elevations are generally settled by Hmong and Yao although many exceptions exist, The choice of higher or more remote locations may partly reflect the fact that these groups have moved to Laos more recently and had to use land which was not yet occupied and thus more remote, and partly the preference for cultural isolation, cooler climate, and environments free of malaria (1-lalpern, 1961). The Hmong and Yao prefer limestone soils for their maize and opium fields.

Cropping/fallow cycles, system sustainability

The most frequently voiced observations relating land use to ethnic groups state that Lao Theung farmers use a comparatively more stable, “ecological”, and environmentally sound system, while the Lao Sung system is very destructive (Hakangard et al. 1990; RICN, 1988; Wirtz, 1959; Table 5). Others suggest that the Lao Theung use largely rotational systems, while the Lao Sung mostly use pioneer systems which destroy large areas of forest (Halpern, 1961; Wirtz, 1959). None of the authors making such claims could offer quantitative or qualitative data to support or validate their assertions and interestingly enough, observations made by Pavie (1901) and Gourou (1942) several decades ago entirely contradict the later observations. During a journey through parts of Pongsaly Province, Pavie (1901) described slopes which have been denuded and made the comment that like the Hmong, the Lamet (Lao Theung) were destroying the forest. Gouron (1942) wrote that the Indochinese mountains are inhabited by different groups of people, but that they had many commonalties, specially concerning land use.

Some have warned that land degradation and declining yields are recent phenomena for the hills of Laos (Pujisaka, 1991; SUAN 1990). Limited quantitative information is available on the productivity and systems sustainability in the past. Pavie (1901) in his extensive travels through Laos made only scant reference to agricultural practices. Yet some of his remarks clearly state that negative effects of slash-and-burn practices have already been visible 100 years ago. Describing his impression from areas in Pongsaly, he said that “slopes are almost always denuded by ancient cultivation.” Drilon (1965) reported upland rice yields of well below it h^{-1}, while statistics for the last 3 years, substantiated by crop cuts in the field show a national average yield of upland rice of above 1.5 t/ha (National Statistical Center, 1993; 1994). Yield data provided by Drilon (1965) was perhaps grossly underestimated, but the comparison illustrates that it will be impossible to prove a declining trend in upland rice yields.

Traditional slash-and-burn systems are believed to be sustainable and well adapted to hilly conditions as those prevailing in northern Laos (Ruthenberg, 1980; Warner, 1991). Some authors suggest that they represent a system where farmers optimize return on labor by using large land resources. To be sustainable and to provide optimum returns on labor, the slash-and-burn system require long fallow periods and the length of cropping/fallow cycles can be used as indicators of sustainability. Gourou (1942) suggested that a 20-year fallow would be the minimum in many situations in the hills of Indochina. The available quantitative data on past and present fallow and cropping cycles do not show differences between ethnic groups (Tables 4, 6, 7, and 8) except for a slight tendency of longer fallow and cropping periods for the Hmong farmers. All records before 1980 indicate fallow periods above 10 years and cropping periods of 1-2 years. Increased population pressure and/or government regulations led to a dramatic reduction in fallow length across all ethnic groups. In a recent survey interviewing elderly farmers, the average fallow periods reported for the I 950s, I 970s, and 1992 were 38, 20, and 5 years, respectively (Roder et al. 1994). The effect of reduced fallow length is felt strongly today in increased weeding requirements. Its effect on soil properties may, however, only become manifest after the same fields have gone through several cropping and fallow cycles. In the household survey, farmers rated weed, drought stress, and rodents as far more important constraints than soil fertility (Roder et al. 1995a). The reduction in fallow length has resulted in much higher weeding requirements but has apparently not yet substantially affected rice yields.

There is no consistent difference between the three categories in rice yield, slope gradient, labor inputs, weeding requirements, and fallow period (Tables 6 and 7). The longer cropping cycles reported by Lao Sung farmers and the higher organic matter levels observed may partly reflect the fact that 1) being recent immigrants they are still working on land with higher fertility status (Table 6), having gone through less cropping fallow cycles; 2) the overall cooler climate results in slower organic matter breakdown, 3) wider crop diversity allows for longer cultivation by reducing the impact of weeds and pests; 4) opium production systems are different from rice production systems. It is quite logical that new settlements of any ethnic groups in a previous uncultivated area would be “pioneer” slash-and-bum farmers. It is well established that members of the Lao Sung group represent the most recent immigrants and are therefore more likely to encroach in new areas.

The available quantitative data do not support the theory of distinct differences in Land use practices between ethnic categories and variations are generally larger within the same category than between categories. If there were distinct ethnic differences in land use in the past as claimed by some, they were most likely lost over the last two decades with tremendous political changes and substantial movements of a large percentage of the rural population. As mentioned by many observers, the land use practices are largely an adaptation of the different ethnic groups to a given environment. Further more, decisions to change to other land use systems are more likely to be influenced by economic standing of the farmers and by market opportunities rather than by ethnicity.

With no major differences in land use practices observed among the different ethnic categories, no differences in system sustainability would be expected. The sustainability of the existing land use systems depends largely on the degree to which the carrying capacity has been filled or exceeded. Population dynamics will strongly influence the options available for future hill populations. In the area surveyed, Lao Sung populations had the highest number of children under the age of 10 years (Table 9). This faster population growth may again reflect the lack of access to education, information, medical facilities, and other socio-economic benefits rather than ethnicity.

CONCLUSIONS

The present terminology used to classify the population in Laos into "dwellers of the lowlands, mountain slopes, and mountain summits" strongly reinforces bias associating land use practices with ethnic identity. Past and recent observations on land use practices do, however, not lend support to the claim that there are distinct ethnic preferences for certain land use practices. When formulating future policies and implementing programs focusing on sustainable upland agriculture for the hilly areas of Laos, it would be more realistic to use economic stratification based on available options and opportunities rather than ethnic divisions. Criteria for stratification into farm typology could include size of farm holding, slope classes, soil type, water availability, livestock, access to markets and inputs, and access to alternative sources of income. To be successful, the hill population should be included in the decision-making process affecting the use of their resources (Ireson and Ireson, 1991). Future changes in land use by all ethnic groups will be more likely made based on economic incentives rather than on long-term ecological concern by the individual farmers. Thus, economic incentives that promote ecological sustainability need to be provided.

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Table 1. Categorization or major ethnic groups in hilly parts of Laos.[1])

Category	Ethnic groups[2])
Lao Loum	Lao, Phu Tai, Lu, Yuan
Lao Theung	Khamu, Lamet, Phong, Lawen
Lao Sung	fimong, Yao, Phu Noi, Ko, Kui, Musser

1) These categories are based on supposed altitudinal delineation and the arbitrary classification of distinct ethnic groups within these categories do not reflect the real situation.
2) Only the most important groups are listed.

Table 2. Main objectives, location of studies, information used in this paper and reference.

Study and main objective	Location (Province/districts)	Information used	Ref.
1. Household survey (1991/92) ● Characterization of land use systems ● Identify constraints to rice production	Luang Prabang (Viengkham, and Xiengnguen districts) Oudomxay (Noun, Say, Heng, and Namo districts)	Fallow, soil parameters, weed species, income	1)
2. Crop cut (1991) ● Estimate rice yield ● Relate yield level to soil parameters	Luang Prabang (Xiengnguen, Viengkharn and Pongsay districts)	Fallow, slope gradient, soil parameters, elevation	1)
3. Yield-soil-weed survey (1993) ● Identify relationships between rice yield, weed, and soil parameters	Luang Prabang (Xiengnguen district)	Fallow, slope gradient, soil parameters, elevation	1)
4. Village survey (1993) ● Statistics on land use, trees, and livestock	Luang Prabang (Viengkham and Xiengnguen districts)	Information on crop, tree and livestock	2)
5. Survey Bokeo (1994) ● Characterization of land use systems ● Identify constraints to rice production	Bokeo.(Houay Xay and Tone Pheung districts)	Land use, weed	3)

1) Roder et al. 1995b.
2) Roder et al. 1995a.
3) LAO-IRRI, 1994.

Table 3. Information on land use, livestock number, and distance from road or river observed in Luang Prabang Province.[1])

Parameter	Lao Loum		Lao Theung		Lao Sung	
	Average[2])	(%[3])	Average	%	Average	%
Crops and trees						
Lowland rice (ha hh^{-1})[4])	0.06	12	0.02	3	-	0
Upland rice (ha hh^{-1})	0.76	88	1.08	98	0.82	100
Maize (ha hh^{-1})	0.14	55	0.25	79	0.47	99
Opium (kg hh^{-1})	-	0	0.4	18	35	69
Mango (no. hh^{-1})	5.1	44	1.6	25	2.5	25
Banana (no, hh^{-1})	2.6	28	5.2	25	11.5	56
Teak (no. hh^{-1})	19.2	20	1.9	5	0.03	<1
Livestock						
Buffalo (no. hh^{-1})	1.89	57	0.83	35	0.49	19
Cattle (no. hh^{-1})	0.13	7	0.53	22	1.88	59
Pigs(no. hh^{-1})	2.57	72	2.33	72	5.48	95
Horses (no. hh^{-1})	0.03	2	0.06	3	0.78	49
Others						
Distance road/river (kin)	9.5		8.4		13.6	

1) Sample no. was 115, 504, and 221, for Lao Loum, Lao Theung, and Lao Sung, respectively.
2) Average of all households, 3) Percent of households, 4) hh = household.

Table 4. Land use reported from surveys in Thongkhang[1]) (Luang Prabang Province) and Norighet2) (Xiengkhouang Province).

Parameter	Lao (Lao Loum)	Khamu (Lao Theung)	Hinong (Lao Sung)
Thongkhang(Nane district)			
Lowland rice (ha hh^{-1})[3]	0.15	0.07	-
Upland rice (ha hh^{-1})	1.24	1.1	0.93
Maize (ha hh^{-1})	0.34	0.19	0.47
Upland rice yield (t ha^{-1})	0.9	0.8	0.9
Cropping periods	1.0	1.3	1.8
Fallow period (years)	3.3	3.5	3.8
Nonghet district			
Lowland rice (ha hh^{-1})	-	-	0.24I
Upland rice (ha hh^{-1})	1.17	1.39	0.83
Maize (ha hh^{-1})	0.15	0.19	0.97
Opium (ha hh^{-1})	0.12	0.26	0.26
Rice production per capita	187	169	1.39

1) Leacock et al. 1993 (Figures for 1989).
2) Hkurn, 1992 (families interviewed were 46, 140 and 340 for Lao, Khamu, and Hmong groups, respectively).
3) hh = household.

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Table 6. Ethnic category and land use in Luang Prabang and Oudomxay provinces.[1])

Parameter	Lao Loum	Lao Theung	Lao Sung
Fallow period (yr)	4.2±0 4[3])	4.9±0.4	5.6±1.1
Elevation (in)	651±68	637±72	991±92
Slope (%)	38±4	39±4	38±5
Rice varieties (no. per household)	2.8±0.6	2.7±0.4	2.3±0.5
Yield (t ha^{-1})	1.3±0.2	1.4±0.2	1.4±0.3
Self sufficiency (mo)	8.1±1.5	8.4±1.5	9.6±1.2
Organic matter (%)	3.7±0.3	3.9±0.3	4.9±0.7
C-N ratio	15±1.4	12±0.9	16±2.6
pH	5.6±0.1	5.5±0.1	5.3±0.2
Total labor input (d ha^{-1})	337±55	308±62	284±65
Labor for weeding (% of total labor)	39±5	45±	36±6
Labor for slashing (% of total labor)	14±2	15±5	12±4
Chrornolaena odorata (frequency)[2])	61± 16	72±8	39±18
Ageratum conyzoides (freguency)[2])	24±15	46±12	39±2 1

1) Average of all measurements made during 1992 and 1993. Sample size for Lao Loum, Lao Theung, and Lao Sung was 113, 189, and 59, respectively, for fallow period; 37, 57, and 24, respectively, for elevation; 128, 175, and 63, respectively for slope; 21,43, and 19, respectively, for rice varieties; 46, 46, and 29, respectively, for self sufficiency; 119, 154, and 49, respectively, for soil parameters; 55, 48, and 27, respectively, for labor input data; and 42, 81, and 27, respectively, for weed frequencies.
2) Presence in transects of I m, 80 transects per field.
3) Confidence interval at P=0.01.

Table 7. Ethnic category and land use in Bokeo Province.

Parameter	Lao Loum (n=8)	Lao Theung (n=11)	Lao Sung (n=37)
Fallow period (yr)	10±3.2[1])	4±1.3	7±2.1
Cropping period (yr)	1.1±0.4	1.3±0.4	1.6±0.4
Slope gradient (%)	1±1	26±15	7±4
Elevation (in)	391±12	411±20	404±9
Weeding (no.)	2.8±0.8	4.0±0.9	3.1±0.3
Rice yield (t/ha)	2.0±1.0	2.7±1.3	2.2±0.4

1) Confidence interval at P=0.01.

Table 8. Fallow-cropping intensities reported.

Reference	Period	Ethnic group.	Location	Cropping	Fallow
Boudene (1913)	1910	Lawen (Lao Theung)	Attopeu	2-3	10-20
Gourou (1942)	1940	Diverse.	Laos and Vietnam		>20
Izikowitz (1951)	1950s	Lamet (Lao Theung)	LuangNamtha	1	12-15
Lemoine (1972)	1964/67	Hmong (Lao Sung)	Sayaboury	I (3-4)[1)]	
Wall (1975)	1967	Nya Hdn (Lao Theung)	Attapeu	1 (2-3)	15-20
Lyman (1969)	1968	Hmong (Lao Sung)	Thailand and Laos	2	5
Dao (1975)	1975	Hmong (Lao Sung)		1-3	15
Dessaint (1981)	1970	T'in (Lao Theung)	Sayaboury	1(2)	Few years
Thongphachan and Birgegard (1982)	1980	Lao Loum	Vientiane	1.3	4.5
lerson (1990)	1990	Hmong (Lao Sung)	Xiengkhouang	2	>3

1) Indicate exceptions i.e. sometimes cropping was up to 3 to 4 years.

Table 9. Family size (Data from 1993 household survey).

Age group	Lao Loum	Lao Theung	Lao Sung
<10yr	2.4	2.6	3.3
10-20yr	0.8	1.0	1.4
>20 yr	2.8	2.6	2.6
Total	6.0	6.2	7.3

Weed management and fallow vegetation

Weeds and fallow vegetation are the main components manipulated by the slash-and-burn farmer. Fallow length and quality of fallow depend directly on the fallow vegetation. 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.

Length of cultivation, or the farmer's decision to abandon a field and move to a new site, is strongly influenced by weed competition to the crop and labor requirements for weeding (Moody 1975, Nye and Greenland 1960, De Rouw 1991). Several authors have also suggested that weeds play a positive role in shifting cultivation systems by recycling nutrients, maintaining soil fertility or productivity, and reducing erosion and/or nutrient runoff and leaching (see Roder et al 1997, included at the end of this section).

Traditional slash-arid-bum systems had long fallow periods, with tree cover eliminating most of the annual weed species. High fallow vegetation biomass resulted in high temperatures at the time of burning, thus decreasing viability of weed seeds, which may have been present in the topsoil.

Weed and weed management during the rice crop

Slash-and-burn farmers in northern Lao PDR considered weeds as the single most important constraint to rice production. Labor inputs of 140-190 days ha^{-1} for weed control resuit in low labor productivity (see Roder et al 1997a, included at the end of this section). Weeds are increasing largely due to a decrease in the fallow period. Average fallow periods decreased from more than 30 years in the 1950s to 5 years in 1992. Reduced fallow length and the introduction of exotic weeds have changed weed composition in crops as well as the composition of fallow vegetation. Weed composition during the cropping period and the vegetation in the initial years of fallow are almost always dominated by Chromolaena odorata, an American species introduced to Lao PDR in the 1930s. Another introduced weed species, Age ratum conyzoides, although less dominant, has shown a strong association with root-knot nematode (Meloidogyne graminicola) (Roder et al 1998). Root-knot nematode may be a major factor in the decline of rice yield with continuous rice cultivation.

Weed populations and weed management strategies tested are discussed in the papers included at the end of this section. Farmers usually provide adequate weed control to avoid yield loss in rice, but yield loss due to an increase in nematode densities associated with A. conyzoides has been suggested (Roder et al 1998). The present practice of burning crop residues or biomass of the fallow vegetation provides the best weed control. Of the various weed management strategies tested (Roder et al 1995a), preplant application of glyphosate and grazing rotation systems are the most promising. In recent studies, shallow tillage before planting rice and multiple cropping reduced weed biomass in the rice crop (Table 9).

Fallow vegetation

During the long fallow periods used in the past, the vegetation progressively developed from

Table 9. Effect of tillage and cropping on weed biomass.[a]

Treatment	Reduction in weed biomass (%) compared with control[b]	
	Ageratum conyzoides	Total weed
Shallow hand tillage	63	38
Planting cowpea before rice	88	31

[a]Data from two separate studies.
[b]Biomass of the first two weedings.
Source: Fahrney (1999).

annuals to tree species. Today, with shorter fallow periods, the vegetation cover is dominated by annuals, shrubby perennials, and bamboo. Of these, *Chromolaena odorata* is the dominant species.

Species dynamics, biomass production, and nutrient accumulation by fallow vegetation were described for four sites in a detailed study carded out in Luang Prabang Province. In these and bther studies, major attention was given to *C. odorata*. The findings from the various investigations are presented in papers included in this chapter and the section "Research methodology." Additional information on C. odorata was collected through household surveys carried out in 1996 (Roder et al 2000), with the objective to document (1) farmers' assessment of *C. odorata* for fallow improvement and (2) farmers' interventions to influence *C. odorata* in the fallow vegetation. A formal questionnaire was used to interview 24 households in three villages in Oudomxay Province and 20 households in four villages in Luang Prabang Province. Criteria applied for selection of the villages were no lowland rice cultivation, being representative for the area, and ease of accessibility.

The results of farmers' assessments are similar to those published in Roder et al (1995b). About 70% of the respondents indicated that they like to have *C. odorata* in their fallow vegetation. The main reasons cited for this preference were better rice yield and the relatively easy control of *C. odorata* as a weed (Table 10). Soil fertility and enabling of shorter fallow duration were also mentioned. Although many respondents were not convinced that *C. odorata* would suppress weeds (Table 11), the positive response by some suggests that suppression of selected species may occur. The question "Does *C. odorata* suppress weeds?" was answered positively by 46%, 33%, and 0% of the respondents for the weed species *Ageratum conyzo ides*, *Imperata cylindrica*, and *Mimosa invisa*, respectively.

While recognizing the positive properties of *C. odorata*, farmers are at the same time concerned about weeding inputs. Any intervention that leads to more weeding would not be acceptable to them and they are therefore very reluctant to have more *C. odorata* in their fields (Table 11). With weeding being the single most important constraint to upland rice production, their reluctance to enhance *C. odorata* presence in the fallow vegetation is understandable. Only a very small number of respondents indicated that they were making some effort to increase the *C. odorata* cover Measures used to enhance *C. odorata* are burning and/or slashing, selective weeding, and avoiding the last weeding.

Table 10. Response to "Why is C. odorata a good fallow species?" (44 respondents).

Reason	Frequency (% respondents)
Good rice yield/rice grows well	50
Easy to control when weeding	18
Good soil or good fertilizer	14
Shorter fallow	9
Easy slashing	9
Burns well	7
Fast growing	2
Many seeds	2
Good soil moisture	2

Table 11. Potential of C. odorata for fallow improvement.

Parameter	Response positive (yes) (% respondents)
Is C. odorata suppressing weeds?	
Weeds in general	40
Mimosa in visa	0
Imperata cylindrica	33
Agera turn conyzoides	46
Potential for fallow improvement and farmers' intervention	
Shorter fallow possible with C. odorata?	75
Liked in fallow?	68
Would you like more *C. odorata*?	32
Doing anything to increase?	11

At this stage, neither farmers nor researchers have sufficient understanding of the effects of *C. odorata* on the species composition in the fallow vegetation, soil properties, and rice yields. The positive effects on rice performance, as observed by farmers. may be mostly due to the suppression of *A. conyzoides* and nematodes.

Papers included with this section

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

RoderW, Phengchanb S, Maniphone S, Songnhikongsuathor K, Keoboulapha B. 1995. Weed management strategies aimed at reducing labor for upland rice production. In: Fragile lives in fragile ecosystems. Proceedings of the International Rice Research Conference, 13-17 Feb. 1995. Manila (Philippines): International Rice Research Institute. p 395-405.

Roder W, Phengchanh S. Keoboulapha B, Maniphone S. 1995. *Chromolaena odorata* in slash-and-bum rice systems of Northern Laos. Agroforest. Syst. 3 1:79-92.

Also consult the following papers included in other sections:

Roder W, Phengchanh S. Maniphone S. 1997. Dynamics of soil and vegetation during crop and fallow period in slash-and-bum fields of northern Laos. Geoderma 76:13 1-144 (see section "Soil and soil fertility").

Rocier W, Keoboulapha B, Phengebanh 5, Prot IC, Matias D. 1998. Effect of residue management and fallow length on weeds and rice yield. Weed Res. 38:167-174 (see section "Fallow improvement/management").

Weeding an upland rice field where *Chromolaena odorata* is the dominant weed species.

Ageratum conyzoides, introduced weed species, in upland rice.

Mimosa invisa in a rice field.

Live mulch of *Arachis pintoi*.

Weed Research, 1997, Volume 37,111-119

Weeds in slash-and-bum rice fields in northern Laos

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Summary

Slash-and-burn farmers in northern Laos consider weeds, insufficient rainfall and rodent damage as the most important constraints to upland rice (**Oryza sativa** L.) production. Labour inputs of 140-490 days ha^{-1} for weed control result in low labour productivity. Average weed cover observed in rice fields was 5.6,4.1,2.1, 1.7, 0.7 and 0.7 cm m^{-1} (transect) for C*hromolaena odorata* (L.) *King and Robinson, Ageratum conyzoides* L, *Commelina* spp., *Lygodium flexuosum* (L.) Sw., *Panicum trichoides* Sw. and Corchorus spp. respectively. *Chromolaena adorata*, which was introduced in the 1930s, has become the main fallow species and is considered a desirable fallow plant by most farmers. Average fallow periods reported for the 1950s, 1970s and 1992 were 38, 20 and 5 years respectively. Reduced fallow periods in the last decades have resuited in a marked increase in weeding requirements. Above-ground biomass for rice stem, herbaceous plants and trees after rice barvestwas 168,67and60gm^{-2}in 1991 and 115,43 and 24 g m^{-2} in 1992. Weeding at 14-day intervals did not increase rice grain yield.

Introduction

In many slash-and-burn farming systems with sufficient land reserves, the manipulation of fallow and cropping period is a major weed control strategy (Moody, 1975; De Rouw, 1991; Warner, 1991). Weed competition, although frequently not a serious problem in the first cropping year (Moody, 1975; Courtois, 1988; Dc Rouw & van Oers, 1988), is often the main reason for tanners moving to a new field (Nye & Greenland, 1960; Moody, 1974; Sanchez, 1976; Warner, 1991). Several authors have suggested that weeds play a positive role in shifting cultivation systems by recycling nutrients (Swamy & Ramakrishnan, 1988), maintaining soil fertility or productivity (Mishra & Ramakrishnau, 1984) and reducing erosion and/or nutrient run-off and leaching (Toky & Ramakrishnan, 1981; Chac6n & Gliessman, 1982).

In the hilly regions of northern Laos, upland rice (Oryza seztiva L.) is the major crop, and slash-and-burn agriculture the predominant land use system (Fujisaka, 1991; State Statistical Centre, 1990). Fujisaka (1991) considered weeds, low and declining soil fertility, shorter fallow cycles, rats and insects to be the main constraints to higher rice yields and improved system sustainability.

Little information is available on land use systems in northern Laos, particularly on weed species, weed ecology and weed management. Observations made in the 1950s (Halpern, 1961) indicate that weed control in upland rice (slash—and-bum systems) was less labour-consuming than for lowland rice. Izikowitz (1951) gave a detailed description of slash-and-burn cultivation by Laniet farmers in northern Laos in the' 1940s. He considered cutting of the fallow vegetation as the most important labour requirement but also mentioned weeding activities in June and July. Shorter fallow cycles and the introduction of exotic weed species may have caused major changes. *Chromolaena odorata* (L.) King and Robinson spread into Laos during the 1930s (Izikowitz, 1951; Vidal, 1960) and has become the most abundant weed within a few decades (Roder et al., 1995).

During 1991 and 1992, various investigations were carried out in Oudomxay and Luang Prabang provinces in northern Laos to: (1) identify major constraints to upland rice production; (2) identify major upland weeds and assess their relative importance; (3) estimate labour inputs for various cultivation activities; and (4) document shifts in weed species and cropping-fallow cycles.

Materials and methods

Household survey

Household surveys were carried out during the rice-growing seasons of 1991-92 using a formal questionnaire supplemented by field observations. Villages visited were chosen randomly. The choice of household informants was left to the discretion of the surveyors and was strongly influenced by advice from the particular village headman. A total of 129 households' was included, located in three districts of Oudomxay (all in 1991) and in four districts of Luang Prabang provinces (mostly in 1992). The survey questionnaire focused mainly on land use-related issues. Respondents were asked to rate a list of possible constraints and rate the constraints in order of importance. Similarly, respondents were asked to list the most troublesome weed species and recall labour inputs for upland rice production in the previous year.

The upland rice fields of each informant were visited within 25-70 days after rice planting (tillering to particle initiation stage) to record observations on altitude, slope and presence of weeds. Weed cover and weed frequency were measured by randomly placing a 10-m measuring tape over the rice canopy and recording the weed cover directly underneath the measuring tape in 1-m sections. The presence of a particular species in a Pm section was used to compute its frequency. Observations were taken in four transects of 10 m in each field. Newly weeded parts of the field were avoided. Soil samples (15-20 subsamples per field) were collected from all fields in Oudomxay province and some of the fields in Xiengngeun district. The relationship between C. odor-cnn, Ageratum con yzoides L., Commelina spp. and Lygodium flexuosum (U) Sw. frequency and fallow period, elevation and various soil parameters was evaluated using correlation analysis.

Results were compiled separately for Oudomxay (including the districts Hune, Beng and Xay of Oudomxay province), Viengkham (Viengkham and No district of Luang Prabang province), Pakseng and Xiengngeun (both districts of Luang Prabang province). These regions differ in latitude, rainfall, market opportunities and road accessibility. Xiengngeun has the lowest rainfall with an annual average of <1300 mm. The ranking of the regions for road accessibility and market opportunities is: Xiengngeun>Oudomxay>Viengkham>Pakseng.

To increase the reliability of information on labour inputs for upland rice cultivation, 16 households (belonging to two villages in Xicngngeun district) were visited at monthly intervals to record labour inputs during the 1991 growing season. The area of each individual field was measured at the end of the season.

Interview with elderly per-sons

In each village visited in the Xiengngeun and Viengkhani districts, one or two elderly persons were interviewed following recommendations from the village headmen. Efforts were made to select the oldest, apparently dependable persons (60-80 years). Each respondent was asked to recollect land use systems in the past at intervals of 20 years, and to indicate fallow and cropping periods, number of weedings required in upland rice, major constraints and important weed species for each interval. Major family and/or historical events (e.g. first child born, Japanese occupation, etc.) were used to help the respondents recall a particular time interval. The authors were aware that the accuracy of this information source may be limited. In the absence of any records, however, this was perhaps the only approach to obtain information on changes in land use systems.

Weed biomass in monitoring plots

Weed biomass was measured during the rice-growing season (in three sites in 1991) and at the time of rice harvest (in seven sites in 1991 and in three sites in 1992) in monitoring plots of 400 in2 located in three villages in Xierigngeun district. At each site, all plant biomass (except rice during the growing season) was harvested from 10 randomly placed frames of 1 in2. Dry matter yields were measured separately for rice stems, tree species, bamboo, *C. odorata*, *Conyza sumatrensis* (Retz~) Walker, *L. flexuosum*, other broad-leaved species, grasses, tree species and bamboo. The presence of a particular weed species in the frame was used to compute the frequency.

Effect of weeding on rice yield

Experiments were conducted on farmers' fields in Houay Khot (site A, approximately 8 years' fallpw) and Phontong (site B, 4 years' fallow) comparing the treatments: (21) no weeding; (2) farmers' weeding (weeding as per farmers' decision, 2-3 times per season); and (3) weeding at 14-day intervals. A randomized complete block design with three replicates and a plot size of 15 m2 was used at both locations. A traditional rice cultivar, Vieng, was dibbled at 20x25-cin distances on 29 May and 8 May 1992 at sites A and B respectively. At rice harvest, weed dry matter and grain yield measurements were taken from whole plots after removing one border row. Above-ground fresh biomass was measured separately for tree and herbaceous species. Rice yields were corrected to 14% moisture content.

Results and discussion

Household interview

On average, weed competition was considered the single most important constraint to upland rice production (Table 1). Some of the other inportant constraints listed, such as land availability and labour, can be directly related to weeding requirements/problems. Regional differences in land availability and the extent of rat and drought problems were observed. There was more pressure on land in areas easily accessible by road. It is estimated that about 60% of all villages in Xiengngeun district are within 1 hour's walking distance from the road. For the Viengkham district, this figure drops to about 30%. As a result, the average fallow periods are comparatively shorter in Xiengngeun. It is probably because of the interaction of lower rainfall that, in spite of the short tallow periods, weed constraints in Xiengngeun were given ratings similar to the other regions. It is also noteworthy that farmers do not perceive the yield potential of the presently used traditional,

Table 1. Major constraints to upland rice production indicated by slash-and-bum farmers of Luang Prabang and Oudomny provinces~

Constraint	Frequency (% of respondents)				
	Oudomxay	Viengkham	Pakseng	Xiengngeun	Average
Weeds	81	83	95	83	85
Rodents	12	85	80	38	54
Insufficient rainfall[a]	47	49	10	83	47
Land availability	47	11	45	62	41
Insects[b]	69	34	20	29	34
Labour	31	25	25	17	24
Soil fertility	31	26	0	29	21
Erosion	9	9	15	25	15
Domestic animals	16	21	15	8	15
Wild animals	6	22	10	4	11
Disease	6	19	5	0	8
Suitsble vadeties	0	0	0	0	0
Sample size	32	53	20	24	129

[a]Also included the constraint 'short fallow period'.

[b]Mostly white grub (Holotrichia sp.).

Table 2. Labour requirement for upland rice production

Activity	Household survey (%)[a]	Additional survey Days ha^{-1}	(%)[a]
Slashing	14	33 (12-61)[b]	11
Burning	<1	2(1-3)	<1
Fencing	3	2(0-10)	<1
Second burning	6	14 (5-30)	5
Weeding before planting	2	13 (0-40)	4
Planting	9	29(16-44)	10
Weeding	41	146(45-455)	50
Harvesting/threshing	16	33 (20-71)	11
Transport	8	22 (747)	7
Total	100	294 (147-643)	

[a] Per cent of total labour requirement.
[b] Numbers in parentheses indicate range observed.

mostly glutinous rice cultivars (Roder et al., 1996), as a constraint to rice production.

It was generally difficult for farmers to recall the labour input during the previous season and inputs reported were highly variable. Differences in weed cover, individual work efficiency, distance from the village and rainfall all added to the variation. For this reason, only the relative contribution for each task is shown from the household survey. The figures from the household survey, covering a much larger geographical area, were, however, comparable with those obtained from monthly monitoring of 16 households.

Because farmers customarily provide adequate weed control, weeds are less of a yield constraint than a constraint to labour productivity. Weed control is by far the most labour-consuming task in upland rice production, accounting far 40-50% of total crap labour input (Table 2). Generally, 3-4 weedings are required per season with a labour input of 45-455 days ha^{-1}. Because fields are burned in March, about 2 months before rice planting, a first weeding is often necessary before planting. Other tasks requiring appreciable labour inputs are slashing of the fallow vegetation and harvesting. Assuming an average yield of 15 tons ha^{-1} and labour inputs of 300 days ha^{-1}, farmers can expect 5kg of rice per working day. Similarly, 120 days ha^{-1} were required to produce 1.05 tons of rice in lowland production systems in southern Laos (Roder et al, 1992). The return on labour input for upland rice production is thus much lower than that in lowland production systems. Local prices of rice and wages for labour in 1992 were 70-100 kip kg^{-1} rice and 500-700 kip per labour day (1 US$=700 kip). At these rates, slash-and-burn

Table 3. Most important weeds in upland ricefields as perceived by household survey respondents

Weed species	Frequency (% of respondents) Oudomxay	Viengkham	Pakseng	Xiengngeun	Average
Ageraturn conyzoides	59	70	50	56	59
ChTornolaena odorata	88	55	15	26	46
Comrnelina spp.	44	38	50	41	43
Pan icurn trichoides	34	9	40	21	26
Lygodium flexuosurn	34	43	5	6	22
Imperara cylindrica	16	28	30	3	19
PueTaria ihomsoni	13	36	10	15	18
Panicum cambogiense	6	38	10	18	18
Cyperustrialatus	13	36	10	15	18
Cypenespilosus	31	11	0	0	11
Dioscorca spp.	0	15	25	0	10

Table 4 Cover and frequency of major weeds

	Oudoinxay		Viengkham[a]		Pakseng		Xiengngeun	
	F[b]	C[c]	F	C	F	C	F	C
Chromotnena odorata	68	9.7	32	65	36	1.9	64	44
Ageranan conyzoides	31	6.6	23	5.5	11	0.7	60	3.4
Commelinaspp.	18	2.6	8	1.3	22	1.2	58	3.4
Lygodiwnflauosunt	13	1.8	13	1.6	28	1.8	34	1.6
Fanicwn wkhoides	5	0.5	3	0.4	6	0.3	32	1.5
Corchonis spp.	3	0.3	8	1.5	8	0.6	10	04
Pueraria thomyoni			7	1.3	5	0.2	12	0.7
Pankwn camnbogiense			4	0.5			8	0.5
Imperata cylindrica			1	<0.1	4	0.2	4	02
Dioscorca spp.			4	<0.4	2	0.1	<1	<0.1
Crassocephatum crepidloides	<1	<0.1	1	0.1			2	0.1
Total cover (cm m^{-1})		22		19		7		16

[a]Additional species of importance in Viengkbam district were Cyperus trialatus and Ptrendium spp. with frequencies of 26% and 13% and cover of 45 and 3.3 cm m^{-1} respectively.
[b]Frequency (%) in transect segments of 1 m
[c]Cover in cm m^{-1}.

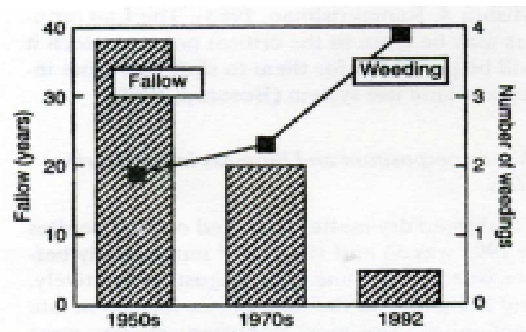

Fig.1. Change in fallow period (years, bar) and weeding requirements (no. of weedings, ■) over the last four decades.

farmers still earn a daily wage that is comparable with local labour rates.

Major weed species, as perceived by the farmers (Table 3), include broad-leaved species, ferns, grasses and sedges, with A. *conyzoide*s as the most important species. Measurements in the field by researchers show that C. odorata was the most abundant weed species, accounting for 44%, 34%, 27% and 28% of total weed covet in Oudomxay. Viengkham, Pakseng and Xiengngeun respectively (Table 4). *Ageratum conyzoides, L. flexuosum* and *Cornmelina* spp. (mostly C. benghalensis L.) were abundant in all the regions surveyed. The last species is difficult to control because it can root easily from the nodes of small stem segments left in contact with moist soil. *Imperota* cylindrica (L.) Raeuschel was present but was not a problem except in very small patches. *Pteridium* spp. and *Cyperus trialatus* (Boeck) Kern,, although present in most areas, were abundant in Viengkham only.

The major weed species appear to be adaptable to a wide range of environmental factors. Correlation analysis between elevation, fallow period, selected soil fertility parameters and frequency of weed occurrence showed no or little relationship. *Chromolaena odorata* frequency declined with increasing elevation (r= -0.23, P<0.05) and the combined frequency of A. *conyzoides, L. flexuosum* and *Commelina* spp. decreased slightly with an increase in fallow length (r= -0.2, P<0.05). Our failure to show dear evidence for a decline in weed cover or frequency with an increase in fallow period can be partly explained by the extremely heterogeneous topography, microclimate and soil condition. Furthermore, attempts to relate land use with weed pressure are compounded by: (a) farmers' adaptation to existing weed pressure, such as choosing shorter fallow periods for fields with fewer weed problems; and (b) cumulative effects of previous cropping and fallow cycles. In our investigations, we could only consider the last fallow period.

Although *C. odorata* is the most abundant weed species, farmers generally do not consider it a major weed. Because of its growth habit (relatively few but large plants, no rooting from above-ground plant parts), it is much easier to control by hand weeding compared with species such as *Commelina* spp. or *L. flexuosum*. Farmers favour *C. odorata* in their fallow field&

When asked to list good fallow species, 76%, 17% and 11% of the respondents listed *C. odorata*, *Castanopsis* spp. and *Dendrocalamus* spp. respectively- The farmers' preference for *C. odorata* may not only be because of its dominance under good sod conditions but also because of its fast growth and large biomass production. Similar preferences for *C. odorota* as a fallow species in Nigeria have been reported (Ruthenberg, 1980)

Interview with elderly persons

The major weed species listed by the elderly persons were similar to: those listed by respondents in the household interview. It was apparent that no major shift in weed species has occurred over the last 40 years. The introduction of *C. odorata* has apparently not resulted in a major displacement of other species. With a coincident ,eduction in fallow period, the spread of *C. odorata* may largely have replaced tree species coppicing from old plants or growing from seeds.

The average fallow reported decreased from 38 years during the 1950s to 5 years in 1992 (Fig.1). Fallow periods were generally longer in the Viengkham district, with 100%, 82% and 0% of the respondents reporting fallow periods of more than 10 years for the 1950s, 1970s and 1992 respectively. For Xiengngeun, fallow periods of more than 10 years were reported by 65% for the 1950s and 29% for the 1970s. Twenty-nine percent of the respondents for Viengkham district reported that one weeding was sufficient in the 1950s, while all reported three or more weedings in 1992. Average weeding requirements for the two districts were 1.9, 2.3 and 3.9 weedings per season for the 1950s, 1970s and 1992 respectively. In his detailed description of land use practices by Lamet farmers in today's province of Luang Namtha. Izikowitz (1951) reported fallow periods of 12-45 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 one to two weedings per season. Effects of reduced tallow length are likely to become more pronounced after the same areas have been used for several short cycles. Weeding requirements and soil fertility problems may, thus, increase further in the near future. Increase in weed problems and decrease in soil fertility are widely cited as negative results of decreased fallow periods in shifting cultivation systems (Moody, 1975; Ruthenberg, 1980; Mishra & Ramakrishnan, 1983). The Lao farmers may be close to the critical point at which it will be profitable for them to shift to a more intensive land use system (Boserup, 1965).

Weed composition and biomass in monitoring plots

Total weed dry matter averaged over three sites in 1991 was 54 and 105 g m^{-2} immediately before weeding in June and August, respectively, and 121 g m^{-2} at the time of rice harvest in late September. The most important species were bamboo and tree species (mostly *Cratoxylon* and Casranopsis spp.), contributing 43%, 41 % and 42%, *C. odorata* contributing 3%, 9% and

Table 5. Plant biomass present at the time of rice harvest as measured in monitoring plots in Luang Prabang during 1991 and 1992[a]

	1991		1992	
Species	Dry matter (gm^{-2})	Frequency (%)	Dry matter (g m^{-2})	Frequency (%)
Chrornoloena odorara	23 (0-42)[b]	100	8(3-14)[b]	87
Conyza sumatrensis	10 (0-33)	69	1(043)	7
Other broad-leaved weeds	13 (4-24)	70	13 (330)	90
Lygodium flexuosuom	17 (7-43)	69	17 (9-20)	73
Grasses	4(0-9)	30	4 (1-tO)	53
Bamboo	15 (0-65)	24	1(0-2)	7
Trees	45 (7-86)	90	23 (10-66)	92
Rice stems	168 (57-218)		115(70-153)	

[a]Average of seven and three sites for 1991 and 1992 respectively.
[b]Numbers in parentheses indicate the range observed

Table 6. Effect of weed control on rice yield and weed biomass at the time of rice harvesta

Treatment	Rice yield (gm -2)			Weed biomass (gm -2): Herbaceous species			Weed biomass (gm -2): Tree/bamboo species			Weed biomass (gm -2): Total		
	Site A	Site B	Average	Site A	Site B	Average	Site A	Site B	Average	Site A	Site B	Average
No weeding	143	52	98	40	355	197	212	20	116	252	375	313
Farmers' weeding	151	195	173	3	2	2	17	0	9	20	2	11
14-day interval	158	183	170	7	13	10	16	2	9	23	15	19
SE	49	41	46	9	32	23	44	12	46	35	44	39
Treatment(T)	NS	0.04	0.04	0.02	<0.01	0.01	0.02	NS	0.05	<0.01	<0.01	<0.01
Location	-	-	0.07	-	-	<0.01	-	-	<0.01	-	-	0.05
TxL	-	-	NS	-	-	<0.01	-	-	NS	-	-	0.04
CV(%)	32.5	28.4	31.0	52	26	33	54	170	103	36	34	34

a Experiment with controlled treatments.

17%, and *L. flexuosum* contributing 8%, 14% and 11% of the total weed biomass measured in June, August and September respectively. Farmers may customarily provide better weed control in the early part of the growing season, as indicated by the lower weed biomass in June. The importance of early weed control is well documented (De Datta, 1981).

Average weed dry matter (including bamboo and trees) present at the time of rice harvest was 127 and 67 g m^{-2} in :1991 (average of seven sites) and 1992 (average of three sites) respectively (Table 5). Lower 'rainfall, the comparatively poor soil condition of the 1992 sites (soil depth) and variations in weed control probably contributed to the lower total weed biomass in 1992. *Chromohzena odorata* and *L. flexuosum* accounted for 60% and 58% of the herbaceous weed biomass (excluding tree and bamboo) in 1991 and 1.992 respectively.

Effect of weeding on rice yield

Farmers started weeding at the early tillering stage and completed two weedings at site A and three weedings at site 13. Weed composition differed markedly between the two sites. The weed biomass at site A consisted of 84% tree and bamboo and 16% herbaceous plants (Table 6). At site B, probably influenced by the shorter fallow cycle, 95% of the weed biomass consisted of herbaceous species, primarily *C. odorata*, *Panicum combo giense Balansa* and *L. flexuosum.*

The different compositions of weed species and total weed biomass resulted in different treatment effects on rice yield. Without weeding, rice yield was reduced dramatically at site B, but it was not affected at site A (Table 6). The yield of the 14-day interval weeding treatment was, however, not different from that obtained with farmers' weeding. The results from this experiment (although limited in scope) support the general observation that farmers provide adequate weed control.

Conclusions

Upland farmers considered weeds as the single most important constraint to rice production. The combined effects of increased population density and government policies limiting farmers' access to land have reduced fallow periods from about 40 years in 1950 to an average of only 5 years in 1992-93. Over the same period, the requirement for weeding has more than doubled. Weed control in slash-and-burn rice production requires about 140-190 days ha^{-1} or 40-50% of the total labour input. Considering the extremely high labour inputs for weed control, the farmers' rating is certainly realistic. The combined effects of increasing labour requirements and stagnant or, as some authors (Fujisaka, 1991) suggest, declining yields resulted in a substantial decline in farmers' return for labour inputs. Farmers are well aware of the effect of fallow length on weed abundance during the cropping period, but have no other options owing to limited land resources. With further reduction in fallow length and the cumulative effects of repeated short fallow cycles, the weed problems are expected to become even more serious in the near future.

The enumeration of weed species through farmer interviews or measurements in the field provided similar results. Chromolaena odorata, followed by *A. conyzoides*, *L. flexuosum* and *Commelina* spp., are the most important weeds throughout the area. Quantification of fallow length effects on weed distribution and species composition was, however, not possible. Long-term monitoring of weed communities and land use practices and/or controlled long-term experiments will be necessary to elucidate these relationships further.

Chromolaena odorata has various properties of a good fallow plant, such as large seed production, fast establishment, suppression of grass weeds, large biomass production and ease of elimination by hand weeding. In future studies comparing improved fallow systems, *C. odorata* treatments should be included, with special attention to its effects on nematodes and allelopathic effects on weeds and crops. The species efficiency in nutrient mobilization and its effects on the biological, chemical and physical soil properties also need further evaluation.

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Weed management strategies aimed at reducing labor for upland rice production

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Weeding requirements in slash-and-burn rice production systems in the hills of northern Laos increased dramatically with shorter fallows. High labor inputs (140-±90 days/ha), increasing population pressure, and rules and regulations pressurize farmers to change to other land use systems. Major weeds include broadleaf, grass, and fern species, and woody perennials. The Lao-IRRI project studies weed management opportunities using herbicides, mulching, improved fallows, and cropping strategies. Of various pro- and postemergence herbicides tested only 2,4-D and propanil offer some promise for weed control in upland rice. Mulching with various plant residues at rates from 1-4 t dry matter/ha did not reduce weed biomass. *Arachis pintoi* as jive mulch reduced rice yield by 80%. Application of glyphosate before planting rice can reduce labor input for weeding by 30-60% and at the same time substantially reduce soil loss. Improved fallow systems combining the effects of fodder plant and grazing animals are expected to result in increased fodder availability, weed suppression, accelerated nutrient cycling, and improved soil moisture conservation due to the mulch cover provided by plant residues. The most promising species tested in various systems include: *Stylosanthes guienensis, Arachis pintoi, Leucaena leucocephala, Crotalaria anagyroides, Giiricidia sepium, and Brachiaria brizantha.*

In the hilly regions of northern Laos, upland rice is the major crop, and slash-and-burn agriculture the predominant land use system (National Statistical Center 1993). Difficult topography and limited access to markets leave few land use options for the farmers Following recent survey 85, 54, 47,41, 34,24,21, and 15% of the respondents considered weeds, rodents, insufficient rainfall, land availability, insects, labor, soil fertility, and erosion, respectively, as the major constraints to upiand rice production. Labor requirement for weed control is the single most important constraint to upland rice production. Constraints such as land availability (or short fallow) and labor, can be directly related to weeding requirements. Weed control in upland rice production requires about 140-190 days/ha or 40-50% of the total labor input (Roder et al 1994). Although labor requirements may be rarely as extreme, weed is a major problem in most upland rice production systems (Moody 1975). Average weed cover observed in rice fields in a 1992 and 1993 survey was 5.6,4.1,2.1, 1.7, 0.7, 0.7, and (16 cm/m (transect) for *Chromoloena odorata*, *Ageraturn conyzoides*, *Commelina sp.*, *Lygodiwnflexuosum*, *Panicum trichoides*, *Corchorus* sp, and *Pueraria thoinsonii*, respectively (Roder Ct al 1994). *Chrornolaena odorora* introduced to Laos in the 1930s has become the most abundant weed and fallow species.

Traditional slash-and-burn systems are expected to optimize labor resources (Raintree and Warner 1986) but due to the high labor requirement for weeding the rice production system practiced by the Lao upland fanner provides only marginal returns for labor. Although there are few quantitative data available on past slash-and-bum practices in Laos it is generally assumed that the high labor inputs for weeding are a relatively re cent phenomenon, related to a decline in fallow periods and the introduction of exotic weed species. Observations made in the 1950s (1-lalpem 1961), indicate that weed control in upland rice (slash-and-bum systems) was less labor-consuming than for lowland rice. Izikowitz (1951) gave a detailed description of slash-and-burn cultivation by Lamet farmers in northern Laos in the 1940s. He considered slashing the most important labor requirement but also mentioned weeding activities in June and July.

Farmers are well-aware of the effect of fallow length on weed abundance during the cropping period. Regulations on land use and increasing population pressure, however, do not allow them to maintain long fallows for weed management. The Lao farmers may be close to the critical point where it will be profitable for them to shift to a more intensive land use system (Boserup 1965). The average fallow periods reported were 38, 20, and 5 years for the 1950s, 1970s, and 1992, respectively. Over the same period, the average weeding inputs increased from 1.9 weedings in the 1950s to 3 S weedings in 1992 (Roder et al 1994). Effects of reduced fallow length are likely to become more pronounced after the same areas have been used for several crop-fallow cycles. Weeding requirements and soil fertility problems may thus increase further in the near future.

Realizing the key role of weed problems in present and future upland rice production systems, the Lao-IRRI project at its inception in 1991, placed high priority on weed and weed management (Fujisaka 1991). Ongoing research activities explore the possibility of weed management using herbicides, mulching, improved fallow, and cropping strategies The initial findings of these research efforts are summarized and discussed in this paper.

Materials and methods

Experiments were conducted at the Houay Khot Research Station (19ºN) or on farmers' fields in the Xiengnguen district in the vicinity of the research station. Soil at the station is classified as Eutric Cambisol with a pH of 6.1 and an organic C content of 1.6%. The station is located in the drier zone of northern Laos with an average annual rainfall of about 1300mm. Annual rainfall for 1992, 1993, and 1994 was 1229,1189, and 1306 mm, respectively (Luang Prabang Station). Details for the individual studies can be found in the annual technical reports (Lao-IRRI 1992, 1993, 1994).

Field preparation consisted generally of slashing the shrub vegetation in January and burning the dry above-ground biomass in March. Soil conditions were frequently highly heterogeneous, as is common in slash-and-bum fields (Andriesse and Schelhaas 1987) resulting in high variations. Rice was planted in hills, using a spacing of 20 by 25 cm, by p]acing about 10 rice seeds in 3-5 cm deep holes made with a dibble stick. The medium-duration, glutinous, local cultivar "Vieng" was used for most experiments. Seeds were generally treated with Carbaiyl (85%) immediately before planting. In the absence of laboratory facilities, weed dry matter was usually not measured and weed yields are reported as fresh weight. Although labor reduction for weeding was the major objective, labor inputs were not measured because of the relatively small plot sizes (20-88 in2).

Results and discussion

Chromotaena odorata is the dominant weed and fallow species (Table 1). Yet the presence of a variety of grass, broadleaf, and fern species, and trees and other woody perennials, poses a difficult challenge for any weed management strategy and consequent2ly the resuits of most weed management studies were rather disappointing (Table 2).

Table 1. Plant biomass present at the time of rice harvest as measured in monitoring plots in Luang Prabang during 1991 and 1992,[a]

Species	1991		1992	
	Dry mailer (g/m^2)	Frequency (%)	Dry matter (g/m^2)	Frequency (%)
Chromolaena odorata	23	100	8	87
Conyza sumatrensis	10	69	1	7
Other broadleaf weeds	13	70	13	90
Lygadiumflexuosum	17	69	17	73
Grasses	4	30	4	53
Bamboo	15	24	1	7

[a]Average of 7 and 3 sites for 1921 and 1992, respectively.

Table 2. Summary of weed management strategies studied under the Lao-IRRI project.

Method	Observations	Po[a]	Limitation
Herbicide			
Pro-planting application of glyphosate	Eliminated need for weeding before plank ing and reduced weed biomass during the rice period by 7-60%- Reduces erosion	***	Cost
Post-emergence herbicides	Weed biomass: Hand weeding < Propanil <2,4- c Logran[b]< Oxidaizon .cWhipC< Control (no weeding)	**	Cost
Mulchinglresidue			
Burning of residue (farmers practice)	Burning reduced weed biomass during season (14-60 %) and at rice harvest (18-42%)	*	Gloss, sys-tems with perennials
Mulching	No effect of pigeon pea and *C. odarata* mulch at rates up to 4 t dry matter/ha	-	
Live mulch	*Arachis pintoi* is too aggressive, no other species available	-	
Improve fallow			
Manipulating fallow species	Weed suppression> *C.odorata> Gliricidia sepium> C. anagyroides> leucaena> Fleming/a con gesta> Pigeon pea> Calli-andra calothyrsus> Sesbania sesban*	*	No eco-nomic bene-fits
Grazed fallow	Most promising species are: *Stylosanthes gulanensis, leucaena, Brachiaria brizan-tha, and A. pintoi* (in combination with trees)		
Cropping management			
Planting density rice	Reduction of weed biomass by 32% in 1993 and 24% in 1994. Closer spacing more difficult to weed and reduced rice yield in 1994	-	Yield reduc-tion
Rotation	Weed fresh biomass in rice was SA, 4.9, 3.2, 5.2 and 3.3 t/ha after rice, fallow, pigeon pea, cowpea, and stylo, respec-tively.		Market
lntercropping	Weed fresh biomass was 5.9 t/ha with rice only and 3.0 t/ha for a rice-maize intercrop-ping system. LER for the intercropping system was 1.12	*	Market

[a]Potential for reducing labor for weed control.
[b]Triasulfuron
[c]Fenoxyprop-P-ethyl.

Herbicides

Herbicides tested had no effect on *L. flexuosum,* tree species and woody perennials. Chemicals with relatively good effect on *C. odorata* and other broadleaf species (2,4-D arid propanil) were inferior to hand weeding (Table 3). Considering the Low costs of 2,4-D (US$2-Mba) it may, however, have some potential which used in combination with hand weeding, but health hazards should not be ignored.

Table 3. Effect of herbicide treatments on rice yield arid weed biomass at harvest.

Treatment	Rice	Weed biomass (g/fresh weight)					
	(t/ha)	c. odorata	B.leaf[a]	Grassesh[b]	L. flexuosum	Tree[c]	Total[d]
1. Control	0.67	189	478	54	43	202	772
2. Hand weeding	1.34	11	142	5	29	124	156
3. 2,4-D	0.99	19	229	44	39	300	394
4. Oxidiazon	0.96	38	370	11	46	369	572
5. Whip[e]	1.07	106	303	50	48	245	563
6. Propanil	0.95	21	54	94	38	382	266
7Rifit[f]	1.02	41	430	31	63	235	597
8. Logran[g]	0.83	104	158	120	46	272	425
Anova (PR>F)							
Location	<0.01	NS	0.02	0.04	<0.01	NS	0.02
Treatment	NS	<0.01	0.10	0.01	NS	NS	0.02
Lx treatment	NS	NS	NS	NS	NS	NS	NS
CV(%)	42	126	97	103	60	60	58
LSD(50%)	-	98	-	62	-	-	322

[a]All broad leaf species excluding C odorata;[b] Grasses and sedges;[c] tree and creepers; [d] TotaI excluding tree and creepers; [e]Fenoxyprop-P-ethyl;[f]Pretilachlor and dimeihametryn; [g] Triasulfuron

In order to avoid the first rains, farmers generally burn the biomass in March or early April or about 2 months before planting. Depending on the rainfall, a first weeding is often necessary before planting. Application of glyphosate at the rate of 2.5 kg a.i. /ha eliminated the need for weeding before planting and reduced the weed biomass during the rice growing season by 7 (Site A) and 60% (Site B, Tables 4 and 5). If planting can be done just before or immediately after glyphosate application the first weeding after planting could be delayed substantially. Elimination of weeding before planting and the first weeding after planting would not only reduce labor input by about 40-80 days/ha but also substantially reduce soil loss by erosion. In the period from weeding before planting to about 40 days after planting, fields are often exposed to soil erosion. Averaged over 3 sites soil loss in June and July contributed 86% of the total loss in the 1992 rice growing season. Pre-planting application of glyphosate is presently the most promising weed management strategy using herbicides. How far it will be suitable for farmers will depend largely on the price of the chemical, the farmers opportunity cost for labor, and the availability of cash. At a low daily wage of 500 kip/day a labor reduction of 40 days would be equivalent to US$28/ha

Table 4. Effect of glyphosate application on weed blomass.

Treatment	Weed biomass first weeding[a] (g /m²)			Weed biomass second weeding[b] (g m²)		
	Site A	Site B	Average	Site A	Site B	Average
1.Control	207	236	221	371	281	326
2.Glyphosate	139	71	105	401	137	269
PR>F)						
Location (L	-	-	NS	-	-	<0.01
Treatment (T)	NS	<0.01	0.01	NS	<0.01	0.06
LxT	-	-	NS	-	-	0,01
CV (%)	49.3	17.8	38.8	15.4	18.0	16.8

[a]30 days after emergence; [b]60 days after emergence (fresh weight).

Table 5. Effect of glyphosate on weed blomass at harvest and grain yield.

Treatment	Weed at harvest (g/m²)	Total weeda (g/m²)	Grain yield (t/ha)
1. Control	268	784	0.86
2. Glyphosate	225	433	0.82
PR>F	NS	<0.01	NS
CV (%)	14.8	8.7	16.2

[a]First weeding 30 days after emergence, second weeding 60 days after emergence and weed at harvest (fresh weight).

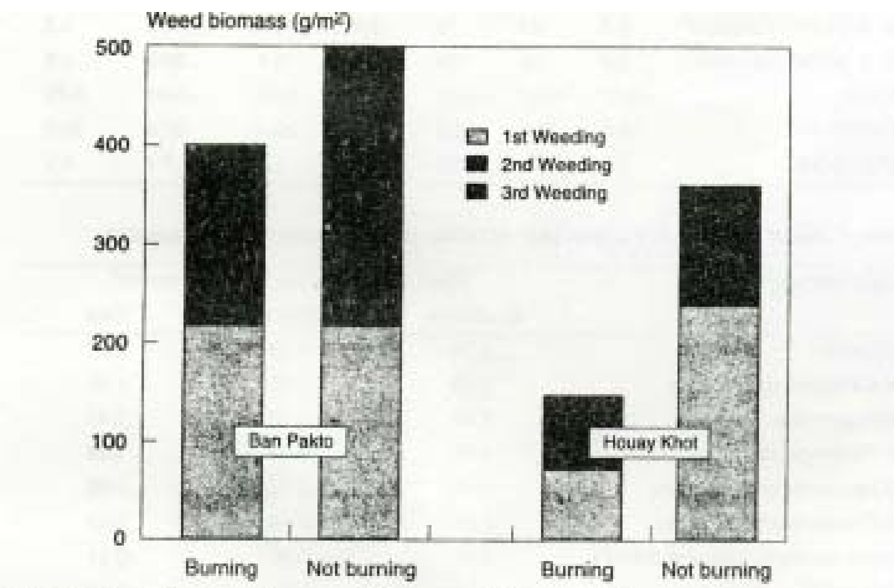
Mulching/residue management

Traditional field preparation involves burning of the slashed above-ground biomass. consisting of 4-20 t of dry matter per ha, depending on fallow period. More and more farmers plant a second or third rice crop before allowing the field to go back to fallow Fields which had rice in the previous year have relatively low above ground biomass quantities (approximately 1-3 1/ha) and field preparation without burning the residue would be feasible. Retaining the residue as a mulch was expected to improve soil moisture conservation and slow organic matter losses. Although residue quantities were only 2.3 t/ha, burning reduced weed biomass at the time of weeding by 14% (at Ban Pakto) and 60% (Houay Khot) in 1993 (Fig. 1). Similarly, burning reduced weed biomass at rice harvest by 42% in 1993 and 18% in 1994 (Lao-IRRI 1993, 1994). At the same time burning increased rice yield by 78% in 1993 and 3% (not significant) in 1994. Farmers are therefore likely to continue the method of burning even if cropping periods are increased, unless other substantial benefits can be demonstrated.

Mulching with C. *odorata* or pigeon pea plant material up to amounts of 4 t dry matter/ha did not reduce weed biomass (Lao-IRRI 1993). *Arachis pintoi* as a Jive mulch had only limited effect on weed biomass but strongly affected rice yield (Table 6). The negative effectof A. *pintoi* on rice yield increases with increasing cover and A *pintoi* is not a suitable live mulch under the prevailing conditions (Table 6).

Improved fallow

Replacement of fallow vegetation by fast growing species, preferably nitrogen fixing legumes, is a widely recommended technique to maintain crop yields and suppress weeds in slasWand-burn systems under reduced fallow periods (Fujisaka 1991, Garrity 1993). Assuming that farmers would more readily adopt sequential improvements to existing systems, Fujisaka (1991) suggested that the initial program of the



1. Effect of residue burning on weed biomass (fresh weight) at two locations. Burning effect was significant for the third weeding at site A (P=0.05) and the second weeding at site B (P=0.05).

Lao-IRRI project should give high priority to improved fallow systems. Among other properties a good fallow plant should have a large biomass production, good weed suppression, easy elimination at the beginning of the cropping period, and not be a weed during the cropping phase. *Gliricidia sepium*, *Crotalaria anagyroides*, and Leuca.ena leucocephala arc the most promising species, with high biomass produc-lion and good weed suppression (Table 7). The dominant weed, C. *odorata* has, how-ever, many of the properties of a good fallow species and, in the absence of any economic benefits during the fallow period, it is not likely that any of the species under observation will be superior.

Table 6. Effect of A. pintoi and field preparation on rice yield, A. pintoi cover and weed biomass.

Treatment	Rice yield (t/ha)	A. pintoi cover (%) 10/7	18/8	At harvest	Fresh biomass (t/ha) Weed 10/7	At harvest A. pintol	Weed
1. Control hoeing	1.0	-	-	-	5.0	-	8.7
2. Control glyphosate	1.2	-	-	-	3.6	-	8.4
3. A. pintoi - hoeing	0.7	15	38	53	3.9	6.6	7.3
4. A. pintoi - glyphosate	1.0	2	3	7	3.2	2.4	5.1
5. A. pintoi - 1 plant/rn2	0.3	43	70	89	3.7	9.1	5.3
6. A. pintoi - full cover	0.2	80	99	97	3.0	20.2	2.5
PR>F	<0.01	<0.01	<0.01	<0.01	0.09	<0.01	0.05
CV (5%)	35.8	30.4	23.1	17.7	20.3	37.4	36.0
LSD (5%)	0-5	21	23	22	14	7.1	41

Table 7. Weed biomass in the first year of fallow under different legume species.

Legume treatment	Weed biomass June 1994 kg fresh/m^2 *C odorata*	Others[a]	Total
1) Control	0.79	0.79	1.57
2) *Calliandra calothyrsus*	1.08	0.88	1 .96
3) Pigeon pea	1.10	0.32	1.41
4) *Flemingia congesta*	0.67	0.62	1.29
5) *Leucaena leucocephala*	0.46	0.52	0.98
5) *Crotolaria anagyroides*	0.34	0.18	0.52
Anova summary Legume (PR>F)	0.11	0.05	<0.01
LSD (0.05)	-	0.51	0.44
CV(%)	45.9	49.6	18.6

[a] *Mostly Conyza sumatrensis and Mimosa invisa.*

Rice fields are presently used for grazing during the fallow period, but little forage is produced because of the dominance of unpalatable species such as C. *odorata* and L.*flexuosum*. Besides increasing the quantity of fodder, replacing the fallow vegetation with palatable species may result in improved weed suppression through the interaction of fallow species and grazing animals. Furthermore, the activities of the grazing animal will accelerate nutrient cycling and reduce the residue load. Although grazing rotation systems may have high potential, only system components were evaluated, such as species introduction and species establishment (Roder and Maniphone 1995). Following these observations the most promising species are: Stylosandies *guianensis*, Leucaena, *Brachiaria brizantha*, and A. *pintoi* (in combination with tree species). The suitability of these species and their effects on weed populations need to be further evaluated in grazed systems, preferably under on-faint fanner-managed conditions.

Cropping strategies

Cropping strategies increasing the competitiveness of the rice crop, or combinations including competitive other crops, have the potential of reducing labor for weeding without the need for expensive chemicals or causing hazards to the environment. Varions strategies have shown some effect on weeds, but they have several limitations (Lao-IRRI 1993, 1994), such as:

- hand weeding becomes more difficult (closer planting density, intercropping)
- risk of lower rice yield or quality (planting density)
- no market for the product (pigeon pea, soybean, maize).

Conclusions

Many of the weed control strategies evaluated have limited effect on weed biomass and labor requirements for weeding. This is partly because of the considerable contribution by L. *flexuosum*, trees, and other woody perennials to the weed biomass. Reduced fallow periods will result in a gradual shift in the weed population towards annual and herbaceous species, and conditions where herbicides and other conventional weed control strategies are more likely to succeed. At the same time labor requirements for weeding may further increase.

Farmers' economic situation, labor availability, ecological constraints, and present and potential markets need to be considered carefully when evaluating potential weed management strategies. Of the various options under evaluation, grazing rotation systems and the use of pre-planting application of glyphosate have the highest potential. While most other methods offer limited promise, some may be useful when used in combination. Considering the need for soil moisture and soil organic matter conservation, the retaining of surface residues is expected to become an important factor in future cropping systems. No tillage systems with heavy loads of surface residues will likely depend on herbicides such as glyphosate.

In the fragile upland ecosystem weed management, nutrient management and soil and moisture conservation are strongly interdependent. An integrated approach combining these elements is the most likely approach to succeed in reducing the cost for weeding while at the same time improving the sustainability of the system. Such a scenario mat. include a combination of chemical weed control measures, improved fallow species, retention of surface residues and controlled grazing.

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Chrornolaena odorata in slash-and-burn rice systems of Northern Laos

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Key words: plant introduction, weed, fallow vegetation, biomass production, improved fallow

Abstract. *Chrornolaena odorata*, introduced to Laos in the I 930s, has become the most abundant weed and fallow species in slash-and-bum fields over a wide range of land use systems, elevation, and pH ranges. Regeneration from roots, high seed production and easy dispersal allow for the rapid colonization of fields in the initial fallow period. At rice harvest, after a I-year and a 2-year fallow, the total aboveground biomass in monitoring plots was 1.4, 10. and 15.4 t ha^{-1} with 16, 48, and 29% contribution by C. *odorata*, respectively. With progressing fallow period C. *odorata* is gradually replaced by tree and bamboo species. Slash-and-bum farmers preferred C. *odorata* over other fallow species common in their fields. *Chromoloena odorata* is an excellent fallow species considering its fast expansion after crop harvest, high biomass production, weed suppression, and fast decomposition rate.. Some of these properties may, however, become a serious disadvantage when tanners gradually change to land use systems that integrate grazed fallow, crop rotation, and/or fruit and timber plantations.

Introduction

Chromolaena odorata, native to subtropical and tropical America, is considered a noxious weed in many parts of the world [Olaoye, 1986; Torres and Paller, 1989; Waterhouse, 1994]. It is often associated with slash-and-burn agriculture and is particularly widespread in slash-and-bum systems in Africa [de Rouw, 1991] and Asia? [Nakano, 1978; Kushwaha et al., 1981]. Nakano [1978] and Nemoto et al. [1983] showed C. *odorata* to be the dominant species in slash-and-bum systems of north and northeast Thailand. High seed production, easy seed dispersal by wind, perenniality, dual reproduction methods, fast growth and wide adaptability all contribute to make C. odorara such a widespread and often dominant fallow species [Kushwaha et al., 1981; Torres and Paller, 1989).

In the hilly regions of northern Laos, upland rice is the major crop, and slash-and-burn agriculture the predominant land use system [National Statistical Center, 1993; Roder et al., 1994]. In a recent survey farmers in northern Laos considered weeds, insufficient rainfall, and rodent damage as the most important constraints to upland rice production in slash-and-burn systems [Roder et a]., 1994]. Labor requirements of 140-190 days ha’ for weed control result in low labor productivity. *Chromolaena odorota* was the most important weed observed in upland rice fields in the Luang Prabang and Oudomxay province [Roder et al., 1994]. Elderly persons interviewed could not recollect the dominant weed species prior to the introduction of C. *odorara*. With a coincident reduction in fallow period, C. *odorata* may have largely replaced tree species coppicing from old plants or growing from seeds.

The present government policies give high priority to reducing the area under slash-and-bum agriculture and thereby limiting farmers' access to land. These efforts, combined with rapid population growth, have resulted in shorter fallow cycles and consequently increased weed problems and soil deterioration [Roder et aL, 1994). Farmers urgently need technologies that can help them sustain rice production with shorter fallow periods. Fujisaka [1991] recommended improved fallow systems as the most appropriate step from slash-and-burn to permanent land use systems in Laos. Improved fallow systems are expected to provide faster, yet similar ecological benefits as natural fallow [Robison and McKean. 1992]. Properties expected of species for fallow 'improvement include: ease of establishment, provision of plant cover after crop harvest, large biomass production, fast decomposition rate, weed suppression, and ability to mobilize plant nutrients from lower soil layers [Fujisaka. 1991; Rao Ct aL, 1990; Robison and McKean, 1992]. Under the Lao conditions improved fallow systems are also expected to increase fodder availability, accelerate nutrient cycling, allow seed bed preparation without burning, and improve soillwater conservation [Roder et al, 1995].

Chromolaena odorata, although not palatable, does have many attributes of an improved fallow species and was considered as a welcome plant rather than a weed in some slash-and-bum systems [Dove, 1986; Keovilayvong et al., 1991; Ruthenberg, 1980]. The widespread dominance of the species in the upland ecosystem of Laos and the ongoing disputes about its merit among agriculture and social scientists, policy makers and others concerned with the wellbeing of the upland farmers, warrants closer examination of the species. From 1991 to 1993 the LAO-IRRI project has collected various data relating to land use practices, weed problems and soil fertility. We used pertinent data from these activities and references available on Laos, to discuss *Chromotaena odorata* in the context of the prevailing slash-and-burn agriculture system, specifically: 1) introduction and spread in Laos, 2) importance during the rice-growing and fallow periods in the present rice-growing systems, and 3) possible advantages and disadvantages as a fallow plant.

Materials and methods

Review of references relating to the introduction of Chromolaena odorata to Laos

References on Laos were reviewed in an attempt to reconstruct the introduction and spread of C. *odorata.*

Plant succession in monitoring plots

Four observation plots of 400 m^2 each were delineated in 1991 in fields that had been newly slashed and burned. All plots were located in the Xiengnguen district at sites considered representative for the area.

Observations made in 1991. Weed biomass was measured 3 during the rice-growing season (one site) and at rice harvest (four sites). At each site, all plant biomass (except rice during the growing season) was harvested from 10 randomly placed frames of I in'. Dry matter yields were measured separately for rice stems, *C. odorata, Lygodium flexuosum*, other broadleaf species. grasses, tree species, and bamboo.

Observations made in 1992 and 1993. Aboveground biomass was measured in December 1992 and December 1993 by cutting and weighing all above ground vegetation from 9 m^2 from representative plots adjacent to the monitoring plots. Dry matter was calculated based on a moisture content of 12% for air dry subsamples. Simultaneously observations recording frequency and density of C. odorata, bamboo, and tree species were made in each plot from 40 frames of 1 m' placed randomly along four transects.

Litter fall and biomass accumulation of fast-growing species and C. odorata

An experiment was initiated at the Houay Khot station in 1992 to compare the performance of potential fallow and multipurpose tree species. Treatments included 1) *Gliricidia sepium*, 2) *Calliandra calothyrsus*. 3) *Cassia* sp., 4) *Mimosa invisa*, and 5) C. odorata (treatments with additional species were not followed because of poor performance. The experimental design was a block design with two replications and a plot size of 36 m2 (6 x 6 in). The experimental area was planted with rice in June- Saplings raised from seed, for treatments 1-3 were transplanted in July, after an initial period of 3 months in the nursery. Planting distance was 1 >c I m. All plots were hand weeded in August. Seeds of treatments 4 and 5 were broadcasted in August. Litter fall was measured during 1993 by placing two boxes, 0.25 x 0.25 m, in each plot and collecting the material at monthly intervals. Dry matter was calculated based on a moisture content of 12% for air dry material. Fresh biomass of the individual species and weed biomass was measured in February 1994. Soil samples at depths 0-7.5 and 7.5-15 cm (10 subsamples per plot) were collected after slashing in April with an Oakfield core sampler (20 mm diameter). Air-dried samples were analyzed for organic matter, total N, pH and available P.

Surveys

Household surveys 1991 and 1992. Household surveys were conducted in the Luang Prabang and Oudomxay Provinces in 1991 and 1992, with the objective to characterize existing land use systems. Field investigations included observations on:

- *Canopy cover of major fallow species* (1991 survey): Fields to be used in the coming year (last year of fallow) and fields having rice in the previous year (first 'rear of fallow) were visited and the canopy cover of the major species estimated visually by the interviewer for a total of 63 fields with fallow periods of 1 year (32), 2 years (2), 3 years (8), 4 years (12), 5 years (5) and 6 years (4).
- *Weed cover and frequency* (1991 and 1992 survey, observations from 99 fields): The upland rice fields of each informant were visited during the interview to measure weed cover and weed frequency by randomly placing a 10-m measuring tape over the rice canopy and recording the weed cover (weed intervals) directly underneath the measuring tape in 10 1--m sections. The presence of a particular species in a 1-m section was used to compute its frequency. Observations were taken in four transects in each field (total 40 in). Newly weeded parts of the field were avoided. Soil samples (15-20 subsamples per field) were collected from all fields during the 1991 season.
- *Ranking of fallow species* (1992 survey, 66 respondents): Farmers were asked to list 'good' and 'bad' plants or plants which they like to see in their fallow fields and plants which they do not like. The frequency was calculated based on the computed number of times a particular species was listed.

Weed survey 1993. A survey was carried out in 1993 with the objective to estimate the interactions between soil properties, weed species, and rice yield. Fifty-five fields were selected in the Xiengnguen district to have representative samples with: 1) wide range of fallow periods, and 2) range of cropping periods (i.e. 1 year rice, 2 years continuous rice and more than 2 years of continuous rice). In each field visited, five plots of 1 x 1 m each were randomly selected in areas where the rice crop visually looked better and areas where the crop looked poor. From each plot *Chromolaena odorata* density was estimated and soil samples collected (six subsamples per square to a depth of 15 cm) for analysis of various soil fertility parameters.

One-way analysis of variance tests were used to compare C. *odorata* frequency and density data from the household surveys and the weed survey over classes of elevation, fallow periods, cropping periods and soil pH. We were aware that these tests were liberal for the given sampling methods, but found it appropriate to use them, especially since all the comparisons were non-significant.

Results and discussion

Introduction and spread of C. odorata *in the Lao PDR*

Chromolaena odorata was introduced to India in the 1840s [McFadyen, 1989] and was recorded as a serious, rapidly spreading weed in Burma in 1920 [Rao, 1920]. Kerr [1932] reported its presence in southern Thailand since about 1922. Vidal [1960] suggested that it spread into Laos by wind in the late 1920s. The species was, however, not yet mentioned in a description of Indochina upland agriculture systems by Gourou [1942], which was based on observations made in the late 1930s. Izikowitz [1951] described the invasion of *C. odorata* as a new weed in what is now Luang Narutha Province during the 1940s. Due to favorable conditions *C. odorata* spread rapidly and had already become the most abundant weed in slash-and-burn rice fields and the successive fallow land in the 1950s [Vidal, 1960]. Probably because its introduction coincided with the French presence, it is known in some areas as 'nia phalang', which translates into 'French weed' or 'foreign weed' (translation for French or foreigner is the same; Vidal, 1960). Interestingly, it is known in the French language as l'herbe du Laos (Laos weed; Leplaideur and Schmidt-Leplaideur, 1985).

The contribution of C. odorata towards the weed population during the rice crop

Following field observations over a wide area in Luang Prabang and Oudomxay provinces, C. odorata contributes almost 40% of the total weed cover during the rice crop (Table 1). Other important weed species were *Ageratum conyzoides*, *Commelina* sp. and *Lygodium flexuosum* [Roder et al., 1994].

Table 1. Frequency and relative importance of *C. odorata* in upland rice fields of northern Laos.

District	F ields (no.)[a]	Frequency (%) (presence in I in intervals)	Contribution to weed cover (%)[b]
Luang Prabang Province			
Xiengnguen	24	66	35
Pakseng	17	36	31
Viengicham	38	42	31
Oudomxay Province			
Xay	8	86	57
Namo	8	84	45

[a] Number of fields sampled.
[b] *Chromolaena odorata* cover in percent of total weed cover

Chromoloena odorota displays a wide range of adaptation. Correlation analysis between fallow period, selected soil fertility parameters, and frequency of C. *adorata* showed no relationships. Likewise, if ranked in classes for fallow period, cropping period, or soil p1-1 no difference was observed between frequency or density of *C. odorata* during the rice crop (Table) 2). Its frequency' and contribution to the weed and fallow biomass may decline at elevations above 1000 m. Nevertheless, Nakano (1978) reported C. odorata together with *Buddleia asiatica* as major tallow species in the first year after rice harvest in slash-and-bum fields in northern Thailand, at elevations above 1000 m.

Chromolaena odorata regrowth from rootstock after burning can be a serious competitor for young rice plants, but farmers find it relatively easy to remove them by hand weeding. Plants growing from seeds have a comparatively slow initial growth phase and are less of a problem for the initial stage of the rice plant (Fig. la). The contribution by C. *odorata* to the weed biomass during the 1991 rice-growing season was 3% on 8 July, 10% on 28 August and 14% on 27 September.

Table 2. Effect of elevation, fallow period, cropping period, and soil pH on *C. odorata*.

Parameter	Class	Survey 1991 and 1992		Weed survey 1993	
		No.[a]	*C. odorata* frequency (%)[b]	No.[a]	*C. odorata* density (no. m^{-2})
Elevation	< 600 m	3	76	41	9
	600-900m	38	53	8	9
	>900m	18	43	6	5
	PR>F		NS	-	NS
Fallow	< 5 years	49	52	24	8
	5-9 years	42	52	22	9
	>9years	-	-	8	8
	PR>F	-	NS	-	NS
Cropping period	1 year	-	-	28	9
	2years	-	-	21	9
	>2years	-	-	6	5
	PR>F	-	-	-	0.18
Soil pH	<5.1	8	80	7	11
	51-6.0	10	96	35	8
	>6.0	2	91	13	8
	PR>F	-	>45	-	NS

[a] Number of fields sample.
[b] Presence in intervals of 1-m transects.

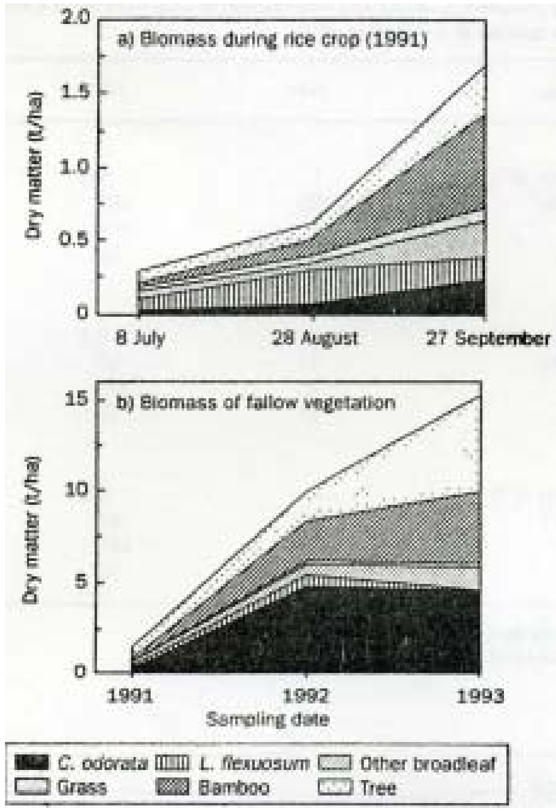

Fig. 1. a) Weed biomass (dry matter t/ha) during the rice crop (1991. one sire only). b) Aboveground biomass of fallow vegetation (dry matter t/ha) measured at the time of rice harvest (1991), after 1 year and after 2 years of fallow (average of four sites).

Contribution of C. odorata towards the *fallow vegetation*

The average above-ground biomass at four monitoring sites was 1.4 t ha^{-1} at rice harvest in 1991 and increased to 10 t ha^{-1} at the end of 1992 (1 year fallow) and 15.4 t ha^{-1} in 1993 (2 year fallow, Fig. lb). At rice harvest tree and bamboo species contributed 61% of the total biomass and had frequencies of 32 (bamboo) and 95% (tree) (Table 3). Their development is, however, 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* accounted for 48%. Plant density and contribution of C. *odorata* to the plant biomass and canopy cover decline in the second year of fallow (Table 3, Figs. 1 and 2). The contribution by grass species to the weed and fallow biomass is very minor and unlike in some other slash-and-bum systems in Asia, *Imperara cylindrica* although present, is rarely becoming dominant.

Table 3. Density, frequency, height and contribution to total biomass of *Chromolaena odorata.* bamboo and tree species in monitoring plots.

Species/Parameter	1991	1992	1993
C. odorata			
Density (plants m^{-2})	[a]	9.5	7.7
Frequency (%)b	100	100	100
Height (cm)	-	274	291
Biomass (%)	16	48	29
Bamboo species			
Density (plants m^{-2})	-	0.2	0.9
Frequency (%)	32	27	24
Height (cm)	-	435	577
Biomass (%)	17	21	26
Tree species			
Density (plants m^{-2})	-	0.3	4.0
Frequency (%)	95	97	98
Height (cm)	-	131	170
Biomass (%)	44	16	34

[a]Plant density and height not recorded in 1991.
[b] Presence in frames of 1 m^2.

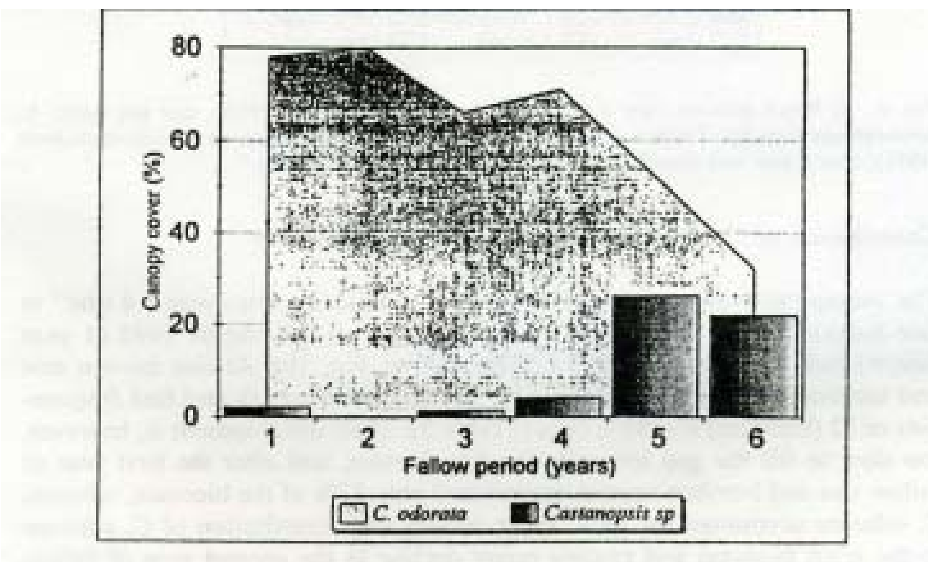

Fig. 2. **Relationship between fallow duration and the contribution of *C. odorata* to the canopy cover of fallow vegetation.**

Another study, with observations over a wide range of conditions showed a similar dominance by C. *odorata* after the rice harvest (Fig. 2). In the first 2 years of fallow C. *odorata* contributed 80% of the canopy cover. Similarly C. odorata was the dominant fallow species in the initial year in slash-and-burn fields in southern Laos [Chansina et al., 1991).

Positive attributes of C. odorata as a fallow species

Although C. *odorata* is the most abundant weed species, farmers generally appreciate it as a 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 (Table 4). None of the respondents considered it as a bad fallow species. Various explanations are given by the farmers for their preference of C. odorata including: its dominance under good soil conditions, absence of negative effects on rice yield, relatively easy to control by band weeding in the ricecrop, fast growth and large biomass production. Some of the plants listed as bad fallow plants, especially Craroxylon *prunifolium* and *Ageratum conyzoides*, are generally associated with poor rice yields. Farmers interviewed in the Savannakhet province suggested that soil structure is better where C. *odorata* is dominant compared to fields with predominantly bamboo species [Keovilayvong et al, 1991]. Similar preferences for C. odorata as a fallow species in Indonesia and Nigeria have been reported [Dove, 1986; Ruthenberg, 1980] and others have suggested that C. *odorata* may be beneficial to resource-poor farmers [Waterhouse, 1994].

Our investigations do not provide any information on the effect of C. *odorata* on nutrient cycling. Compared to some of the other fallow species,

Table 4. Good[a] and bad fallow species listed by fanners interviewed (66 respondents).

Species	Good fallow plant (%)[b]	Bad fallow plant (%)
Good species		
Chromolaena odorata	85	0
Casranopsis hynerix	20	9
Bambusa tulda	15	0
Dendrocalamus brandisii	15	0
Bad species		
Cratozylon prunifolium	2	55
Symplocos racemosa	0	26
Imperata cylindrica	5	24
Ageratum conyzoides	5	12

[a] Plants farmers like to have in their fallow fields (good plants) and plant they do not like to have (bad plants).
[b] Percent of respondents listing a particular species as 'good' or 'bad' fallow plant.

especially bamboo. C. *odorata* has a relatively high P and Ca content (Table 5). Depending on the importance of ash residues on the soil fertility and the performance of the rice crop this higher mineral content may be important. *Chromoloena odorata* has a fast decomposition rate, can improve quantity and quality of soil organic matter [Obatolu and Agboola, 1993], and showed good results as a green manure plant when used for lowland rice [Litzenberger and Ho Tong Lip, 1961].

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 slopping fields prevailing in Laos. This fast expansion is made possible by the abundance of seed produced and their mobility. Under favorable conditions C. *odorata* was shown to produce close to 0.5 million seed m^{-2} [Kushwaha et al., 1981]. The seeds are dispersed by wind during April and May and germination starts about the same time as planting of rice.

Of the various fast-growing leguminous species tested as fallow replacement, only *Gliricidia sepium* had a higher litter production (not significant due to high variation) and higher total biomass when compared to C. *odorata* (Table 6). *Chromolaena odorata* was most effective in weed suppression and had the lowest weed biomass measured. Weeds are largely suppressed by the vigorous growth of C. *odorata* but allelopathic effects have also been demonstrated IlAmbika and Jayachandra, 1992; Nakamura and Nemoto, 1994]. Suppression of weeds is another very important characteristic expected from a good fallow plant. Soil samples (0-15 cm) collected before planting rice did not show any treatment effect on soil organic matter, total N, available P , or pH.

Table 5. N, P. K and Ca content of major fallow species (December 1992).

Plant species	N (%)	P (%)	K (%)	Ca (%)
C. odorata				
Leaf and flowers	2.10	0.130	2.04	0.55
Stems	0.49	0.042	1.02	0.27
Bamboo				
Leaves	2.17	0.042	1.88	0.42
Small branches	0.63	0.022	1.37	0.19
Stern	0.38	0.015	1.19	0.08
Cratoxylon sp.				
Leaves	0.98	0.037	0.91	0.50
Stems	0.56	0.020	0.40	0.32
Lygodium flexuosum[a]	1.68	0.048	1.84	0.39

[a] Whole plant.

a

Table 6. Comparison of *C. odorata* with other potential plants for fallow improvement.

Species	Litter fall 1993 (t ha[1] year^{-1})[a]	Biomass after 2 years (fresh, t ha^{-1})		
		Species	C. odorata	Weeds
Gliricidia sepium	6.4	24.1	1.6	5.6
Calliandra calothysus	3.3	7.3	7.1	6.7
Cassia sp	*4.5*	3.5	8.1	8.9
Mimosa invisa	*2.9*	23.6	3.8	1.5
Chromolaena odorata	4.5	18.0	-	1.0
PR> F	0.26	<0.01	0.10	0.01
CV (%)	32.3	23.8	15.2	30.5

[a] Dry matter.

Summary and conclusions

Chromolaena odorata the dominant weed and fallow species in slash-and-burn areas throughout Laos. Researchers and farmers testing the species in upland cropping systems therefore do not face the risk of introducing a new weed through their activities. Upland farmers have become familiar with the plant for at least one generation. In fact even elderly persons found it difficult to recall the weed and fallow species composition prior to the introduction of C. odorata [Roder et al.. 1994].

Chromolaena odorara has various properties required of a plant for fallow improvement under the conditions of Lao, such as:
- Self seeding.
- Relatively slow initial development and limited competition during the early course of the rice crop.
- Fast development in the initial year of the fallow period providing a protective cover.
- Large biomass production.
- Good weed suppression.
- Suppression of nematodes [Atu, 1984; Subrarnaniyan, 1985].
- Fast decornpgsition rate [Obatolu and Aghoola, 1993].

It is often suggested that legumes would make better fallow plants and that C. *odorata* has serious adverse effects on agriculture productivity [McFadyen, 192; Waterhouse, 1994]. For the conditions prevailing in Laos we however, have yet to identify a suitable legume, which would have the above listed properties. It is. expected that C. *odorata* will continue to be a preferred fallow species for slash-and-burn systems where no other benefits, such as livestock fodder, are expected. With a progressive change to shorter fallow periods its ability to suppress weeds and nematodes could become more important. Nevertheless the species may become a serious nuisance in a gradual change from slash-and-burn rice production to systems that integrate grazed fallow, crop rotation, fruit and/or timber production. Properties that are considered advantages in the present system may become serious constraints in others, especially:

- High seed production and easy dispersal by wind, will result in continuous heavy weed seed influx from fallow land to cultivated areas.
- Plant residues from a C. *odorata* fallow are difficult to manage and.fire may be the only practical field preparation method for areas dominated by this species after a fallow period of one or more years.
- Allelopathic effects on tree growth. C. *odorara* was considered harmful in rubber and teak plantations in Indonesia [Tjitrosoedirdjo et al., 1991] and allelopathic effects on teak have been reported [Arnbika and Jayachandra, 1992].
- Its presence is likely to reduce fodder production of fallow land, and it is disposed to become a serious weed in grazing systems.

Whether C. *odorata* will be considered a serious weed or a preferred fallow species will largely depend on the evolving land use systems. It is quite likely that the controversy surrounding this plant will continue and invite further debate. Its potential as a fallow plant should not be ignored and future studies comparing improved fallow systems need to include C. *odorata* treatments with special attention to its effects on nematodes and allelopathic effects on weeds and crops. The species efficiency in nutrient mobilization and its effect on biological, chemical, and physical soil properties also need further evaluation.

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Fallow improvement/management

Inherent soil fertility, topography, and high precipitation limit options for permanent cultivation under Lao conditions. Although possible in favorable sites, permanent cultivation would require labor-intensive technologies and/or expensive inputs to maintain fertility. Replacing the fallow vegetation with fast-growing species, preferably legumes, is widely recommended as an approach that will help maintain soil fertility without requiring a complete change in the production system.

Improved fallow systems are expected to provide faster, yet similar, ecological benefits than natural fallows (Robison and McKean 1992). Properties expected of species for fallow improvement include ease of establishment, provision of plant cover after crop harvest, large biomass production, fast decomposition rate, weed suppression, ability to mobilize plant nutrients from lower soil layers, improved water infiltration, easy elimination at the beginning of the cropping phase, and not becoming a weed during the cropping period (Fujisaka 1991, Rao et al 1990, Robison and McKean 1992, Roder et al 1995). For Lao conditions, preference was given to species that have some fodder value. There is good potential for increased livestock production by replacing fallow vegetation with fodder species. The initial phase of the fallow period is currently used for grazing ruminants, but little forage is available because of the strong dominance of unpalatable species such as *Chromolaena odorata*.

The development of strategies that may help the upland farmers adapt to shorter fallow and longer cropping cycles while optimizing nutrient and water conservation and use was a major component of the research activities under the Lao-IRRI project. Activities carried out during 1991-95 involved (1) introducing and screening potential species for fallow improvement and fodder production, (2) developing and adapting establishment methods for promising fallow species, and (3) evaluating the effect of selected fallow species and residue management of those species on crop, weed, and soil parameters in various cropping systems.

Introduction and evaluation of potential species

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) recoinmended *Chromolaena odorata* for fallow improvement in Lao PDR. The main species promoted by various agencies for fallow improvement over the past two decades were *Leucaena leucocephala*, *Gliricidia sepium*, pigeonpea (*Cajanus cajan*), and Calliandra *calothyrsus*. Little or no adoption by farmers was observed, probably because the technologies recommended were not appropriate or economcal.

Many legume and grass species were introduced and tested (Lao-IRRI annual reports 1993, 1994, unpublished). 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. Most of the species evaluated have multiple uses including food, fodder, and/or fuel (Table 12).

Table 12. Most promising species based on observations made in observation nurseries.

Species	Food (quality)	Fodder	Fuel	Weed (suppress)	Seed	Use for,
Arachis pintoi		***[a]		**	*	Cover under perennial crops
Cajanus cajan	*	*		**	***	Short rotation
Calopogonium caeruleum				***		Cover under perennial crops
Centrosema pubescens		***			*	Fodder
Crotalaria anagyroides				****	***	Green manure, short rotation
Lablab purpureus	**	**		**	***	Short rotation
Leucaena leucocephala	*	***	**	***	***	Fodder, rotation of various length
L. diversifolia		**	**	***	***	Rotation of various length
Gliricidia sepium		*	*	****	*	Rotation of various length
Stylosanthes gulanensis		***		**	**	Fodder, rotation
Pueraria phaseoloides		**		**	*	Fodder, rotation
Mucuna cochinchinensis	**	*		**	***	Food, concentrate, mulch
Brachiaria brizantha		***		***	*	Fodder, rotation, erosion barrier

[a]Potential of a particular species.* = some potential, **** = high potential.

The adoption of fallow management strategies and the fallow species will depend largely on the farming systems evolving. Pigeonpea, 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 ruminants or pigs. L. *leucocephala* has potential in a system that may still involve the use of fire and/or if firewood has a certain market value. Further research, with farmers' participation, will be necessary to identify suitable species and to develop suitable rotation systems and technologies to manage the introduced species and their residue cover during the rice crop. The work carried out with pigeonpea is summarized in Roder et al (1998), included at the end of this section.

We expect 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 presently tested on-station and in farmers' fields are *Stylosanthes guianensis*, L. *leucocephala*, and *Brachiaria* species. Caution is required to avoid introducing new weed species, as happened with Mimosa invisa.

Establishment

A range of studies were conducted to develop and test methods of legume establishment in the rice system. The results from these activities are presented in the papers included at the end of this section.

Effects on rice yield

Although the expectations are high, only limited benefits of using a legume as a rotation or intercrop were observed. In a 4-year study begun in 1995, in which rice was intercropped with the most promising legumes (*Leucuena leucocephala*, *Gliricidia sepium*, and *Crotalaria anagyroides*), no consistent benefit from the legumes was apparent after 4 years of continuous rice cropping. In the same study, application of P had no effect on rice or legume biomass yield (Fahrney 1999). In a rotation study with L. leucocephala, the legume had a positive effect in one year but a strongly negative effect in a drought year (Table 13). These results demonstrate that replacing the fallow vegetation with legumes may not provide sufficient benefits to justify the additional cost (or labor) and the additional risk. A legume rotation will only be accepted if the legume included has some direct market value (pulses, firewood. etc.), contributes

Table 13. Effect of improved fallow treatment on rice yield.

Treatment	Rice yield (t ha^{-1})	
	1996	1998
Control (no legume)	2.19	1.1
Legume[a], 1 m spaced	2.23	0.5
Legume, 2 m spaced	2.18	0.7
ANOVA[b], level at P	ns	0.01

[a]Leucaena Ieucocepha/a
[b]ANOVA = analysis of varriance. ns = nonsignificant.
Source: Fahrney (1999).

toward the production of marketable products is used for livestock production, or provides food for direct consumption (pulses).

Residue management

The benefits derived from improved fallow systems will largely depend on residue management. Mulching with residues from crop or fallow vegetation can strongly influence physical, chemical, and biological soil properties (Unger et al 1988, Thurston, 1997). These effects could be particularly important with respect to water infiltration and storage and the reduction of soil, N, and C losses. Furthermore, residue management may be the key to the introduction of no-till systems. A large volume of data show that crop residue mulch alone, or in combination with conservation tillage, can reduce soil erosion and improve water infiltration substantially (Lal 1984, Gupta and O'Toole 1986). It is important to recognize, however, that the biomass loads accumulating during fallow periods of more than 8-12 months are difficult to manage without burning and farmers are not likely to accept fallow systems with heavy residue loads. Grazing the fallow vegetation was expected to reduce the residue load, enhance nutrient cycling, and make the transition from fallow to cultivation possible without the requirement of burning. Fodder production was therefore an important consideration in the assessment of potential fallow improvement species.

Various studies focused on the effect of residue management on rice yield, weed biomass, and other parameters. Although drought is considered a major yield constraint, no positive short-term benefits of mulching for grain yield could be demonstrated except in a study involving mulching with pigeonpea residues (Table 14; additional results from studies focusing on residue management are discussed in the papers included at the end of this section). Burning of crop and fallow vegetation residues consistently reduced weed biomass and made field preparation easier.

Table 14. Effect of pigeonpea residue management.

Treatment	Rice yield (t ha^{-1})
No pigeonpea	0.7
Removing residue	0.9
Burning residue	1.2
Mulching residue	1.5
LSD[a] (0.05)	0.5

[a]LSD = least significant difference.

Papers included with this section

RoderW,ManiphOfleS. KeoboulaphaB. 1998. Pigeonpea for fallow improvement in slash-and-bum systems in the hills of Laos. Agroforest. Syst. 39:45-57.

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

Roder W, Maniphone S. 199$- Shrubby legumes for fallow improvement in northern Laos: establishment, fallow biomass, weeds, rice yield, and soil properties. Agroforest. Syst. 39:291-303.

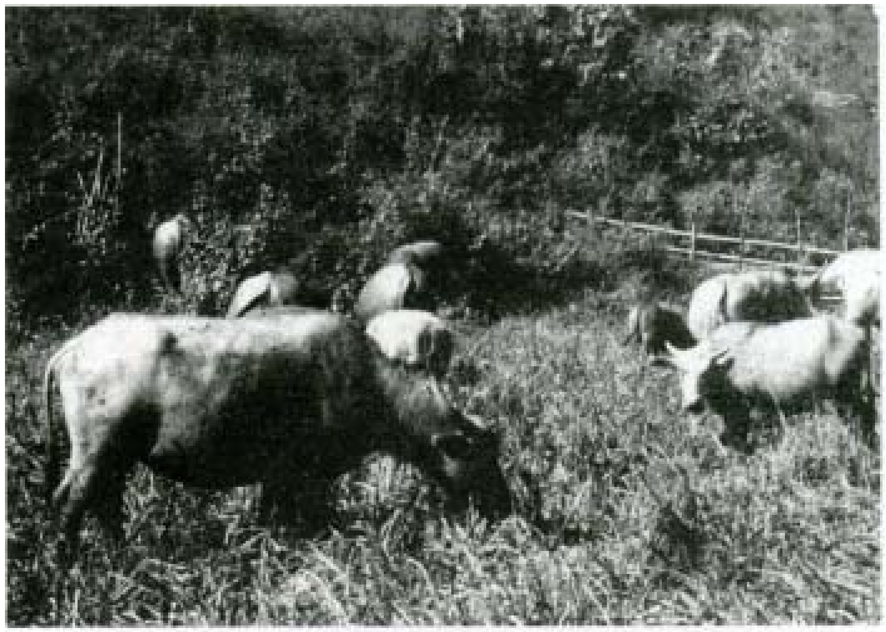
Roder W, Keoboulapha B, Phengchanh S. Prot JC, Matias D. 1998. Effect of residue management and fallow length on weeds and rice yield. Weed Res. 38:167474.

Calopogonium mucunoides broadcast-seeded into rice.

Leucaena leucocephala seeded together with rice (same hill).

Stylosanthes guianensis growing through rice residues. It was established through broadcast seeding before the rice harvest.

Residue from fast-growing tree legume species. Burning is the only option to get the field ready for planting rice.



Buffalo grazing *Brachiaria brizantha*.

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Pigeon pea for fallow improvement in slash-and-burn systems in the hills of Laos?

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Key words: *Cajanus cajan*, intercropping, rotation, upland rice, weeds

Abstract. Slash-and-bum farmers in the hills of Laos urgently need techniques that can sustain rice yields and reduce weed pressure under short fallow periods. For this, the potential of pigeon pea (*Cajanus cajan* (U) Huth) as a fallow crop was evaluated in variety, establishment, and cropping Systems studies conducted at Houay Khot station (19^0 N) from 1992 to 1995. Introduced perennial varieties were not superior to local material for the parameters evaluated. Some semi-perennial varieties produced grain yields up to 2.2 r ha^{-1} but were inferior in weed suppression and survival 12 months after planting. All varieties lost much of their weed competitiveness after the first picking of pods. In studies without weeding. < 10% initially established plants were present 15 months after planting. Compared with pigeon pea, *Gliricidia sepium* and *Leucaena leucocephala* performed better in biomass production, weed suppression, persistence, and self-regeneration after cultivation of rice. In a rotation study, rice yield was 1.3, 1.5, 2.3, 1.6, 1.8, 1.8, and 2.2 ha^{-1} (LSD 5% = 0.5 t) for continuous rice, rice-pigeon pea intercropping, rice after pigeon pea, rice after cowpea, rice after *Srylosanthes hamata*, rice after maize, and rice after fallow, respectively. Compared with continuous rice, intercropping or rotation with pigeon pea reduced nematode (*Meloidogyne graminicola*) infestation of rice and weed biomass in the rice crop. In spite of the beneficial effects, rotation or intercropping systems with pigeon pea will only be viable if economic benefits from harvested grain or from using plant parts as livestock, feed can be obtained. Because of high mortality and weed invasion pigeon pea is not suitable for fallow improvement if fallow duration is more than one year.

Introduction

Traditional slash-and-burn rice production systems common in the hills of northern Laos are in a transition phase. Reduced fallow and increased cropping periods have substantially increased the labor requirements for weed control, and farmers are under pressure to change to other production systems. Replacement of the fallow vegetation by fast-growing species, preferably nitrogen-fixing legumes, is a widely recommended technique to maintain crop yields and suppress weeds in slash-and-burn systems under reduced fallow periods (Fujisaka, 1991; Garrity, 1993; Raintree and Warner, 1986)- Assuming that farmers would more readily adopt sequential improvements to existing systems, Fujisaka (1991) suggested that the initial research programs aimed at facilitating the transition phase should give high priority to improved fallow systems.

Pigeonpea (*Cajanus cajan* (L.) Huth) is widely recommended as a multipurpose species for fallow improvement, agroforestry, and rotation systems (Boebringer and Caldwell, 1990; Daniel and Ong, 1990; Gooding, 1962; Ong and Daniel, 1990). It produces an edible seed, is well adapted to poor soil conditions and dry environments, and is competitive with many weed species. Gooding (1962), reviewing the rotation and green manure value of pigeon pea, concluded that pigeon pea fallows are better than bush fallows of equal duration. Furthermore, Ae et al. (1990) have shown that pigeon pea is more efficient in utilizing the iron-bound P in Alfisols than the other crops tested and Adu-Gyamfi et al. (1990) concluded that cultivation of pigeon pea increases total P availability in cropping systems with low available P.

Pigeon pea is traditionally used in Laos and it was an important feed resource for the insect *Laccafer lacca* in the production of sticklac (Malpuech, 1924). Upland farmers often have a few plants in their ricefield near the temporary shelter or along a path. Small bundles with young pods, which are eaten in soups, can be found in the local markets from December to February. Unlike in some other Asian countries, the use of mature seed is, however, not known in Laos. There is presently no market for pigeon pea seed and farmers have no incentive for growing this crop on a larger scale. Yet extension and development agencies working with bill farmers in Laos widely recommend ‘pigeon pea to be used in hedgerow, alley, and other alternative cropping systems advocated as replacement for the traditional slash-and-bum methods. Adoption of these systems by the upland farmers remains, however, almost negligible.

The development of strategies that may help farmers adapt to shorter fallow and longer cropping cycles while reducing labor for weed control was a major component of research activities under the LAO-IRRI program (1991-95). Pigeon pea was included in various experiments with the objective to 1) evaluate the’ performance of traditional and improved cultivars, 2) compare pigeon pea with other potential fallow improvement species, and 3) quantify the potential and limitations of pigeon pea as a crop for fallow improvement and other cropping systems that may eventually replace the present slash-and-burn methods.

Materials and methods

All fields experiments were conducted at the Houay Khot Research Station (19^0 N), under typical upland conditions. Soil at the station is classified at Eutric Cambisol (Soil Survey and Soil Classification Laboratory Dongdok, Ministry of Agriculture and Forestry, LAO PDR, Vientiane, unpublished) with a pH of 6.1, and an organic C content of 1.6%. The station is located in the drier zone of northern Laos with an average rainfall of 1 340 mm recorded for 1961-90 in Luang Prabang town, Rainfall recorded at the station was below this average for 1992 and 1993, but follows the normal pattern, with most of the precipitation occurring from May to September and dry periods from October to April (Table 1).

Field preparation generally consisted of slashing the fallow vegetation one to two months before planting. As far as possible, areas with termite mounds and tree stumps were excluded from the experiments. Nevertheless, soil conditions were highly heterogeneous, as is common in slash-and-burn fields (Andriesse and Schelhaas, 1987), resulting in high variation in some of the studies. Four to eight pigeon pea seeds were dibbled at a spacing of 20 or 25 cm in 3-5 cm deep boles made with a dibble stick, following the traditional planting method for rice. Stands were thinned to two to three plains per bill at 15-30 days after emergence. The cultivar ICP 8094 was included as a check variety in all studies except for the 1992/93 nursery with local cultivars. In all experiments where rice was included, the medium-duration, glutinous, local cultivar 'Vieng' was used.

Table 1. Rainfall distribution (mm) at Houay Khor Station (Luang Prabang Province, Lao PDR).

Month	1992	1993	1994	1995
January	50	0	0	12
February	62	0	0	0
March	92	139	32	
April	53	66	89	56
May	68	133	229	130
June	232	97	164	113
July	316	220	223	216
August	177	222	258	369
September	13)	113	216	111
October	91	67	63	0
November	41	0	19	32
December	28	2	82	45
Total	1149	1032	1482	1116

Nurseries and variety trials with local and introduced material

Local varieties collected in Luang Prabang. Vientiane, and Xiengkhouang provinces were evaluated in single plot nurseries for plant height, days to maturity, seed size, and seed yield. Plot size was 9 m^2 (3 rows, spaced 0.6 m in 1992/93 and 0.75 m in 1993/94). Planting dates were 9 June in 1992 and 29 June in 1993. Observations for seed yield and seed size were taken from the center row of the plot. Height was measured from 10 plants per plot approximately one year after planting.

The performance of perennial and semi-perennial cultivars received from ICRISAT and selected local varieties was evaluated in simple variety trials; using randomized complete block designs (Table 2). Observations made

Table 2. Details of variety trials with local and introduced pigeon pca varieties carried out at Honay Khoc Station, Luang Prabang. Lao PDR, 1992-1994.

Trial	Number of entries[a]	Planting date	Plot size (m^2)	Replicates (no.)	Row distance (m)	Row length (m)
Perennial (1992)	5	14/6/92	17.5	3	0.7	5
Perennial (1993)	7	17/5/93	8.4	3	0.7	4
Semi-perennial	12	17/5/93	8.4	3	0.7	4
Advanced	9	6/7/94	25.2	4	0.7	6

[a]Source of all imported cultivars was ICRISAT except N826. which was received through the Nitrogen Fixing Tree Association of Hawaii.

included plant height, vigor (score 1-10 comparing relative vigor among entries), days to harvest, and seed yield (after removing border row). In the experiment ('Advanced', Tables 2 and 6), with selected entries of perennial local, perennial introduced, and semi-perennial introduced varieties, plots of the individual varieties were split and subjected to the treatments: 1) no pruning and 2) pruning to 50 cm above ground, applied after harvest in March 1:995. Pruning and variety effects on weed competition and pigeon pea persistence (long life) were evaluated by:

- measuring weed (fresh weight) from whole plots at the time of weeding on 11 July;
- visually estimating weed contribution to canopy cover (in % of total canopy): and weed ground cover (in %) on 17 October;
- counting total hills and hills with dead plants on 17 October

Comparison with perennial follow species

An experiment was initiated in 1992 to compare the performance of potential fallow and multipurpose tree species. Tree species including pigeon pea (Entry N826) received from the Nitrogen Fixing Tree Association, Hawaii, were raised in a nursery and transplanted in June 1992, with a spacing of I x I m in randomized complete block design with two replicates and a plot size of 36m'. Number of plants surviving were counted at intervals specified in Table 7. Fallow vegetation was slashed and burned again in 1994 and plots planted to rice.

Methods of pigeon pea establishment

Two methods of establishment were evaluated, namely I) broadcasting seed into a rice crop at the time of weeding and 2) dibbling pigeon pea at the same time as rice either mixed with rice or in a separate hill. Methods were described earlier (Roder and Maniphone, 1995).

Rotation effect and residue management

A crop rotation experiment comparing 1) continuous rice, 2) continuous rice-pigeon pea intercropped. 3) rice-pigeon pea rotation, 4) rice-cowpea rotation, 5) rice-stylo (*Stylosanthes hamata*) rotation, 6) rice-maize rotation, and 7) rice-fallow rotation was initiated in 1992 (all treatments, including fallow, refer to periods of one year). A randomized complete block design with 4 replicates and a plot size of 21 m^2 was used for the experiment. All treatments had rice in 1992 and again in 1994. Planting densities were 20 x 25 cm for rice, 25 x 50 cm for cowpea, and pigeon pea and 50 x 50 cm for maize. Stylo was broadcast sown at the rate of 30 kg ha^{-1} at the last weeding of rice in August. In the intercropping treatment pigeon pea was spaced at 100 cm alternating with three rows of rice. In the intercropping treatment pigeon pea plants were pruned back twice in July and August to the level of the rice canopy. Vetiver grass was planted along the plot boundaries. Rice yield was measured from whole plot after removing a border row. Weed biomass (fresh) was measured from whole plots at all weedings in 1994. Soil samples collected at the time of planting in 1994 (eight subsamples per plot from the 0-7.5 cm depth interval) were air-dried and analyzed by the Soil Survey and Soil Classification Laboratory Dongdok, Vientiane for soil PH, total N, and extractable P (Olson). Samples of rice root and soil were collected from five hills per plot in 1994 (all treatments) and 1995 (treatments continuous rice and rice intercropping with pigeon pea) to quantify root knot nematode *(Meloidogyne graminicola)* infestation following methods described by Prot and Matias (1995).

Results and discussions

Characteristics/performance of local and exotic varieties

The local cultivars evaluated were generally vigorous, tall perennials with relatively small seed size and moderate grain yield potential (Table 3). Introduced perennial cultivars did not show any advantage over the local entries for plant height, vigor, days to maturity, or seed yield (Table 4). In an experiment comparing selected, introduced semi-perennial varieties with selected local and introduced perennial varieties, average grain yield was 1.1 t ha^{-1} for the perennial and 1.7 t ha^{-1} for the semi-perennial varieties (Table 5). The latter were, however, inferior in weed suppression and survival (Table 6). Some of these semi-perennial varieties, specially C11, could be useful for systems where grains are harvested for ‘feed or human consumption and where pigeon pea will be replaced by other crops after grain harvest.

Table 3. Characteristics of local pigeon pea varieties, evaluated in single-plot nurseries at Houay Khot Station, Luang Prabang, Lao PDR.

	Height (cm)		Days to harvest (no.)		1000-gain weight (g)		Seed yield (g m^{-2})	
	Average	Range	Average	Range	Average	Range	Average	Range
1992/93								
ICP 88040	177	-	321	-	78	-	67	-
Local varieties[a]	216	201-250	291	266-321	78	58-108	171	78-333
1993/94								
ICP 8094	302	-	231	-	86	-	150	-
Local varieties[b]	326	272-358	242	231-253	63	53-70	183	80-280

[a] Six entries form Vientiane and Lang Prabang provinces (1992 collection, altitude range 400-600 m).
[b] Six cranes form Vientiane and Xiengkhouang provinces (1993 collection, altitude range 400-1200 m).

Table 4. Pigeon pea variety trials with perennial and semi-perennial varieties conducted a Houay Khot station Luang Prabang, Lao PDR, during 1992-1993.

Varieties	Entries (no.)	Plant heighta (cm)	Vigor (scale 1-10)	Days w harvest	Seed yield (g m-2
Perennial (1992)					
Local	1	214	9	288	54
Introduced	3	156 (142-165)	5.7 (4.0-6.7)	291 (261-316)	25 (7-44)
ICP 8094	1	181	7.7	317	71
LSD at 0.05		28	1.6		NS
CV (%)		8.7	12.7		32
Perennial (1993)					
Local	2	254 (250-257)	6.0 (4-8)	309	36
Introduced	4	256 (217-280)	6.6 (4-10)	309	46 (35-58)
ICP 8094	1	238	4.6	309	52
LSD at 0.05		29	NS		NS
CV%)		13	56		41
Semi-perennial (1993)					
Introduced	11	216 (169-216)	7.2 (4.7-10)	290 (280-325)	43 (2045)
ICP 8094	1	231	9.2	281	49
LSD a: 0.05		19	1.2		NS
CV (%)		5.1	18.8		57

[a] Observations for plant height and vigor were taken 173, 456 and 183 d after planting for perennial varieties 1992. perennial varieties 1993, and semi-perennial varieties 1993, respectively.

Table 5. Performance of selected local ad introduced perennial and semi-perennial pigeon pea cuhivars at Houay Khot Station, Luang Prabang, Lao PDR (Experiment Advanced', 1994).

	Height (cm)		Survival (%)	Yield (t ha^{-1})	Days to harvest
	18/8	18/10			
Perennial varieties					
HK 5 (Local)	63	216	91	104	262
HK9(Local	62	212	95	1.12	262
ICP 8094	69	222	94	117	261
ICP 8860	66	204	91	1.09	261
Perennial varieties					
ICPL 87119	57	204	86	1.40	261
ICPL 88046	57	399	80	1.66	219
ICPL 89052	59	214	88	1.56	261
ICPL 87051	65	213	76	156	218
C11	73	204	84	2.15	260
LSD at 0.05	-	-	12	0.43	
CV (%)	13.8	6.4	9.3	21.2	

Table 6 Variety and pruning effect on survival and weed suppression of selected local and introduced perennial and semi-perennial pigeon pea cultivars at Houay Khot Station. Luang Prabang, Lao PDR (Experiment 'Advanced', 1994).

Treatment	Observation 11/7/95	Observations 17/10/95			
	Weed[a] ($t\ h^{-1}$)	Weed (%)		Survival[d]	Dead plants[e]
		Biomass[b]	Cover[c]	%	%
Perennial varieties					
HK5(Local)	1.6	3	6	83	8
HK9(Local)	2.0	5	9	88	6
ICP 8094	2.4	6	16	75	22
ICP 8860	3.2	8	13	75	16
Semi-perennial varieties					
ICPL 87l19	4.8	15	29	66	19
ICPL 88046,	4.4	31	49	57	23
ICPL 89052:	3.3	13	21	68	17
ICPL 87051	4.1	10	24	61	12
C11	3.3	38	60	63	29
Pruning treatment					
No pruning	2.7	13	23	71	14
Pruning	3.8	16	27	70	19
ANOVA summary					
PR > F variety (V)	< 0.01	<0.01	<0.01	0.01	NS
PR> F pruning (P)	<0.01	0.63	0.04	NS	0.11
PR>FVXP	NS	NS	NS	NS	INS
CV (%)	24.2	35-2	36.3	14.2	73.9

[a] Fresh weight.
[b] Weed contribution to total canopy cover.
[c] Weed ground cover.
[d] Hills present in % of hills planted.
[e] Hills with dead plants.

Weed suppression and persistence

Pigeon pea requires weed control in the initial three months after planting. Thereafter it becomes vigorous and competitive against most weeds up to the time of maturity of the first seed flush. Seed maturity occurs toward the end of the dry season and plants are not only weakened by age but also strongly affected by moisture stress. Several of the major weed species, especially *Chromolaena odorata* and *Mimosa invisa*, are superior to pigeon pea in drought tolerance andlor in recovering after drought stress. The competitiveness of pigeon pea after the first dry season declines fast and. without weed control it generally disappears during the second year after planting.

Weed biomass in the 1994 variety trial, measured in July, about five months after grain harvest, was 2.3 and 4.2 t ha^{-1} for the perennial and semi-perennial varieties, respectively (Table 6). In observations made three months later, average weed contribution to canopy biomass, weed ground cover, and survival of pigeon pea plants were 6, 11, and 80% for perennial varieties and 21, 36, and 63% for semiperennial varieties, respectively (Table 6). Although there was a substantial difference between perennial and semi-perennial entries even the former lost much of their vigor after the first year and were unable to successfully compete with the existing weed species. Pruning not only opened the canopy cover but also further reduced the vigor of the plants, resulting in a higher number of dead plants and higher weed competition (Table 6).

In a study comparing different fast-growing perennial fallow species, only 9% of the pigeon pea plants were still present 15 months after transplanting (Table 7). Compared with pigeon pea, some of the perennial species, specially leucaena *(Leucaena leucocephala)* and *Gliricidia sepium,* are not only superior in vigor and weed suppression but also in their capacity to survive during the phase of a rice crop. They coppice from roots and/or from the stem base left at the time of field preparation and provide fast canopy cover after rice harvest (Table 7). In another study comparing pigeon pea with leucaena and *Crotalaria anagyroides*, pigeon pea was completely suppressed by weed one year after planting, while the other two species contributed more than 80% to total aboveground biomass at the time of slashing two years after planting (LAO-IRRI, Technical Report 1995, LAO-IRRI project, Vientiane, LAO PDR, unpublished).

Following these results, pigeon pea has little merit for fallow improvement, especially for systems with fallow periods longer than one year. Thus the assertions by various authors (Boebringer and Caldwell, 1990; Daniel and

Table 7. Performance of selected perennial species evaluated at the Houay Khor station, Luang Prabang, Lao PDR.

Treatment	Survival[a]		Height	Rice	After rice harvest 1994	
	(%) 1992	(%) 1993	(cm) 1992	($t\ ha^{-1}$) 1994	Survival (%)	Cover (%)
Gliricidia sepium (N604)	100	99	98	2.0	83	90
Calliandra calothyrsus	100	86	45	2.1	18	10
Pigeon pea (N 826)	94	<9	100	1.7	0	-
Sesbania grandiflora (N 835)	100	50	70	1.8	0	-
Sesbania sesban (N 769)	94	18	80	1.2	1	< 5
Cassia sp. (Local)	94	90	38	1.3	5	< 5
PR>F	NS	<0.01	<0.01	NS	<0.01	-
CV (%)	132	63	4.6	21.0	49.6	-

[a]Observation dates were: survival we 7/13/92 and 20/9/93; height 17/11/92; survival and cover after the rice harvest November 1994.

Ong, 1990; Gooding, 1962; Ong and Daniel, 1990) that pigeon pea is a good plant for fallow improvement cannot be supported by our findings.

Ease of establishment

Establishing of pigeon pea in a upland rice crop is not as easily achieved as it is with small-seeded, shade-tolerant forage species such as stylo (*S. hamata* and S. *guianensis*) or *Centrosema pubescens* (Roder and Maniphone, 1995). By broadcasting seeds immediately after weeding at varying dates, establishment was 4, 5, 8, 20, 22 and 26 plants m^{-2} and legume cover at harvest was 1, 2, 2, 7, 17, and 14% for pigeon pea, lablab (Lablab purpureus), Crotalaria juncea, *Centrosema pubescens*, *Calopogonium mucunoides*, and *Pueraria phaseoloides*, respectively (Roder and Maniphone. 1995, seed rates used were 60, 80 30, 30, 20 and 20 kg ha^{-1} for pigeon pea, lablab, *Crotalaria, juncea*, *Centrosema pubescens*, *Calopogonium mucunoides*, and Pueraria *phaseoloides*. respectively).

Good establishment of pigeon pea was achieved by dibbling it in hills separate of the rice as well as in hills mixed with rice. Vigorous growth of pigeon pea, however, suppresses rice yield unless plants are pruned back below the rice canopy. In an establishment study in 1992 without pigeon pea pruning, rice yield was reduced by 55% where pigeon pea was mixed with rice and by 66% where pigeon pea and rice were dibbled separately (Roder and Maniphone, 1995). In a similar study conducted in 1993, establishment of, pigeon pea was 72% when mixed with rice and 74% when planted in separate hills. Pigeon pea was pinned back below the rice canopy and rice yield was not affected (LAO-IRRI, Technical Report 1995. LAO-IRRI project, Vientiane, LAO PDR, unpublished).

Rotation and intercropping effects

In the rotation study, highest rice yields were observed after a year of pigeon pea or fallow (Table 8). Furthermore, rice after pigeon pea had lower weed biomass than rice after rice, fallow, or cowpea. Soil N, pH, and extractable P in the 0-7.5 cm depth were highest for the pigeon pea (only significant at $P = 0.1$ for extractable P). The apparent higher P availability with pigeon pea supports findings by Adu-Gyamfi et al. (1990), but it is not possible to infer from this study how far it is caused by faster residue turnover, by organic acids released by pigeon pea, or by other factors. This effect of pigeon pea rotation warrants further studies and could be very important under P-limiting conditions.

In 1994, nematode infestation was high for the continuous rice and low for rice after fallow (Table 8). In spite of the high variation, pigeon pea as a previous crop or intercrop significantly reduced nematode infestation when compared with continuous rice treatment. Similarly nematode infestation in 1995 was 2794 and 1940 no. g^{-1} root (not significant) or 5.6 and 0.4 no. g^{-1} soil ($P > F = 0.1$), for the treatments continuous rice and rice intercropping

Table 8. Effect of rotation treatments on rice yield, weed biomass, nematode infestation and selected soil parameters at Houay Khot Stations Luang Prabang, Lao PDR.

Treatment	Rice yield ($t\ ha^{-1}$)			Observations 1994				
	1992	1993	1994	Weed ($t\ ha^{-1}$)[a]	Nematode[b]	pH[c]	Total N (%)	P[d] ($mg\ kg^{-1}$)
Continuous rice	3.4	1.8	1.3	5.1	63	6.3	0.26	5.2
Rice-pp[e] incercropping	2.7	1.0	1.5	3.4	14	-	-	-
Rice-pp rotation	3.3	-	2.3	3.2	13	6.5	0.28	7.0
Rice-cowpea	3.4	-	1.6	5.2	33	-	-	-
Rice-stylo	3.2	-	1.8	3.3	21	-	-	-
Rice-maize	3.5	-	1.8	3.3	10	6.3	0.24	4.6
Rice-fallow	3.2	-	2.2	4.9	2	6.0	0.25	5.8
PR > F	0.21	< 0.1	0.02	0.01	0.02	0.12	0.37	0.10
LSD 5%	-		0.5	1.4	33	-	-	2.0
CV (%)	13.5	13.3	20.5	23.7	98.8	4.3	10.6	23.8

[a] Fresh weight.
[b] Number of nematodes per g root transformed by $(x + 1)^{1/2}$.
[c] Soil measurements for 0-7.5 cm depth.
[d] P extracted by Olson method.
[e] Pigeonpea.

with pigeon pea, respectively, Nematode infestation could be the major cause for declining rice yield in continuous rice cropping systems. The results confirm the high rotation value of pigeon pea as reported by others (Gooding 1962; Daniel and Ong, 1990; Willey et al.. 1981). Grain yield of pigeon pea was 0.7, 0.5, 0.5 and 0.6 t ha' for the intercropping treatments 1992, 1993 and 1994, and the rotation treatment 1993, respectively. Yet establishment of a pigeon pea stand will require extra labor and seed and unless there is an economic, return from pigeon pea harvested or there are other long-term advantages from pigeon pea rotation, the traditional fallow rotation will be the better option for the farmer.

Residue management becomes a major problem when planting rice after a pigeon pea crop without tillage or burning. Much of the benefits of pigeon pea, especially N and mulching effects, are lost if the residue is removed or burned. In a study conducting in 1993. rice yields were 0.7, 1.2 and 1.5 t ha^{-1}, with removing, burning, or chopping, and mulching the pigeon pea residue, respectively (LAO-IRRI, Technical Report 1993, LAO-IRRI project, Vietiane, LAO FOR, unpublished). Farmers are, however, unlikely to accept mulching of pigeon pea residues due to difficulties during planting and weeding operations and increased risk of rat damage.

Pigeon pea harvested at maturity or green pods could be used as an ingredient for locally used animal feeds (Grimaud, 1988; Salunkhe et al., 1986). Further investigations addressing the economic aspects and labor requirements for pigeon pea used in rice rotation systems may be relevant. Semi-perennial varieties with good initial vigor and high seed yield would be more suitable for grain or pod production than the traditional varieties presently used by farmers.

Summary and conclusions

Pigeon pea is well adapted to the soil and climatic conditions in northern Laos. It can produce high quantities of biomass and grain with minimal input. The local varieties have excellent properties for biomass production. weed suppression, and persistence, while semi-perennial varieties have better grain yield potential. Provided that a market can be found for seed or that parts of the plant can be used as a feed, it may have some potential as a rotation crop.

It is, however, important to note that

- pigeon pea is not suitable for fallow improvement in systems with fallow periods of more than one year;
- pigeon pea is inferior for biomass production, weed suppression, and persistence when compared with leucaena, *Gliricidia sepium*, and *Crotalaria anagyroides*;
- unlike many small-seeded, shade-tolerant species such as stylo, Pueraria sp. and *Cenirosema* sp., pigeon pea cannot be established by broadcast seeding into the rice crop and requires extra labor for establishment;

- unlike leucaena, *Gliricidia sepium* and stylo, pigeon pea is not capable of self-regenerating from roots or seeds after a rice crop;
- because of poor persistence, pigeon pea is not a suitable species for hedgerow or alley cropping systems;
- without economic returns in the form of cash for grain or livestock products. pigeon pea does not provide sufficient benefits to the upland rice farmer to pay for the extra labor and seed required to maintain a pigeon pea rotation system.

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Forage legume establishment in rice slash-and-burn systems

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Abstract

Increasing population pressures combined with government policies exert considerable pressure on traditional slash-and-burn farmers in northern Laos to change to other production systems. Replacing the natural fallow vegetation with fodder legumes could increase fodder availability, suppress weeds, and accelerate nutrient cycling. Establishment methods for potential forage species were evaluated at the Houay Khot station during 1992 and 1993. When broadcast into upland rice immediately after weeding in July, good or excellent establishment was observed for *Stylosanthes guianensis, S. hamata, Macroptlium atropurpureum, Pueraria javanica. P. phaseoloides, Calopogonium mucunoides, C. caeruleurn, Leucaena leucocephala, Centrosema pubescens,* and C. *plumieri*. Poor establishment was observed for Arachis pinto!, Flemingia congesta, Crowaria anagyroides, C. juncea, pigeon pea (Cajanus cajan), Tephrosia vogelil, and Lablab purpureus. July and August sowings resulted in better plant densities thaui June or September sowings. However,, early sowing of &ylosarzthes species reduced rice yield by 20-30% in 1993. Dibbling rice mixed (same hill) with leucaena resulted in good establishment without detrimental effect on rice yield, while dibbling race mixed with pigeon pea reduced rice yield by 55-65%.

Introduction

Slash-and-turn agriculture remains a dominant land-use system in many parts of the tropics (Warner 1991). Among other options, forage legumes which may be used in crop rotation, ley farming or pasture systems, have been widely recommended as alternatives to existing slash-and-burn systems (Nye and Greenland 1960; Spencer 1966; Sanchez 1987) and there is a strong interest in fodder legumes in cultivated upland environments (Thomas and Bennett 1975; Hulugalle 1988; Thomas et *al* 1992).

In the hilly regions of northern Laos, upland rice is the major crop, with an annual area of about 200 000 ha (National Statistical Center 1993), produced mainly in slash-and-burn systems (Fujisaka 1991). Slash-and-burn farmers consider weeds, insufficient rainfall, and rodent damage as the foremost constraints to upland rice production (Roder c/ at. 1994). Shorter fallow periods resulted in high labor requirements for weeding, and farmers are under pressure to change to other land-use systems. Considering the limited market opportunity for annual crops and horticultural products, the comparatively low population density, and the hilly topography, timber and livestock production are generally thought to be the best alternatives for the Lao upland farmer. Livestock production is the major source of cash income for farmers in much of Laos, relying on fallow land, waste land, and forest as the major grazing resources (Roder et at. 1993). There is potential for increased livestock production by replacing the fallow vegetation with fodder crops. Improved fallow systems combining the effects of fodder plants and the grazing animal may increase fodder availability, suppress weeds, and accelerate nutrient cycling (Roder et *al*. 1993). Furthermore, residues retained in systems without burning may improve soil and water conservation during the rice crop.

Potential forae species include: lablab (*Lablab purpureus*), pigeon pea (*Cajanus cajan*), Centre *sema pubescens*, *Stylosanthes gulanensis*, Pueraria phaseoloides, *Arachis pintoi*, !eucaena (*Leucoena leucocephala*,), and *Brachiaria* spp. (Thomas and Humphreys 1970; Shelton and Humphreys 1972; Roder et *al*. 1993). Farmers'

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acceptance of forage species partly depends on the availability of cheap and practical establishment methods.

Seeding forage species with a companion crop is a widely used practice in temperate as well as tropical conditions(Heath et at. 1973; Humphreys 1978). This method has several advantages, including: greater farmer acceptability, income from the companion crop, weed suppression, protection against adverse conditions, and an increase in forage quality and quantity after crop harvest (Thomas and Bennett 1975; Humphreys 1978). Successful establishment of S. guianensis in upland rice under slash-and-burn conditions of Laos has been reported earlier (Thomas and Humphreys 1970; Shelton and Humphreys 1972). Shelton and Humphreys (1972) showed that good stylo stands can be obtained by this method, without negative effects on rice yield, provided the seeding rate was kept low and the sowing of legumes delayed- Partly due to the lack of dissemination of the findings and the non-availability of S. guianensis seed, this method of legume establishment has not become popular in Laos. As a follow-up on the findings of Shelton and Humphreys (1972), there is a need to evaluate establishment techniques for a wider range of potential species, planting methods and environments.

Experiments were conducted during the 1992 and 1993 rice-growing seasons to: assess the suitability of simple methods of legume establishment in a growing rice crop; and evaluate the effect of planting date cm establishment success arid its interaction with rice yield.

Table 1. Rainfall (mm) at Houay Khoi Station.

Month	1992	1993
January	50	-
February	62	-
March	-	92
April	53	66
May	68	133
June	232	97
July	316	220
August	177	222
September	131	113
October	91	67
November	41	-
December	28	2
Total	1249	1012

Materials and Methods

All experiments were conducted at the Houay Khot Research Station (19 0N), under typical upland conditions. Soil at the station is classLied as Eutric Cambisol with a pH of 6.1, and an organic C content of 1.6%. The station is Located in the drier zone of northern Laos with an average annual rainfall of about 1300 mm. Annual rainfall for 1992 and 1993 recorded at the station was close to the long-term average for the region, but was unusually low for the last 3 months of 1993 (Table 1).

Field preparation consisted of slashing the shrub vegitation in January and burning the dry above-ground biomass in March. As far as possible, areas with termite mounds and tree stumps were excluded from the experiment. Nevertheless, soil conditions were highly heterogeneous, as is common in slash-and-turn fields (Andriesse and Schelhaas 1987; Pushparajah and Chan 1987). Rice was dibbled in hills with a spacing of 20 by 25 cm. Approximately 10 rice seeds were placed in 3-5 cm deep holes made with a dibble stick following the traditional planting method. The medium-duration, glutinous, local cultivar "Vieng" was used for all experiments. Seeds of C. *pubescens, Stylosanties hamata, S. gulanensis, P. phaseoloides, Pueraria javanica, Calopogonium caeruleum,* and leucaena were dipped in boiling water for 15 seconds prior to planting to break the dormancy. Rice arid legume seeds were treated with Carbaryl (85%) immediately before planting. Seeding rates used for legumes were generally higher than the recommended rates, in an endeavour to get more uniform establishment and help reduce the high variation expected due to heterogeneous soil conditions. Following the results of the first year, the experimental designs were modified in the second year. Combined statistical analysis over the 2 years was therefore not possible. Rice yields, adjusted to 14% moisture, were measured from whole plots after removing the border rows.

Establish by broadcasting in a sanding rice crop

Planting date experiment, 1992. The experimental design was a split-plot, with legume planting date as the main treatment, 4 replicates and a plot size of 6 m^2. Rice was planted on May 21. Seed of the legumes [lablab, pigeon pea, *Calopogonium mucunoides*, *C. pubescens*, *P. phaseoloides*, and sun hemp *(Crotalaria juncea)*] was broadcast into the rice crop at the rate of 80, 60, 20, 30, 20 and 30 kg/ha, respectively, on 4 occasions at monthly intervals from June 16. Weeding was done in all plots before each legume planting date. Legume density and/or cover was recorded one month after legume broadcast, at the time of rice harvest, and at the end of the dry season from the area between 3 centre rows of rice. Rice was harvested on October 19.

Planting date experiment, 1993. The experimental design was as for 1992. Rice was planted on June 4. Legume seed was broadcast into the rice on 3 occasions at monthly intervals from July 6, at 15 kg/ha. The legume treatments consisted of: control (no legume); *P. phaseoloides*; *C. mucunoides*; *S. hamata* (cv. Amiga); and *S. guianensis* (cv. Cook). All plots were weeded before each planting date. Legume density, cover, and height were recorded one month after legume broadcast (density and cover only) and at the time of rice harvest from the area between the 3 centre rows of rice. Rice was harvested on October 21. Legume dry matter yield and cover were estimated visually at the end of the dry season on May 5, 1994.

Establishment of various legume species. The experimental design was a randomised complete block with 4 replicates and a plot size of 7 m^2. Rice was planted on June 14. The legumes [green leaf desmodium *(Desmodium intortum)*, Siratro *(Macroptilium atropurpureum)*, *P. javanica*, *P. phaseoloides*, leucaena, *C. caeruleum*, *Centrosema plumieri*, *Crotalaria anagyroides*, *Flemingia congesta*, *Tephrosia vogelii*, and *Arachis pintoi* (cv. Amarillo)] were broadcast into the rice crop on August 10 at the rate of 15, 25, 25, 25, 30, 30, 50, 25, 15, 25 and 60 kg/ha, respectively. Plots were weeded in July and immediately before broadcasting legume seeds. Legume density, cover and height were recorded from 3 randomly placed frames of 0.05 m^2 on August 28 (density only) and at the time of rice harvest on October 26. With the late sowing date for legumes, no effect of legume treatment on rice yield was expected, and rice yield was not measured for individual plots.

Establishment by planting rice and legume seed in the same hill

The treatments were: control (rice only); pigeon pea (ICP 11298) mixed with rice; pigeon pea (ICP 8094) mixed with rice; leucaena mixed with rice; ICP 11298 and rice separately; ICP 8094 and rice separately; and leucaena and rice separately. The experimental design was a randomised complete block with 4 replicates and a plot size of 13.5 m^2. Both rice and legume were planted on June 3. Where legumes were mixed with rice, they were dibbled at a distance of 1 m with the rice seed (same hill, every fourth row); and where rice and legume were dibbled separately, every fourth row was sown to legume. Seeding rate was 4–6 seeds per hill. Rice planting density was 25% lower where legumes were dibbled separately. ICP 11298 (erect type) and ICP 8094 (prostrate type) were obtained from ICRISAT. Rice was harvested on October 20. In December, the number of hills with leucaena present was recorded as well as the height of 10 randomly selected plants per plot . Pigeon pea plants showed vigorous growth with all treatments but no additional observations were taken on their performance.

Results and discussion

Establishment by broadcasting in a standing rice crop

Planting date experiment, 1992. Mean rice yield was 3.8 t/ha and was not affected by the legume or planting date treatments (Table 2). Best legume establishment was achieved from the July sowing. Good establishment was obtained for *C. mucunoides*, *C. pubescens*, and *P. phaseoloides*, while irregular or insufficient establishment of pigeon pea, sun hemp and lablab was observed for all planting dates. The poor results obtained for the latter 3 species may be due in part to insect damage, sensitivity to shading and establishment problems with large seed when placed on the soil surface. Pigeon pea (8 entries) and lablab (2 entries) cultivars were tested in a separate experiment in 1992 (W. Roder, unpublished data) but no pigeon pea and very few lablab plants established.

Plant cover and density followed similar trends. Planting date by legume treatment interactions were significant for most observations,

Table 2. Planting date and species effect on rice yield, legume density, and cover in 1992.

Category	Rice yield	Legume			
		Density		Cover	
		30 d[1]	19.30.92[2]	19.10.92[2]	24.4.93[3]
	(t/ha)	(plants/m^2)		(%)	
Planting date					
June 16	3.7	26	37	11	14
July 16	3.7	41	25	18	35
August 16	4.0	19	9	1	2
September 16	4.0	6	6	0.2	1
Legumes					
Lablab		3.8	9	5	2
Pigeon pea	3.9	5	4	5	
C. mucunoides	3.9	35	22	17	7
C. pubescens	3.8	30	20	7	14
P. phaseoloides	4.0	38	26	14	20
C. juncea	3.7	22	8	2	1
Anova summary: (PR> F)					
Planting date (A)	NS	<0.01	<0.01	<0.01	<0.01
Legume (B)	NS	<0.01	<0.01	<0.01	<0.01
AxB	NS	<0.01	<0.01	<0.0!	<0.01
CV (%)	16.6	42.5	56.3	82.5	83.5

[1] Observations taken 30 days after broadcasting legume seeds.
[2] Observations taken at the time of rice harvest.
[3] Observations taken at the end of the dry season.

but these are shown only for the plant density estimates at the time of rice harvest (Figure 1). In contrast to other species, establishment rate for pigeon pea and sun hemp increased again with the last planting date. This may be the result of a decline in shading effects in the last phase of the rice crop. interactions for other observations did not reveal any particular trend, nor did they affect the conclusions drawn from the means shown in Table 2.

At the end of the dry season, *P. phaseoloides* and C. *pubescens* had the best plant cover. Planting date effects on plant cover of individual legume species remained constant through the dry season. Plant cover for the drought-resistant species, C. *pubescens* and pigeon pea, increased dramatically, but decreased for C. *mucunoides*.

Planting date experiment. 1993. Soil conditions were more variable in 1993, resulting in higher variation in rice yield data (Tab]e 3). As in 1992, the best establishment was observed for the July planting date, but establishment was still good for fir August and September sowings. Early sowing of stylo species reduced rice yield for S. *hamata* to 75% and S. *gulanensis* 70% of that of the control treatment. S. *guianensis* is the most competitive species tested arid has the best establishment rate but is also the legume most likely to reduce the yield of the companion rice crop. Shelton and Humphreys (1972) suggested that the negative effects of S. *guianensis* on the yield of the companion rice crop could be minimised by low seeding rates and delayed legume planting.

Plant height at the time of rice harvest decreased with planting date (Table 3). All legumes from the last planting were small at the time of rice harvest, but in spite of' the extremely dry period from October 1993-February 1994 (Table 1), a few plants survived for all species. In early May 1994, S. *gulanensis* had dry matter yields of 3.5, 2.5 and 0.3 t/ha for the July, August and September planting dates, respectively. Weed growth was inversely related to legume growth. The weed biomass, consisting mostly of Chromolaena odorata and *Crassocephalum crepidioides,* was 15, 21 and 91% of the total above-ground biomass for the S. *guianensis* planting dates of July, August arid September, respectively. Planting in August thus resulted in a competitive plant cover of stylo without affecting the rice yield.

Table 3. Effect of planting date and legume species on rice yield, legume density, cover, height, and dry matter yield in 1993.

Category	Rice yield	Legumes - 1993				Legumes - 1994[3]	
		Density		Cover[2]	Height[2]	Yield	Cover
		30 d[1]	20.10[2]				
	(t/ha)	(plants/m²)		(%)	(cm)	(t/ha)	(%)
Planting dale							
July 6	1.32	54	40	55	71	1.5	55
August 6	1.58	44	32	21	33	1.0	38
September 6	1.44	21	28	2	1	0.3	11
Legumes							
Control	3 .59						
C. *mucunoides*	2.33	25	23	18	42	0.3	14
P. *phaseolaides*	L55	17	16	18	36	0.5	20
S. *hamata*	1.44	52	42	25	32	0.9	41
S. *guianensis*	130	64	51	43	40	2.1	64
Anova summary (PR>F)							
Planting date (A)	0.09	<0.01	0.06	<0.01	<0.01	<0.01	<0.0!
Legume (B)	NS	<0.01	<0.01	<0.01	NS	<0.01	<0.01
A x B	NS	<0.01	NS	<0.01	NS	<0.01	<0.01
CV (%)	36.2	32.4	38.9	61.1	52.1	59.0	51.0

[1] Observations taken 30 days after broadcasting legume seeds.
[2] Observations taken on October 20. 1993, at the time of rice harvest.
[3] Observations taken on May 5, 1994.

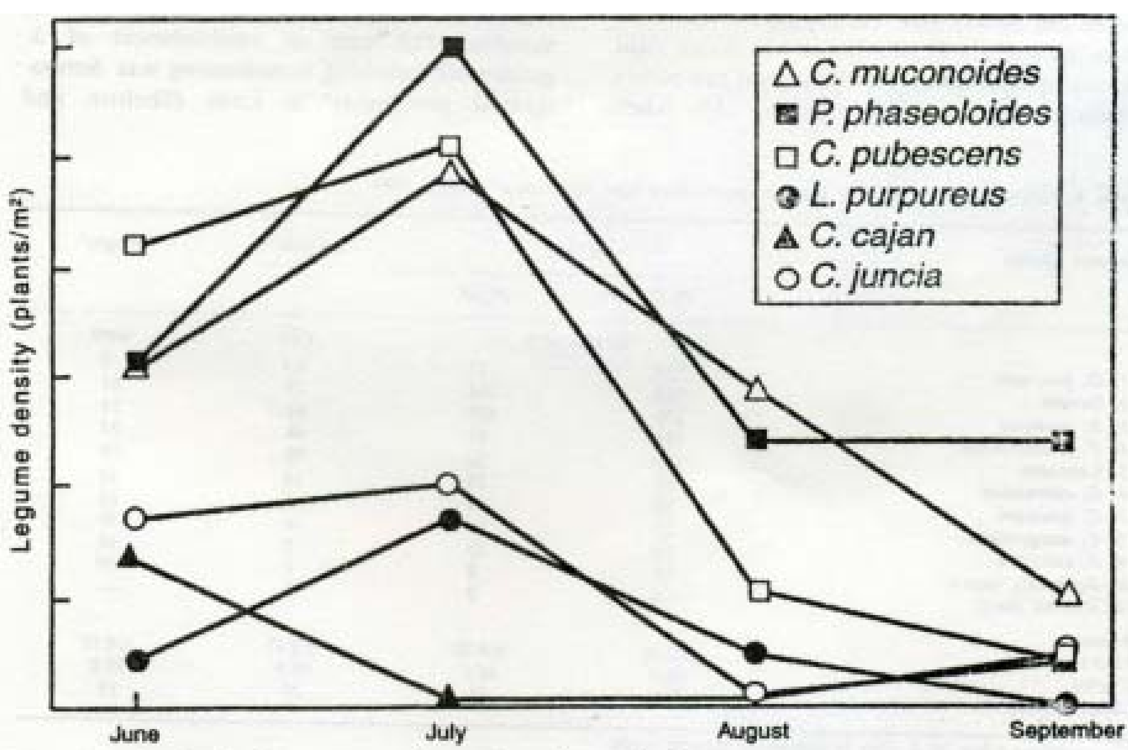

Figure 1. Planting date by legume treatment interactions on legume density.

Establishment of various legume species. Plant densities observed were largely a result of seeding rate. Furthermore, differences in initial establishment were influenced by seedling vigor, a variable that was not measured in the experiment. Excellent establishment was observed for Siratro, *P. javanica*, *P. phaseoloides*, *C. caeruleum*, leucaena, and C. *plumieri* (Table 4). Between the observation taken 18 d after broadcasting seed and the time of rice harvest, the loss of plants was 0-45% for all legumes except green leaf desmodium. Green leaf desmodium had a very high plant density 18 d after broadcasting seed, but only a few weak plants survived at the time of rice harvest. Combined effects of shading and diseases may be responsible for the heavy loss of desmodium plants. Similar observations were made for green leaf desmodium seedings in 1992 (W. Roder, unpublished data), but green leaf desmodium sown in a nursery, without a companion crop, developed well.

Establishment by planting rice and legume seed in the same hill

Leucaena and *pigeon pea*, 1992. Rice yields were low with only 1.7 t/ha for the control treatment. Both legumes established well. Leucaena developed slowly and was always much shorter than the rice plant, with no effect on rice yield. Strong competition from the pigeon pea plants, however, depressed rice yield by 55% where pigeon pea was mixed with rice and 66% where pigeon pea and rice were dibbled separately (P cc 0.05). The vigor of pigeon pea was slightly reduced when dibbled together with rices but difference in rice yield was not significant due to high variation (CV 24.6%) Leucaena established in 73% of the hills and was not affected by planting method (CV 11%). Leucaena height in December was 50 cm when dibbled with rice and 78 cm when dibbled in separate rows (CV 14%, P<0.02).

Conclusions

Results were consistent over both years. Both broadcasting and sowing mixed with rice offer considerable potential for selected species. These methods are well adapted for upland rice systems such as those in Laos. Establishment success or failure will be influenced by many factors, including: soil, climate, pests, diseases, weed control, weed competition. planting date, rice variety, rice cover, rice vigor, legume seed quality and legume shade tolerance. S. *guianensis*, S. hamata, C. *mucunoides*, C. *pubescens*, P. *phaseoloides*, P. *javanica* and Siratro are well suited for broadcasting, while others such as pigeon pea, sun hemp and lablab are less suitable. The ease of establishment of' S. *guianensis* following broadcasting was demonstrated previously in Laos (Shelton and

Table 4. Establishment of various legume species broadcast into rice in August 1993.

Legume Species	Density		Cover[2]	Height[2]
	28.8[1]	26.10[2]		
	(plants/m²)		(%)	(cm)
1. D. *intortum*	525	11	<1	5
2. Siratro	350	298	73	6)
3. P. *javanica*	228	125	41	23
4. P. *phaseoloides*	128	88	48	27
5. Leucaena	110	88	10	19
6. C. *caeruleum*	45	28	18	16
7. C. *plumieri*	33	28	15	22
8. C. *anagyroides*	23	15	4	39
9 F. *congesta*	15	25	3	14
10. *Tephrosia vogelii*	12	8	1	29
11. *Arachis pintoi*	0	0	0	-
Anova				
PR>F	<0.01	<0.0!	<0.01	<0.0!
Cv (%)	38.3	46.4	58.5	39.0
LSD(P <0.05).	100	59	22	19

[1] Observations taken 18 d after broadcasting legume seeds.
[2] Observations taken on October 26, at the time of rice harvest.

Humphreys 1972). Delayed broadcasting combined with low seeding rates will result in good establishment without negative effects on rice yield, as demonstrated in this and earlier experiments. The vigor and heavy seed production of S. *guianensis* may, however, become a serious problem if farmers must use the same fields again for rice production. Further studies are warranted o clarify the potential for S. *guianensis* in rice rotation systems under Lao upland conditions.

Planting a mixture of legume and rice seed is probably the best approach for the establishment of slow-growing shrubby or tree species, of which leucaena is the most promising species presently available. Advantages of this method include: no extra labor requirements; young seedlings growing in a rice hilt will be protected during farmers' weeding operations; less weed competition compared with establishment in fallow land; and reduced competition effects on the companion rice crop.

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Shrubby legumes for fallow improvement in northern Laos: establishment, fallow biomass, weeds, rice yield, and soil properties

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Key words: *Calliandra calorhyrsus, Crotalaria anagyroides, Flemingia congesta, Leucaena leucocephala, slash-and-burn*

Abstract. An experiment was carried out in a slash-and-bum production system in northern Laos to evaluate legume establishment methods and effects of legume species on fallow vegetation. weeds, yield of upland rice, and soil parameters. *Cajanus cajan, Calliandra calorhyrsus. Crotalaria anagyroides. Flemingia congesta, Leucaena leucocepha to, and Sesbania sesban* were dabbled separately or mixed with rice. Legume and planting method had no effect on rice yield. Legume establishment was slightly improved and vigor after rice harvest was higher when planted in separate hills. Compared to control (no legume), the above ground fallow biomass observed 13 months after establishment, consisting mostly of *Chromolaena odorata*, was reduced by 68% with C. *anagyroides* and by 40% with L. *leucocephala*, while other species had no effect. Most of the C. *cajan* and S. *sesban* plants died. In March 1995, 22 months after planting, the biomass was 0.21, 0.25, 1.62 and 2.56 kg m2 for F. *congesta*, C. *colothyrsus*, C. *anagyroides*, and L. *leucocephala*, respectively. Legume species had no effect on rice yield or weed biomass in the rice crop. The species tested can influence fallow vegetation but do not allow for field preparation without burning Compared to mulching, burning of residue reduced weed biomass by 42%, soil organic C by 9% and the C/N ratio by 6% but increased extractable P by 90% and pH by 8%.

Introduction

In the hilly regions of northern Laos, upland rice is the major crop in slash-and-bum systems, produced annually on about 200,000 ha (National Statistical Center, 1993). Slash-and-burn farmers consider weeds, insufficient rainfall, and rodent damage as the foremost constraints to upland rice production (Roder et al., 1997a), Shorter fallow periods resulted in high labor requirements for weeding, and farmers are under pressure to change to other land-use - systems.

Improved fallow systems have been recommended as a strategy to offset the effects of short fallow periods with the assumption that farmers would more readily adopt sequential improvements to existing systems rather than wholly new systems (Fujisaka. 1991). Improved fallow systems are expected to provide faster, yet similar ecological benefits as natural fallow (Robison and McKean, 1992). Properties expected of species for fallow improvement include: ease of establishment, provision of plant cover after crop harvest, large biomass production, fast decomposition rate, weed suppression, and ability to mobilize plant nutrients from lower soil layers (Fujisaka, 1991; Rao et at, 1990; Robison and McKean, 1992). Under the Lao conditions improved fallow systems are also expected to increase fodder availability, accelerate nutrient cycling, suppress weeds, allow seed bed preparation without burning, and improve soil/water conservation (Roder et al., 1995). Considering the limited market opportunity for annual crops and horticulture products, the comparatively low population density, and the hilly topography, timber and livestock production are generally thought to be the best alternatives for the Lao upland farmer. Livestock production is the major source of cash income for farmers in much of Laos, relying on fallow land, waste land, and forest as the major grazing resources (Roder and Maniphone, 1995). There is potential for increased livestock production by replacing the fallow vegetation with fodder crops.

Introduction trials with potential species for fallow improvement, green manure, and/or fodder production were conducted in Luang Prabang during 199 1-1995. The most promising shrubby species following these experiments included: *Leucaena leucocephala, Crotalaria anagyroides, Flemingia congesta,* pigeon pea (*Cajanus cajan*) and *Gliricidia sepium* (LAO-IRRI, Annual technical reports 1993, 1994 and 1995, unpublished). Farmers acceptance of introduced species will partly depend on the availability of cheap and practical establishment methods and the ease of residue management. Earlier studies have demonstrated the feasibility of broadcast seeding into a standing rice crop for a wide number of species and the possibility of establishing shrubby legumes by dibbling legume seed mixed with rice seed (Roder and Maniphone, 1995).

There is need to further rest planting methods and to evaluate the effect of the planted species on fallow vegetation, their residue management, and the effect of species and residue management on soil properties and successive rice crops. An experiment was conducted during 1993-95 to: 1) assess the possibility of establishing selected fast growing legume species simultaneously with a rice crop; 2) quantify the effect of legume species and establishment method on legume survival, legume biomass production, and weed suppression;' and 3) quantify the effect of legume species and residue management on weed and pest populations, rice yield, and selected soil parameters.

Materials and methods

The experiment was conducted at the Houay Khot Research Station (J90 N), under typical upland conditions. Soil at the station is classified as Eutric Cambisol (Soil Survey and Soil Classification Laboratory Dongdok, Department of Agriculture and Extension, Vientiane, unpublished). The station is located in the drier zone of northern Laos with an average annual rainfall of about 1300 mm. Annual rainfall for 1993, 1994 and 1995 recorded at the station was close to the long-term average for the region, but was unusually low for the last 3 months of 1993 (Table 1), As far as possible, areas with termite mounds and tree stumps were excluded from the experiment. Nevertheless, soil conditions were highly heterogeneous, as is common in slash-and-bum fields- (Andriesse and Schelhaas, 1987). The medium duration, traditional, glutinous rice variety 'Vieng' was used for the experiment. Spacing of rice was 0.2 x 0.25 m in 1993 and 0.25 x 0.30 m in 1995.

Planting and observations in 1993

The legume treatments 1) Control (rice only); 2) *Calliandra calothyrsus*; 3) *Leucaena leucocephala*; 4) *Flemingia congesta*; 5) *Crotalaria anagyroides;* 6) *Sesbania sesban* and 7) Pigeon pea (ICP 8094) were planted on 26 May at a distance of 1.5 x 0.2 m either mixed with rice (rice and legume in the same bill) or in a separate row replacing every sixth row of rice. Planting legume in separate row resulted in 17% lower rice density. The experimental design was a split-plot (legume as main plot and planting method as split plot treatment) with three replicates and a sub-plot size of 25 m^2. All seeds. except pigeon pea and C. *anagyroides* were dipped in boiling water for 30 s immediately before planting to break dormancy. Rice and legume seeds were treated with Carbaryl (85%) immediately before planting. Approximately 10 seeds of rice and/or five seeds of the respective legume species were placed in 3-5 cm deep holes made with a dibble stick following the traditional planting method. Weed was controlled by hand weeding. Pigeon pea and C. *anagyroides* plants growing taller than the rice plants were cut below the rice canopy in August and September. Rice yields adjusted to 14% moisture, were measured from whole plots after removing the border rows on 8 October.

Table 1. Rainfall (mm) at Houay Khoc Station in Houay Khoc, Laos.

Month	1993	1994	1995
January	-	-	12
February	-	-	-
March	92	139	32
April	66	89	56
May	1323	229	130
June	97	164	113
July	220	223	216
August	222	258	369
September	113	216	111
October	67	63	-
November	-	19	32
December	2	82	45
Total	1012	1482	1116

The success of legume establishment was recorded as number of hills with legumes present at the time of harvest. Legume height was measured at rice harvest from 10 randomly selected hills.

Vigor of legumes and weed suppression in 1994

A double sampling method (Cook and Stubbendieck, 1986) was used to estimate weed biomass in June. Fresh biomass for *Chromolaena odorata* and other weeds was estimated from five frames of 0.5 m2 placed randomly in the plot between the legume rows. One frame was clipped from each plot to calibrate the visual estimate,

Legume height was measured from 10 plants per plot. The canopy cover was calculated based on the distance between canopy cover of legume rows at 10 positions [% cover = (distance measured - row distance)/row distance]. The numbers of legume hills present was counted from the whole plot to estimate legume persistence.

Observations in 1995 (rice yield, soil and pest parameters)

During 1994 most of the S. *sesban* and pigeon plants died. Since the vegetation cover for these two treatments was not different from the control treatment, no further measurements were taken from these plots. The plant cover for the remaining treatments was slashed in March 1995. Legume biomass was measured separately for woody parts (diameter> 0.2 cm) and leaves and small branches, C. *odorata*, and other weed species from an area of S m2 per plot. Sub-samples for each fraction were air dried from the first replicate to estimate moisture content. After slashing the whole plots were split into two randomly allotted treatments of 1) burning residue and 2) mulching residue. Each residue management plot included both legume establishment treatments and all observations in 1995, except biomass at the time of slashing, were made for the residue management plots (combining the earlier establishment sub-plots). Residue were burned on 22 April. After removing weed by hoeing on all plots, rice was planted on 15 May.

The following observations were made during the season:

- Fresh weed and legume biomass was measured at the time of weeding on 16 June (from 4 frames of 0.5 m^2) and 25- July (from whole plot).
- White grub damage was estimated by counting damaged hills on a whole plot basis.
- Soil samples were collected 40 days (before N application) after planting, taking four sub-samples per plot for the depths of 0-7.5 and 7.5-15 cm. Air dried soil samples were analyzed by the Analytical Service Laboratories at IRRI Los Baños, for pH (in 1120), organic C. (Walkley and Black method), extractable P (Double acid extraction), total N and available ammonium-N.

- Chlorophyll content of the upper most, fully expended leaf was measured on 15 August with the Minolta SPAD-502 Chlorophyll meter taking three readings per leaf from 10 leaves per plot.
- Close to rice maturity, five rice hills per plot were uprooted and root and soil samples collected to quantify root knot nematode (Meloidogyne graminicola) density on the crop root and in the soil, following methods described by Prot and Matias (1995).
- At maturity rice grain yields were measured from whole plot after removing 2 border rows.

Results and discussion

Legume establishment and initial performance (1993)

The rice yield was moderate with 1.4 t ha^{-1} and not affected by the legume species or planting method (Table 2). The establishment of legumes was good for both methods, except for *Sesbania sesban* (Figure 1). This species showed

Table 2. Effect of legume species and planting method on rice yield, legume establishment and height in Houay Khot, Laos.

Category	Rice yield (t ha^{-1})	Density (% of hills)[a]			Height (cm)	
		10/93	6/94	3/95	10/93	6/94
Legume species[b]						
Control (No legume)	1.4	-	-	-	-	-
Calliandra calothyrsus	1.5	39	34	29	42	153
Leucaena leucacephala	1 .5	64	65	51	99	255
Flenmingia congesta	1.5	74	67	48	45	141
Crotalaria anagyroides	1.3	74	77	52	112	248
Pigeon pea.	0.2	75	58	-	89	130
SE. legume species[c]	0.2	7	5	7	7	14
Planting method						
Mixed with rice	1.4	63	59	45	74	170
Legume seeded separately	1.4	68	60	45	85	201
Anva summary (PR > F)						
Legume (A)	NS	<0.01	<0.01	0.06	< 0.01	< 0.03
Planting method (B)	NS	0.02	NS	NS	< 0.01	0.05
AxB	NS	0.09	0.02	NS	<0.01	NS
CV (%)	21.2	8.3	8.0	9-0	7.3	20.0

[a] As percentage of hills planted.
[b] Average density on 10/93 for Sesbania sesban was 11% when planted mixed with rice and 55% when planted separate.
[c] df is 12 for yield, 6 for density observed on 3/95 (pigeon pea was excluded), and 8 for other parameters.

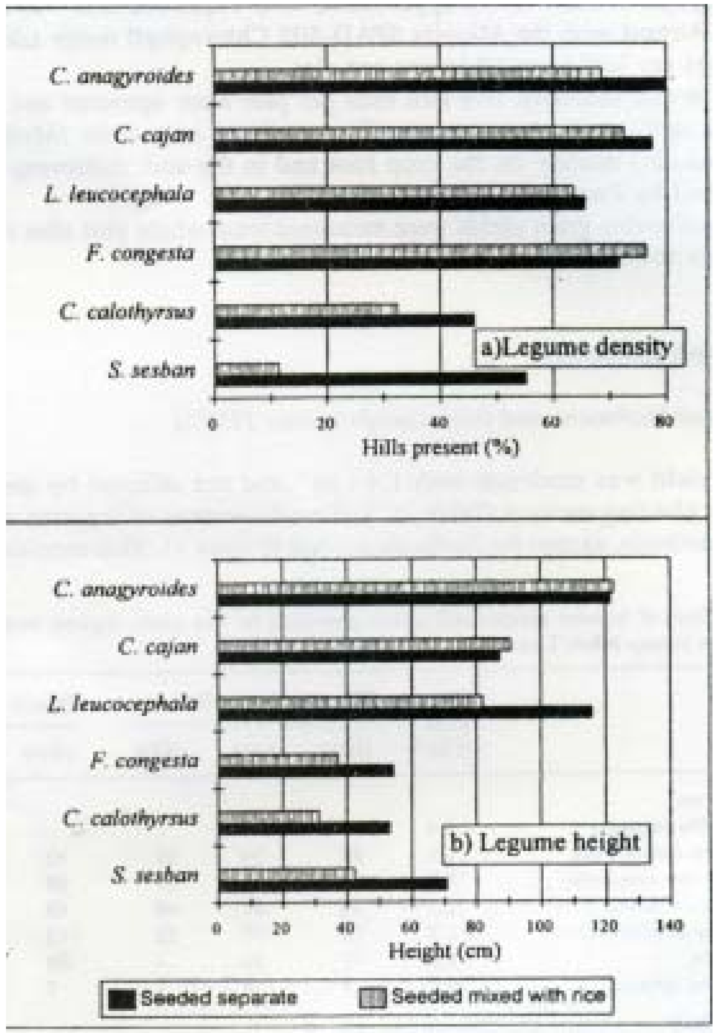

Figure 1. interaction between legume species and planting method on establishment success and growth of legumes at Houay Khot, Laos: a) Legume density (establishment success) (SE: legume treatment - 6.8%. establishment method =2.3); and b) Legume height (SE: legume treatment - 100 cm, establishment method = 2.3 cm) observations recorded in October 1993 at the time of rice harvest.

good germination but it is apparently sensitive to shading and therefore not suitable for establishment in a growing rice crop. Compared with mixed planting, plant height for C. *calothyrsus*, L *leucocephala*, F. *congesta*, and *S. sesban* was increased by 70, 41, 46, and 100% when planted in separate rows, respectively (Figure 1). No effect of planting method on the height of pigeon pea and C. *anagyroides* was apparent because these species were cut back to uniform levels (below rice canopy) in August and September. In an earlier study (Roder and Maniphone, 1995) establishment success of leucaena and pigeon pea was similar, but pigeon reduced rice yield by 55-65%.

Effect on weed biomass and legume performance during fallow period (1994)

Over the period October 1993 to June 1994 most of the S. *sesban* plants disappeared and pigeon pea lost about 23% of its stand (Table 2), while plant density was little changed for the other species. The remaining pigeon pea plants were very weak and largely overgrown by weeds. *Crotalaria anagyroides* and L. *leucocephala* were outstanding in growth and vigor manifested in superior plant height (Table 2) and better canopy cover (Table 3). *Chromolaena odorata* was the dominant weed species contributing 44-77% of the total weed biomass Compared to the control, the total weed biomass was reduced by 68% with C. *anagyroides* and by 40% with L. *leucocephala*.

Establishment method had no effect on legume survival or weed biomass in 1994, but slightly affected legume vigor. Compared to planting mixed with rice, legumes seeded separately were taller and had a better canopy cover (Tables 3 and 4).

Table 3. Weed biomass and canopy cover observed in June 1994 in Houay Khor, Laos.

Category	Weed biomass (fresh kg m^{-2})			Canopy (% cover)
	C.adorata	Others	Total	
Legume species				
Control (no legume)	0.73	0.91	1.64	-
Calliandra calorbyrsus	1.08	0.88	1.96	51
Leucaena leucocephala	0.46	012	0.98	86
Flemingia congesta	0.67	0.63	1.30	37
Crotalaria anagyroides	0.34	0.18	0.52	99
Pigeon pea	1.10	0.22	1.42	47
SE. legume species[a]	0.26	0.22	0.19	5
Planting method				
Mixed with rice	0.71	0.65	1.36	60
Legume seeded separately	0.75	0.49	1.24	68
Anova summary (PR > F)				
Legume (A)	0.08	004	<0.01.	< 00l
Planting method (B)	NS	NS	NS	0.01
AXB	NS	NS	NS	0.04
CV (%)	50.1	57.4	31.7	12.1

[a] df is 8 for canopy and 12 for other parameters.

Table 4. Biomass a; the time of slashing (March 1995) in Houay Khot. Laos.

Category	Legume (kg m^{-2})			Weeds (kg m^{-2})		Total (kg m^{-2})
	Branches	Leaves	Total	C. *odorata*	Total	
Legume species						
control (No legume)				0.16	049	0.49
Calliandra calothyrsus	0.11	0.14	0.25	0.23	0.30	0.56
Leucueno leucocephala	2.09	0.47	2.56	0.08	0.42	2.98
Flemingia congesta	0.12	0.09	0.21	0.16	0.27	0.48
Crotalaria anagyroides	0.86	0.76	1.62	C 0.01	0.23	1.84
SE. legume species[a]	0.42	0.05	0.45	0.12	0.18	0.45
Planting method						
Mixed with rice	0.82	0.33	1.15	0.12	0.31	1.22
Legume seeded separately	0.77	0.40	1.17	0.14	0.37	1.31
Anova summary (PR > F)						
Legume (A)	0.01	<0.01	< 0.01	NS	NS	<0.01
Planting method (B)	NS	NS	NS	NS	NS	NS
A X B	NS	NS	NS	NS	NS	NS
CV (%)	40.4	41.3	39.0	66.1	42.8	36.0

[a]df is 6 for legume biomass and 8 for other parameters.

Biomass at the time of slashing (1995)

The pigeon pea and S. *sesban* plants had all disappeared during the 1994 season and no further observations were taken on those plots. The contribution by the other legumes towards the total above ground biomass present at the time of slashing was 88, 86, 45 and 44% for C. *anagyroides*, L. *leucocephala*, C. *calothyrsus* and F. *congesta*, respectively (Table 4). The highest total biomass was produced by L. *leucocephala* with over 80% of the biomass consisting of woody branches> 0.2 cm diameter *Calliandra calothyrsus* and F. congesia had no influence on the total biomass. *Crotataria anagyroides* produced the highest biomass of non-woody parts. When excluding woody pans, the total biomass was 0.49, 0.45, 0.89, 0.36 and 0.98 kg m^{-2} for control, C. *calothyrsus*, *L. leucocephala*, *F con gesra* and C. *anagyroides.* respectively. Unless woody parts have some value for the farmers (fire wood, market) they provide little benefits to the system except that they may increase the burning temperature. Root biomass, nutrients recycled through leaf fall, and decomposition rates of root, litter, and fresh biomass will largely influence the effects of a particular species on soil fertility and succeeding crops.

The performance of pigeon pea is rather disappointing as it is widely recommended as a multipurpose species for fallow improvement,. agroforestry, and rotation systems (Boehringer and Caldwell, 1990; Daniel and Ong, 1990: Gooding, 1962). Gooding (1962), reviewing the rotation and green manure value of pigeon pea, concluded that pigeon pea fallows are better than bush fallows of equal duration. Following various additional studies with pigeon pea (Roder et aL, 1997b) it was, however, concluded that under the conditions in northern Laos. pigeon pea is not suitable for fallow improvement if fallow duration is more than one year.

Weed biomass during the rice crop (1995)

Legume species had no effect on weed biomass except for a reduction in Mimosa invisa caused by C. *anagyroides* (Table 5). Compared to mulching, burning reduced C. *odorata*, M. in visa, other broadleaf species, and grassy species by 66, 35, 48, and 47%, respectively Ax the same time burning increased the biomass of woody perennials by 63%. These effects of burning are consistent with observations made in other studies (Roder et al., 1998).

Most of the L. *leucocephala* plants and about 7% of C. *calothyrsus* and 52% of F. *congesta* plants present at the time of slashing survived and started coppicing from the left over root stock with no effect by the burning treatment (Tables 2 and 5). Biomass from re-growth of legume root stocks or seedlings contributed 76, 28, 8. and 3% of the total biomass measured for L. *leucocephala*, C. *anagyroides*, F. *congesta*, and C. *calothyrsus*, respectively.

Effect of legume and residue management on rice yield and soil parameters

The incidence of white grub damage on rice plants and the density of root knot nematodes on rice roots was increased by C. *calorhyrsus* but not affected by residue management treatment (Table 6). At this stage insufficient information is available on the reproductive biology of the white grub species prevailing in Northern Laos to explain this results. The red inflorescence or the foliage of C. *calothyrsus* could be a major attraction for the adult insect, but the main period of egg laying activity is likely to be after the time of slashing the vegetation.

Chlorophyll estimates taken shortly before rice flowering indicated higher nitrogen status with L *leucocephala* and C. *anagyroides*. The same treatments had the highest grain yield, although legume treatment effects on yield were not significant. Yields were substantially reduced with mulching. This may be a combined effect of lower plant densities, increased rat damage, increased weed competition, and N immobilization. Mulching reduced rice yield by 43, 39, 24, 25 and 26% for the treatments control, C. *calothyrsus*, t. *leucocephala*, F *congesta*, and C. *anagyroides*, respectively.

Legume treatment had no effect on any of the soil parameters measured, As expected burning compared to mulching increased soil pH and extractable P and reduced the soil organic C and the C/N ratio in the 0-7.5 cm soil layer (Table 7). This effect of burning although modest are, consistent with observations made by others (Nye and Greenland, 1964; Sanchez et al., 1983).

Table 5 Weed and legume biomass during the rice growing season (June and July 1995) in Houay Khot, Laos.

Category	Fresh-biomass g m^{-2} (measured during weeding in June and July)								Legume
	Weed biomass					Legume		Total	Density (Hills %)
	C. (*odorata*	M. *invisa*	Other broadleaf	Grasses	Woody perennials	Coppice	Seedlings		
Legume species									
Control (No legume)	119	62	92	22	79	-	-	374	-
Calliandra calothyrsus	138	54	63	11	34	8	0	308	2
Leucaena leucocephala	60	37	37	6	36	562	1	739	51
Flemingia congesta	121	33	75	8	66	27	0	329	25
Crotalaria anagyroides	89	1 2	93	11	48	0	96	349	0
SE. legume species	58	14	36	9	28	119	12	105	4
Residue management									
Burning	54	31	48	8	65	149	4	326	18
Mulching	157	48	93	15	40	149	45	501	22
Anova summary (PR > F)									
Legume (A)	NS	0.05	NS	NS	NS	<0.01	<0.01	0.02	<0.01
Residue management (B)	< 0.01	0.04	NS	0.02	0.04	NS	<0.01	<0.01	0.06
AxB	NS	NS	NS	NS	NS	NS	NS	NS	NS
CV (%)	83.8	52.1	110.4	62.1	54	38.1	101.0	29.8	18.6

[a] df is 6 lbs coppice. seedlings and legume density and 8 for other parameters.

Table 6. Effect of legume and residue treatment on white grub incidence, nematode density. leaf chlorophyll content, and rice yield in Houay Khot, Laos

Category	White grub (%)[a]	*M. graminicola* (nos. g root^{-1})[b)]	Chlorophyll (SPAD reading)	Rice yield (t ha^{-1})
Legume species				
Control (No legume)	2.0	4	39.7	2.5
Calliandra calothyrsus	3.1	10	40.1	2.7
Leucaena leucocephala	1.8	2	41.1	2.8
Flemingia congesta	2.0	3	38.9	2.7
Crotalaria anagyroides	1.7	1	40.9	3.1
SE. legume species (8 df)	1.1	3	0.5	0.4
Residue rnanagemenr				
Burning	2.2	3	40.3	373
Mulching	2.0	5	40.0	2.2
A nova summary (PR > F)				
Legume (A)	0.01	0.11	0.02	NS
Residue management (B)	NS	NS	NS	< 0.01
AxB	NS	NS	NS	NS
CV (%.	24.0	128	3.2	12.6

[a]In % of rice hilts damaged.
[b] Transformed by $(x + 0.5)^2$

Summary and conclusions

Planting a mixture of legume and rice seed is probably the best approach for the establishment of Woody perennials, of Which, L. *leucocephala* and C. *anagyroides* are the most promising species of those tested in this experiment. Advantages of this method include: no extra labor requirements; young seedlings growing in a rice hill will be protected during farmers' weeding operations; less weed competition compared with establishment in fallow land; and reduced competition effects on the companion rice crop. Legume performance during the fallow period was not affected by establishment method.

Compared to the control with common fallow species, the best legume treatment increased the biomass by over 500%. In spite of this remarkable increase in biomass the effect of legume species on the subsequent rice crop, on weed occurrence during the rice cropping phase and on soil parameters was nor significant. Repeated fallow-crop cycles will be necessary to evaluate the potential of these legumes for fallow improvement. The effect of legume species on pest such as white grub and root knot nematodes can be more readily quantified and may have stronger immediate impacts on crop yields.

When compared to mulching, burning of the biomass, had strong effects on weed biomass in the rice crop, rice yield, and most of the soil parameters measured. It will be impractical to attempt mulching of large, rank biomass quantities as produced by C. *anagyroides* and L. *leucocephala* and such

Table 7. Effect of legume and residue treatment on selected soil parameters in Houay Khot, Laos.

Category	pH		Exiract P (mg kg^{-1})		Organic C (%)		C/N ratio		Ammonium N (mg kg^{-1})	
	A[a]	B	A	B	A	B	A	B	A	B
Legume species										
Control (No legume)	5.4	4.8.	8.2	1.9	2.1	1.2	8.1	5.9	11.4	5.6
Calliandra calothyrsus	5.5	5.0	8.0	2.2	2.2	1.3	8.4	6.5	9.6	5.4
Leucaena leucocephala	5.5	5.0	11.7	2.2	2.1	1.3	8.0	6.8	10.8	6.4
Flemingia congesta	5.6	4.9	10.4	2.0	2.0	1.2	8.0	6.3	7.2	6.6
Crotalaria anagyroides	5.5	4.9	10.3	21	2.0	1.3	7.8	6.5	8.6	5.2
Residence management										
Burning	5.7	5.0	12.7	2.2	2.0	1.2	7.8	6.2	11.0	5.6
Mulching	5.3	4.9	6.7	2.0	2.2	1.3	8.3	6.6	8.0	6.0
Anova summary (PR > F)										
Legume (A)	NS	NS	0.09	NS	NS	NS	NS	NS	NS	NS
Residue management (B)	0.01	NS	< 0.01	NS	0.03	0.03	0.06	0.07	0.03	NS
AxB	NS	NS	NS	0.04	NS	NS	NS	NS	NS	NS
CV (%)	5.4	6.4	32.2	17.7	7.2	8.8	7.3	8.4	31.8	39.3

[a] A = soil depth 0-7.5 cm; B = soil depth 7.5-15 cm.

systems will have to depend on burning as field preparation. In future studies of improved fallow species it would be important to compare species which could be used as mulch without burning (e.g. velvet bean [*Mucuna pruriens*]), and/or grazed forage species, with shrubby/woody species that, require burning.

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Effect of residue management and fallow length on weeds and rice yield

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Summary

Reduced fallow length in slash-and-burn rice (*Oryza sativa* L.) production systems of northem Laos increased weed pressure, labour requirement and the need for soil and moisture con, servation. On-farm and on-station studies and on-farm surveys were used to evaluate the effect of residue management and cropping intensity on weed population, rice yield and nematode density. Residue loads were 2.3-44 t ha^{-1} after a rice crop and 9.5 t ha^{-1} after 1 year of fallow. Compared with farmers' traditional burning of crop and weed residues, mulching reduced rice yield by 43% in one out of four comparisons and increased weed biomass by 19-100%. Compared with continuous rice treatments (averaged over burning and mulching treatments), treatments with fallow or cowpea [*Vigna unguiculata* (L.) Walp.] in the previous year had 32% less, herbaceous weed biomass, 90% fewer Ageratuni conyzoides L. and over 99% fewer Meloidogyne graminicola Golden & Birchfield. Rice yield was negatively associated with A. *conyzoides* density (-041 P < 0.01) and M. *graminicola* number (-0.42. P < (105). Less striking effects of fallow period on A. *conyzoides* and M. *graminicola*, observed from on-farm surveys, demonstrate the limitations of on-farm studies because of undocumented effects of farmers' management decisions.

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Introduction

Slash-and-burn agriculture systems practised in the hilly parts of northern Laos are in a transition phase, with a fast reduction in the fallow and a gradual increase in the cropping periods (Roder et at, 1997). The shift towards shorter fallow periods has substantially increased the weeding requirements and is gradually resulting in a shift in weed populations, with more annual weeds and fewer perennial, woody species Traditional field preparation involves burning of the slashed above-ground biomass, consisting of 4-20 t ha^{-1} dry matter, depending on the fallow period. Residue loads and their woody composition after 1 or more years of fallow make management without burning difficult or impossible. More and more farmers plant a second or third rice (*Oryza sativa* L.) crop before allowing the field to go back to fallow. Fields that had rice in the previous year have relatively low above-ground biomass quantities (approximately 2-4 t ha^{-1}) and field preparation without burning the residue would be feasible

The advantages of crop rotation for weed and pest management are well established, especially for temperate climates (Karlen et *al*, 1994). Continuous upland rice cropping can cause considerable yield depression (Ventura & Watanabe. 1978; Ventura et *al*, 1984). These yield depressions have been partly attributed to fungi and other micro-organisms (Nishio & Kusano, 1976; Ventura et *al*., 1984). As both crop and fallow rotation can reduce pest problems. rotation with selected crops can replace some of the fallow effects. Through the choice of the crop, farmers may influence weed populations, pest dynamics. residue load and nutrient availability. Unfortunately, the options available to the Lao upland farmer are severely limited because of additional labour requirements and lack of markets.

Erosion and drought stress are considered important constraints to upland rice production. Crop residue management can influence the capacity of soil to receive, store and release water and nutrients (Sojka el *al*., 1984; Unger et *al*.. 1988). A large volume of data shows that crop residue mulch alone, or in combination with conservation tillage; can reduce soil erosion and improve water infiltration (Lal, 1984; Gupta & O'Toole, 1986). Non-tillage systems with surface residues generally have a more favourable microclimate, resulting in higher microbial biomass and larger pools of temporarily immobilized nitrogen (N) than conventional systems. This temporary N immobilization can reduce N loss and, depending on the timing of crop requirements, may increase or reduce N deficiency.

The traditional slash-and-burn system used by the Lao upland farmer is essentially a non-tillage system without the benefit of the surface residues. Considering the urgency for soil moisture, nutrient and organic C conservation, there is a need to develop production systems that will allow farmers to retain surface residues. During 1992-95, various investigation, were carried out in Luang Prabang province in northern Laos to evaluate the effect of residue treatment (burning vs. mulching) and cropping intensity on crop yield, weeds, nematodes and selected soil parameters.

Materials and methods

On-farm experiments comparing burning with, no burning

Two experiments in the form of a split-plot design with four replicates and a subplot size of 50 m2 (5 m x 10 m, 1993) or 18 m^2 (3m x 6 m, 1994) were carried out in fields where farmers had planted rice in the previous year. The main plot treatments, consisting of residue burning or residue mulching, were split into two subplot treatments: (1) no fertilizer and (2) 30 kg of urea N applied at the time of panicle initiation.

Weeds were controlled on all plots by light hoeing immediately before rice planting. A traditional, glutinous rice cultivar, 'Vieng', was planted in hills spaced at 20 cm x 25 cm. Approximately 8-10 seeds treated with carbaryl were placed in 3- to 5-cm deep holes made with a dibble stick. Residue dry matter was measured in 1994 by collecting the slashed biomass from four randomly placed quadrats of 1 m^2 per plot immediately before burning. Weeding with the small, traditional weeding blade was carried out once in 1993 and three times in 1994.

In 1993, fresh weed biomass was measured at the time of rice harvest from whole plots. In 1994, fresh weed biomass was measured at every weeding, and at rice harvest from four quadrats of 0.5 m^2 placed randomly in the plot.

Soil samples were collected at the time of N application with an Oakfield core sampler (20 mm diameter) from the 1994 study by taking six subsamples per plot to a depth of 0-15 cm. Air -dried samples were analysed by the Soil Survey and Soil Classification Laboratory Dongdok, Department of Agriculture and Extension, Vientiane, for soil organic C (wet combustion with K_2CrO_7 in H_2SO_4) and extractable P (Olsen). Rice yields were measured from whole plots after removing two border rows

On-station experiment wit/i residue and cropping treatments

An experiment comparing continuous rice and rice in alternate years was initiated at the Houay Khot station in 1993. The experimental design was a split-plot experiment with five replicates and a subplot size of 44 m^2 (5 m x 5.5 m). The main treatments were (1) continuous rice with burning of residues before planting rice; (2) continuous rice with mulching of residues; (3) fled/fallow/rice rotation with burning of fallow residues before planting rice; and (4) rice/cowpea/rice rotation with mulching of cowpea [*Vigna unguiculata* (L.) Walp.] residues. Treatments (1) control and (2) 30 kg N (at panicle initiation) were applied as split-plot treatments Soil at the station is classified as Eutric Cambisol (Soil Survey and Soil Classification Laboratory Dongdok, Department of Agriculture and Extension. Vientiane, unpublished). The station is located in the drier zone of northern Laos with an average annual rainfall of about 1300 mm. Annual rainfall for 1993-95 recorded at the station was close to the long-term average for the region The experimental area was slashed and burned in 1993 and planted with upland rice. As far as possible, areas with termite mounds and tree stumps were excluded from the experiment. Nevertheless, soil conditions were highly heterogeneous, which is common in slash-and-burn fields (Andriesse & Schelhaas, 1987). The area had a slope gradient ranging from 10% to 20%. Vetiver grass [*Vetiveria zizanioides* (L.) Nash.] was planted along the outline of the plots to provide permanent boundaries and to reduce plot-to-plot interaction Run-off water was removed through a combination of grass strips and drainage. Rice cultivar and planting method were the same as for the on-farm study.

Following the treatment design, only treatments I and 2 had rice in 1994, whereas all treatments had rice in 1995. Rice planting dates were 26 May 1994 and 13 June 1995. Hill spacing was increased from 20 cm x 25 cm in 1994 to 25 cm x 30 cm in 1995 because the closer spacing in 1994 resulted in yield depression caused by drought stress. Rice grain and straw yield were measured for the whole plot after removing two border rows. In 1995, the rice yield could only be measured from four replicates because of heavy damage by rats in replicate 5.

Additional observations/methods 1994

Residues for treatments 1 and 2 were slashed in early May and measured from four randomly placed quadrats of I m2 per plot before burning towards the end of May. Hand-weeding was carried out on 9 June and 10 August. Fresh weed biomass was measured at every weeding and- at rice harvest from four quadrats of 05 m^2 placed randomly in each plot.

Residues for treatment 4 were slashed and cowpea (local cultivar) planted in June. Hand-weeding was carried out twice, but no observations were taken for weed biomass from this treatment.

Soil samples for treatments 1 and 2 were collected on 7 June at the time of N application by taking six subsamples per plot to a depth of 0-15 cm using an Oakfield core sampler (20 mm diameter). Air-dried samples were analysed as described earlier.

Additional observations/methods 1995

Residues in all treatments were slashed in April and measured from a 2 m x 4 ~n area in the centre of each plot. Crop residues and residues of *Chromolaena odorata* [(L.) H.M King and B.L. Robinson], other broadleaved species, grasses and sedges. and woody perennials were measured separately. Dry matter for each species/category was estimated based on subsamples collected in the first replicate.

Hand-weeding was carried out on 23 May (before planting), 12 June and 10 August. Fresh weed biomass was measured from each plot by randomly placing quadrats of 1 m^2 (two per plot for the first weeding) or 0.25 m^2 (10 per plot for the second weeding and four per plot for the third weeding). The number of quadrats was increased and the quadrat size was reduced after the first weeding to reduce variability without increasing labour requirement Weed biomass was measured separately for C. *odorata*. *Mimosa invisa* (Mart. ex Colla), other broadleaved species, grasses and sedges, and woody perennials. Additional observations taken on 10 August included density (number per area) for C. *odorata*, *Agerarum conyzoides* (L.), and woody perennials and biomass for A. conyzoides Soil samples for all treatments were collected at the time of N application as described earlier.

Root samples from five hills per plot and soil samples from below the hills removed for root sampling were used to quantify root knot nematode (*Meloidogyne graminicola*, Golden & Birchfield) density on the crop root and in the soil, following methods described by Prot & Matias (1995). Samples were collected shortly before rice harvest.

Weed surveys

Following the observations in the on-station experiment, where fallow and crop treatments showed a strong effect on A. *conyzoides*, the resuits of weed surveys carried out during 1991-93 were re-evaluated. Special attention was given to the effect of fallow and cropping period on *A. conyzoides*. Materials and methods of these surveys were described previously (Roder et at, 1995a, 1997).

Results and discussion

Nitrogen treatments did not affect weed growth or interact with the residue management treatments; therefore, the data presented arc generally pooled across the N treatment& The on-farm studies consisted of two independent experiments, whereas the on-station study was a long-term experiment with treatments applied over time to the same plots. The results of the on-station study in 1995 are, therefore, influenced by the cumulative effects of treatment applications in 1994 and 1995.

Effect of residue management and previous crop

Residue load. Residue quantities were not measured in the 1993 oh-farm experiment In 1994, residue quantities at the time of burning were 2.3 ± 03 t ha^{-1} at the on-farm and 3.9 ± 0.6 t ha^{-1} at the on-station site. Treatments with rice in 1994 at the on-station site had an average residue load of 4.4 t h^{-1} for 1995. with 38-42% of the residues consisting of rice straw (Table 1). The cowpea treatment had the lowest total residue load with only about 20% contribution from the cowpea. After 1 year of fallow the residue load was 9.5 t ha^{-1} of which about 70% was C. *odorata*. After rice straw. C. *odorata* was the next most important residue material for all the other treatments, contributing about 40% of the non-crop residue Residue quantities and composition after 1 year of fallow were similar to those observed previously (Roder at aL, 1995b). Mulching with rank, partly woody residues of about 10 t ha^{-1} after 1 year of fallow is very difficult or impossible and farmers are not likely to adopt mulching under these conditions.

Table 1. Residue load at the time of slashing (on-station experiment, 1995)

	Residue (dry matter, t ha^{-1})					
Treatment	Rice	Cowpea	C. *odorata*	Woody perennials	Other species	Total
Continuous rice - burnt	1.9	-	1.4	0.8	0.9	5.0
Continuous rice - mulched	1.6	-	0.9	0.5	0.8	3.8
Rice/fallow - burnt	-	-	6.5	1.6	1.4	9.5
Rice/cowpea - mulched	-	0.5	0.9	0.8	0.5	2.7
SE*	0.18	0.09	1.39	0.29	0.48	1.20

*df = 4 for rice and cowpea and 12 for others.

Table 2. Effect of residue treatment On fresh weed biomass over the rice growing season (on-farm and on-station experiments. 1993-94).

	Weed biomass (fresh. g m^{-2})*		
Residue treatment	1993 (On-farm)	1994 (On-farm)	1994 (On-station)
Residue .- burnt	430	830	220
Residue - mulched	740	990	440
SE (3 d.f.)	145	123	75

*Weed biomass consisted of: 1993, weed at rice harvest; 1994. two weedings and weed at rice harvest.

Table 3. Effect of cropping/mulching treatments on weed biomass and composition (on-station experiment, 1995)

	Weed biomass (total of three weedings, fresh Wt g m^{-2})			
Treatment -	C. *odorata*	Herbaceous*	Woody perennials	total
Continuous rice - burnt	70	261	160	49!
Continuous rice - mulched	165	402	91	663
Rice/fallow/rice - burnt	136	164	179	479
Rice/cowpea/rice - mulched	100	213	I 18	430
SE (12 d.f)	54	65	20	76

*Excluding C. *odorata*..

Table 4. Effect of cropping/mulching treatments on *A conyzoides. C. odorata* and woody perennials observed on 10 August 1995 (on-station, experiment)

Treatment	A conyzoides		C. odorata		Woody perennials	
	Density*	Weight	Density	Weight	Density	Weight
Continuous rice-burnt	77	93	12	14	5	9
Continuous rice - mulched	131	182	57	42	2	2
Rice/fallow/rice - burnt	2	2	17	4	9	12
Rice/cowpea/rice - mulched	26	25	21	18	4	5
SE (12 d.f.)	40	6l	25	15	2.2	4.5

* No. m^{-2}, + Fresch weight, g m^{-2}.

Weed biomass and weed populations. Compared with burning, total fresh weed biomass was higher with mulching by 72%, 19%, 100% and 35% for the 1993 on-farm, 1994 on-farm, 1994 on-station and 1995 on-station study, respectively (Tables 2 and 3). Although mulching increased the biomass of herbaceous species it tended to reduce the biomass of woody perennials (Table 3) The reduction in woody perennials was 71% in 1995 (Table 3). Because of this decrease in woody perennial biomass and high variation in all weed measurements, mulching effects on total weed biomass were not always significant. The rice/fallow rotation had the lowest biomass of herbaceous and the highest biomass of woody species. Rotation treatments (fallow or cowpea) had a strong effect on the weed composition. With rice as the previous crop, the A. *conyzoides* density was 77-131 plants in m^{-2}, whereas after fallow or cowpea, the density dropped to 2-26 plants m^{-2} (Table 4).

Soil parameters and M. graminicola Unlike other reports (Sanchez et at, 1983) soil organic C, pH, average bulk density, total N and extractable P were not significantly affected by burning or previous crop treatments at any of the sites (data not given). However, biomass quantities of 2-10 t ha^{-1} in our studies were much less than the 30-100 t ha' biomass loads of traditional slash-and-burn systems (Sanchez et at, 1983; Andriesse & Schelhaas, 1987). The number of *M. graminicola* nematodes present in 1995 (on-station study) was negligible for the treatments with fallow or cowpea in the previous year, but high for the treatments with rice in the previous year (Table 5). There were significant differences between replicates, with more .M. *graminicola* in replicates 4 and 5, which had a slightly lighter soil texture The numbers of M. *graminicola* were correlated with the density of *A. conyzoides* with correlation coefficients of 0.52 ($P<0.01$) for observations on rice root and 0.46 ($P < 0.01$) for observation from soil samples.

Table 5. Effect of cropping/mulching treatment on nematode numbers (1995. on-station experiment)

Treatment	M. graminicola	
	No. g^{-1} root	No. m^{-3} soil
Continuous rice - burnt	742	2.0
Continuous rice-mulched	187	0.7
Rice/fallow/rice - burnt	3	< 0.01
Rice/cowpea/rice - mulched	1	<0.01
SE (12 d.f.)	495	1.36

Table 6. Effect of residue treatment on rice yield (on-farm and on-station experiments, 1993-95)

Residue ttea(men[*	Rice yield (t ha^{-1})			
	1993 (on-farm)	1994 (on-farm)	1994 (on-station)	1995 (on-station)
Residue - burnt	1.21	0.84	0.95	2.0
Residue - mulched	0.68	0.74	099	2.0
Ricejfallow!rice-burned	-	-	-	2.0
Ricejcowpea/rice -mulched	-.	-	-	2.4
SE	0.07	0.10	0.09	0.19

* Means are averages of N treatments. N effects were significant for 1993 only.
+ d.f. = 3 for 1993 and 1994 and 9 for 1995.

Rice yield and its association with other parameters measured. Rice yields were 44% less on residue-mulched plots in 1993, but there was no significant difference between mulching and burning on yields in the other years (Table 6). Nitrogen fertilizer effects were only evident in 1993, when N application increased rice yield by 18% with burning or residues and by 74% when mulching with the residues (data not shown). Weed competition and N immobilization by mulching are possible explanations for the inconsistent mulching and N effects on rice yields. Such effects can be influenced by a range of factors including soil moisture stress at various periods during the' season, N immobilization through mineralization by the residue biomass. timing of N application, N leaching and effects of residue treatments in the previous year (for the yields in 1995 only) Many studies have shown that systems with surface residues generally have a more favourable soil microclimate, resulting in higher microbial biomass and larger pools of temporarily immobilized N than other systems- However, because of the complicated interactions, it is difficult to predict the effect of residue and tillage practices on soil microbial activity or N cycling (Power & Doran, 1988; Babalola & Opara-Nadi. 1993). Although cropping treatments had no significant effects on grain yield there was a strong negative association observed between rice yield and *A. conroides* density at the last weeding, total herbaceous weed biomass from three weedings and the number of *M. graminicola* found on the roots of the rice plant (Table 7).

Effect of fallow duration on A. conyzoides and other weed species

Data analysis of two weed surveys previously carried out on farmers' fields did not show good correlation associations between fallow length and A. *conyzoides* frequencies and its contribution towards the total weed cover or its frequencies (Tables B and 9). The trends of the negative association between fallow length and A. *conyzoides* were, however, consistent in both studies, and when averaged over classes of different fallow length, the A. conyzoides cover (Table 8) or density (Table 9) showed a decline with increasing fallow length. For C. *odorata*, the most common weed species, no trends in density or frequency were evident in either survey and no association with fallow length was discernible. The occurrence of M *graminicola* infection was also decreased by fallow length (Table 9) and

Table 7. Relationship between rice grain yield and other selected parameters (on-station experiment, 1995)

Parameter	Range	Grain yield
A. conyzoides density (no. m^{-2})	0-265	-0.62***
C. *odorata* weed biomass (fresh wt, g m^{-2})	0-448	-0.39**
Herbaceous weed biomass (fresh wt. g m^{-2})	292-896	-0.45***
M. graminicolo density (no. mg^{-1} root)	0-3.6	-0.42**

⁺ Observed on 10 August.
•! Total of three weedings.
¶Total of three weedings. including A. *conyzoides* and C. *odorata*.
*****Significant at the 1% or 01% level respectively

Table 8. A. *conyzoides* and C. *odorata* frequency and cover for fallow categories (years of fallow) observed in the wee survey (1991-92)

Fallow (no. of years)	Sample no.	A. *conyzoides*		C. *odorata*	
		Frequency*	Cover⁺	Frequency*	Cover⁺
1-3	28	11 ± 3•!	21 ± 5	18 ± 2	32 ± 4
4-6	55	13 ± 2	18 ± 3	22 ± 2	37 ± 4
>6	16	11 ± 4	14 ± 5	17 ± 4	25 ± 8
Correlation with fallow					
Coefficient		-015	-0.19	-	-
Probability		0.15	0.06		

*Frequency (%) in transect segments of 1 m.
'!Cover in cm m^{-1}.
"! Mean and standard error.

Table 9. *A. conyzoides, C. odorata* and *A. graminicola* density and frequency for fallow categories (years of Callow) observed in the weed survey (1993)

Fallow (no. of years)	Sample (no.)	*A. conyzoides* Density*	*A. conyzoides* Frequency+	*C. odarata* Density*	*C. odarata* Frequency+	*M. graminicola* Density*	*M. graminicola* Frequency+
2-3	15	15 ± 4	64 ±12*	8 ± 2	84 ± 7	156 ± 82	57 ± 6
4-5	22	11 ± 2	63 ± 8	8 ± 1	92 ± 4	72 ± 28	44 ± 7
6-8	11	9 ± 3	51 ± 13	10 ± 1	89 ± 5	41 ± 17	44 ± 5
>8	7	5 ± 3	44 ± 16	8 ± 3	80 ± 8	32 ± 31	21 ± 7
Correlation with fallow							
Coefficient		-016	-0.12	-	-	-0.15	-0.29
Probability		NS	NS	-	-	NS	0.03

*No. m^{-2}.
+Presence (%) in 10 plots of 1 m^{-2} per field.
•! No. g^{-1} root.
¶ Mean and standard error.

M. *graminicola* density showed a weak positive correlation (r = 0.23, P = 0.09) with A. *conyzoides* density. A. *conyzoides* is a good host of M. *graminicola* (Waterhouse, 1993) and shifts in weed population towards more A. conyzoides are likely to result in increased damage to the rice plant by M. *graminicola.* Following the results of the on-station study in which 1 year of fallow reduced A. *conyzoides* densities from 77 plants m^{-2} (burning treatment) to two plants m^{-2}, a stronger association between fallow length and A conyzoides density or cover was expected, Farmers are, however, already well aware of the negative association between it *conyzoides* and rice yield and they may adopt fallow and cropping periods according to the expected extent of A. conyzoides infestations, Furthermore, they may start weeding earlier if high numbers or it conyzoides are present in a particular field.

Such an adaptation by the farmer to expected weed problems could neutralize the expected survey effects of fallow length on A. *conyzoides* and M *graminicola.*

Conclusions

Burning of residues not only makes land preparation easier for the farmers but also offers a cheap method of weed control In spite of drought being considered a major yield constraint, no positive short-term effects of residue mulching on grain yield could be demonstrated in mulching experiments carried out over a period of 3 years There will be no benefits for farmers from residue mulching in production systems with short cropping and short to medium fallow period& For permanent rice production systems, however, especially in the light of accelerated loss of soil organic C and N through mineralization (Roder et at., .1995a) and the need for nutrient and water conservation, residue mulching is likely to become an important strategy. Further research into systems that integrate crop rotation, residue management and weed management strategies is required.

In an on-station study the introduction of fallow or crop rotation treatments had a strong effect on *A. conyzoides*, an introduced weed species that serves as a host of M. *graminicola* and is often associated by farmers with poor rice yields. The effect of fallow length on A. conyzoides populations was much less pronounced in the on-farm weed surveys. The absence of a strong relationship between fallow period and A. conyzoides or M. *graminicola* in the on-farm survey is probably the result of unaccounted interaction of farmers' management decisions with the other variables. In fields where a farmer expects a high prevalence of A. conyzoides, he or she may increase the fallow period, and/or reduce the cropping period, or alter the weeding efforts. The relatively strong effect of cropping on A. *conyzoides* populations and the absence of N effects further supports the theory that weed pressure and associated pest problems, rather than soil fertility, are the main factors that influence farmers' decisions in relation to fallow and crop management.

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Alternative land use

Many attempts aiming at establishing "sustainable upland production systems" or "stabilizing slash-and-bum production systems" are documented. These efforts typically ranged from some kind of soil conservation measures providing simple erosion barriers to the extreme of constructing terraces. Often, the combination of perennial crops with cultivation was promoted. Despite isolated success, the adoption of the promoted technologies has generally been disappointing. The limited adoption is largely due to the fact that the technologies offered provided limited or no long-term benefits (Fujisaka 1989). Fujisaka (1989) proposed that, for technologies to be adopted, they have to be necessary, appropriate, and economical.

Options explored by researchers and technologies recommended to Lao slash-and-bum farmers were similar to those tested and recommended in other regions with similar production systems. Furthermore, the solutions recommended were similar to those advocated decades ago with emphasis on soil conservation measures, alley cropping, rotation systems, and planting of perennials. Many of the technologies recommended may not fulfill the criteria suggested by Fujisaka (1989) and may thus not be adopted. We have to be aware that technologies that are adopted under coercion, or with subsidy incentives, are unlikely to provide long-term solutions. The greatest effort toward changing agricultural practices of slash-and-bum farmers in Lao PDR during the 1980s focused on soil conservation through terracing and contour tillage (Fujisaka 1991, Roder 1997). Although early project reports were very enthusiastic over the high adoption rate and the impact of these activities, no evidence of changes in slash-and-burn practices was traceable only a few years later.

As long as rice production for home consumption remains the main objective, Lao slash-and-bum farmers will have limited options for changing their land-use practices. From various studies focusing on rice varieties and agronomic aspects of rice production, it was concluded that traditional varieties and farmers' management practices were well adapted to the given conditions (Lao-IRRI, annual technical reports 1991-99, unpublished, Fahrmey 1999). Thus, opportunities to improve rice production or to reduce labor are limited (Table 15). The most promising options are planting of perennials and improved fallow systems with components of food and livestock production. These options have become more realistic through growing markets and changes in rules relating to land ownership and the use of forest products. Considering the low population density, it was postulated that Lao upland households would have a comparative advantage for livestock and timber production. Teak appears to be especially promising and is widely planted. The recent experience with teak and other perennials is discussed in a separate paper included at the end of this section.

Although planting of teak and other perennials appears to be promising as an alternative production system, it has to be realized that resource-poor families, representing the bulk of the slash-and-burn farmers, can generally not risk the long-term investments (land, labor, fencing material, planting material) required. In the worst-case scenario, the promotion of teak may result in further deterioration of the slash-

Table 15. Alternative land-use options tested or recommended.

Technology	Adoption criteria[a] N	A	E	Limitations	Reference[b]
Soil conservation (main advantage: reduction in erosion)					
Terracing	√√[c]	√	-	Cost, return on investment	1,2
Hedgerow	√√	√	-	Reduce land for cultivation	
				Yield reduction	1
Planting perennials (main advantage: low labor inputs, high-value products)					
Teak	-	√√√	√√√√	Long-term investment	3
Fruit trees	-	√√√√	√√√	Market	1,3
Rice variety/agronomic aspects (main advantage: rice production)					
Application of N fertilizer	√	√	√	Economics, availability	4
Application of P fertilizer	√	√	-	Downstream effects	4
Selection of improved varieties	√	-	-	Eating quality	5
Cropping systems (main advantage: rice production)					
Crop rotation	√	√	-	Additional labor, market	4
Planting density	√	-	-	Labor, grain quality	4
Intercropping (legume or maize)	√	√	-	Market, labor	4
Improved fallow	√	√√√	√√√	Availability of livestock, residue management	6. 7

[a] N = needed, A = appropriate, E = economical (criteria for adoption as per Fujisaka 1989).
[b] References: (1) Fujisaka 1991. (2) Racier 1997, (3) Roderetal 1995, (4) [so-IRRi annual technical reports, 1991-95 (unpublished), (5) Roder et al 996, (6) Roder et all 993, (7) Roder and Maniphone 1998.
[c] Relevance of adoption criteria: - = not relevant, √ = some relevance, √√√√= high relevance.

and-bum farmers' resource base as they lease out their land-use rights to lowland farmers or other investors.

Efforts should be made to support resource-poor upland farmers through credit and other means to make it possible for them to purchase livestock and plant teak or other perennials. Available markets, credit opportunities, and land tenure appear to be the key factors that will affect the direction of production systems evolving from the present slash-and-bum systems.

<u>Papers included with this section</u>

Roder W. 1997. Slash-and-burn rice systems in transition: challenges for agriculture development in the hills of Northern Laos. Mountain Res.Dev. 17:140.

Roder W et al. 1995. Teak (*Tectona grandis*). fruit trees and other perennials used by bill farmers of northern Laos. Agroforest. Syst.

Young teak planted into the rice field.

Two-year-old teak plants in the rice field.

Upland rice intercropped with mungbean.

Firewood is an important by-product of the slash-and-burn system but markets are found only near centers with a large urban population.

Livestock products walk to the market on their own.

MOUNTAIN RESEARCH AND DEVELOPMENT, VoL. 17, No. 1,1997, pp. 1-10

SLASH-AND-BURN RICE SYSTEMS IN TRANSITION: CHALLENGES FOR AGRICULTURAL DEVELOPMENT IN THE HILLS OF NORTHERN LAOS[1]

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ABSTRACT Slash-and-burn rice production in the hilly areas of Laos have changed little over the past decades except for a reduction in the Callow period which has caused a tramendous increase in labor requirements for weed control. From 1950 to 1990, the population density increased from 7.6 to 17.6 persons/km^2, fallow periods den-eased from 38 to 5 years, and weeding requirements increased from 1.9 to 3.9 weedings/rice crop. because of high requirements for weeding, the return to labor is only 5 kg rice/labor day For slash-and-burn systems compared with 13 kg/day in lowland rice production. Soil organic C levels arc declining fast, with losses of S t/ha observed during a single rice crop Improvements of the living standard of the farm population, food security stabilization of upland agriculture, and increased rice production are the main objectives of development agencies working in hilly areas. However, the options available are limited by the market opportunities and there is little chance that any of the technologies offered will be adopted on a significant scale. Hill farmers have a comparative advantage for livestock and timber production but generally lack the necessary resources to make long-term investments in either operation. Market, credit opportunities, and land tenure are key factors affecting the direction of future bill agriculture in Laos.

RESUME *Systèmes de culture du riz sur brulis traition —Difficulties pour le developpement del' agriculture dans les collines du Laos du Nord.* Les systèmes de culture du riz sur brmllis dans les du collines du Laos ont peu change an cours des dernières dècennies, si ce n'est tine réduction de la période dejachère qui a cause une augmentation considérable de la main d'ceuvre néscesaire au désherbage. De 1950 à1990, la density de la population a augmentaté de 7, 6 à 17,6 habitants au km^2, les périodes dejachhé ont diminué de 38 à 5 ans et la nécessité du désherbage a augmenté de 1,9 à 3,9 désherbages par récolte de riz. A cause de la grande nécessité du désherbage, le rendement de production n'est que de 5 kg de riz par jour de travail pour les systèmes de culture sur brûlis, compare à 13 kg par jour de travail pour la production de riz aquatique. Les niveaux de C organique du sol tombent rapidement, avec des pertes de 5 t/ha enregistrées au cours d'une seule récolte de riz. L'amélioration du niveau de vie de la population vivant de l'agriculture, la sécurité alimentaire, la stabilisation de l'agriculture en altitude et l'augmentation de la production de riz constituent les objectifs principaux des agences de développement travaillant dans les zones de collines. les options disponibles sont cependant limitées par les débouchés et est peu probable que les technologies offertes soienc adoptées à une échelle significative. Les fermiers des collines jouissent d'un avantage relatif en termes de bétail et de production de bois d' ceuvre, mais ils ne disposent pas en générale des ressources nécessaires aux investissements à long terme pour ces deux activités. Le marché, les possibilités de crédit et le régime foncier Constituent les facteurs clés affectant l'evolution de l' agriculture dans les collines da Laos.

ZUSAMMENFASSUNG *Brandfeld-Reisanbau im Wechsel — Aufgaben bei der lantwirtschaftlichen Entwicklung im hügeligen Nordlaos.* Im hügeligen Teil von Laos hat sich der Reisanbau mittels Brandfeldtechnik ûber die vergangenen jahrzehnte kaum verãndert; auâer daâ die Zeit, in der die Felder brach liegen, verkürzt wurde, was zur Folge hatte, daâ der Arbeitsaufwand zur Unkrautkontrolle enorn zunahm. Die Bevolkerungsdichte wuchs zwischen 1950 und 1990 von 7,6 auf 17,6 Personen /km^2, die Brachzeiten der Felder gingen von 38 bis auf 5 jahre zunrück, wobei die Unkrautbeseitigung von 1,9 bis auf 3,9 mal pro Reisernte anstieg. Wegen des groâen Arbeicsaufwandes bei der Unkrautbeseitigung ist der Ertrag beim Brandfeldbau nur 5 kg Reis/Arbeitstag, venglichen mit 13 kg Reis/Arbeitstag im Tiefland. Den organische Kohlenstoffgehalt des Bodens verbraucht sich schnell; bel einer einzigen Reisemte wurde ein Verlust von 5 t/ha festgestellt. Die Hauptziele der Entwicklungsorganisationen im hûgeligen Teil des Lanties sind: Verbesserung des Lebensstandards der Landbevõlkenung, gesicherte Lebensmittelversorgung, Stabilisierung der Landwirtschaft und Entragszunahmen beim Reisanbau. Da der Vcrinarktung Grenzen gesetzt sind, besteht kaum eine Chance, daâ irgend eine von den angebotenen Technolo. gien in groâem Rahmen zum Tragen kommt. Bergbauern haben zusàtzlich die Mõglicbkeit, Viehzucht und Holzproduktion zu betreiben, jedoch fehlen ihnen im allgemein die nõtigen Mittel für langfristige Investitionen. Die Richtung tier zukûnftigen Landwirtschaftsentwicklung im hûgeligen Laos wird entsacheidend von Fraktoren wie Marktlage, kredimõglichkeiten und Landbesitzverhàltnissen bestimmt.

INTRODUCTION

in the past, shifting cultivation or slash-and-burn agriculture was a major land-use system throughout the world (Spencer, 1966; Hillel, 1992). While it has largely disappeared in temperate regions, it remains important in subtropical and tropical environments, especially in mountainous regions, where it supports at least 300 mil-

[1] The research presented in this paper was supported by the Department of Agriculture, Luang Prabang, Laos, and the Swiss Development Cooperation.

lion people (Warner, 1991). Slash-and-burn farmers often belong to minority groups. use fragile or poor soil resources, have disputed land tenure, and live in hilly, remore areas. Any of these factors will put them at a serious disadvantage when compared with other segments of the rural or urban populations. Poor communication, limited access to socioeconomic benefits and markers, poor repre-Sensation in government bodies, and lack of understanding by other groups contribute in maintaining or increasing the existing disparity. Thus, it is not surprising that slash-and-burn farmers are often blamed for forest destruction, land degradation. poor productivity poor response to new technologies offered, or simply for being backward (Singh and Singh, 1980; Dessaint, 1981; Mackie, 1985; Vienne, 1989). To redress these real or conjectured problems. many countries have mounted large campaigns to replace slash-and-burn agriculture with other land-use systems (Myers, 1992; Kleinman a at, 1995). Often these efforts have had little impact. Recent studies of slash-and-burn systems conclude that such systems are economically and ecologically sound in areas with low population densities (Fujisaka. 1991; Kleinman et at, 1995).

Slash-and-burn rice production is the major land-use practic'e in the hilly areas of Laos. Wherever possible, flood plains and valley bottoms where fields are bunded and level are used for lowland rice production (Roder et aL, 1996). but due to limited area of available lowland, farmers depend largely on upland fields that are not bunded and usually are not: level. Low population densities have made slash-and-burn agriculture the best land-use option for the rural population in the hilly regions of Laos and the adjacent hilly areas of Northern Thailand (Kunstadrer and Chapman, 1978), Burma, and Vietnam.

As in other parts of the world (Karlen at *al*, 1994; Kleinman et *al*, 1995), the dangers of resource degradation had been recognized in Laos decades ago. Many records gave evidence of such concerns and/or extension efforts aimed at improving productivity of slash-and-burn agriculture. 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). More than 50 years ago, Gourou (1942) made the following statement: "To avoid loss of soil fertility, upland farmers should change from slash-and-burn to permanent systems using perennials such as coffee, tea, rubber, fruit trees, lac, etc," However, Gouron (1942) realized that most of these options were not viable because of transportation problems. Similarly, 30 years later, Phommasthit (1975) wrote that 'the government has cautioned (the upland fanners) not to destroy the trees and dense forests for upland fields and has encouraged them to use the land for horticultural purpose or for reforestation.

The justification for change and the solutions offered today are no different from statements and recommendations made 50-70 years ago. Since then, however, the rural population has experienced significant changes, especially increased population density. wider access to education, increased economic expectations, better road facilities, and marginally better access to markets. The combined effect of these factors exerts substantial pressure on today's slash-and-bum farmers. Now they are eager to change to other land-use systems or live from other sources of income, provided that opportunities are available.

The present efforts of the government and numerous organizations committed to the betterment of the Lao upland ecosystem are laudable. To avoid unnecessary repetition, to achieve the best results possible for the hill populations, and to avoid disappointments, it is important not only to learn from past experiences but to analyze past and present development efforts honestly and realistically. In this paper, I will review and discuss, first, the trends in agricultural practices and their effect on the resource base, second, efforts of government and non-government agencies to change existing agricultural practices and their results and, third, recent findings from investigations that evaluated possible alternatives to slash-and-burn agriculture and technologies to improve upland rice yields.

MATERIALS AND METHODS

All available publications on agricultural research and development in Laos were reviewed and information pertaining to bill agriculture was used to discuss past and present research development efforts. Additional infomation was collected from development agencies working with slash-and-burn farmers in the uplands of Laos. Following a list compiled by the United Nations Country Program (UNDP, 1994), contact was made with all agen cies with active programs in 1994. Using a formal questionnaire, these agencies were asked to list the objectives of their project. major strategies used, and methods recommended to improve upland rice production. Responses were received from 12 out of 15 agencies addressed by the survey. The activities of the agencies interviewed were mainly located in the hilly regions of the north in the provinces of Luang Prabang. Bokeo, Viendane, and Xieng Khouang (Figure 1).

RESULTS AND DISCUSSION

GENERAL DESCRIPTION OF SLASH-AND-BURN AGRICULTURE

The population of Laos is made up of more than 60 ethnic groups (Stuart-Fox, 1986). The majority of the hill dwellers belong to Mon-Khmer (Lao Theung) and Tibeto-Burman (Lao Sung) groups. The northern part of the land-locked country consists of a continuous succession of rolling hills and rugged mountains with peaks

FIGURE 1. Location map of Laos.

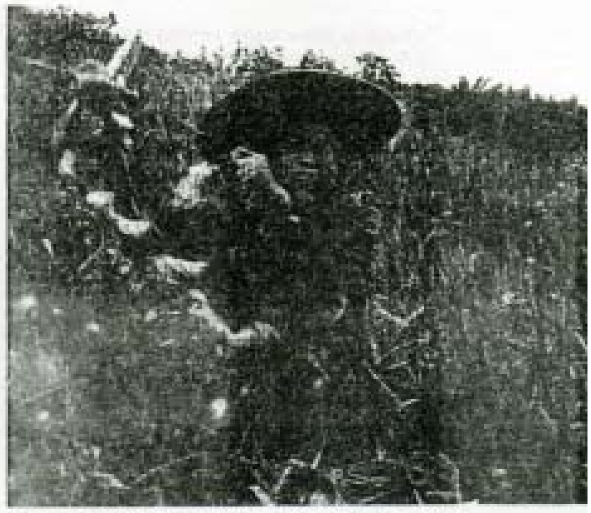

FIGURE 2. Weeding upland rice in northern Laos.

rising up to 2,800 in. In the south, the Annmite Cordillera forms an almost unbroken range dividing Vietnam and Laos. The climate is tropical, with distinct dry and wet seasons. Precipitation occurs mostly from May to October and fluctuates widely, influenced by topography and the flow of monsoon winds.

Slash-and-burn agriculture is the prevalent land-use practice throughout the hilly regions, with most of the cultivation limited to the altitude range of 300-1,200 in. According to recent statistics (World Bank, 1995), 69% of the area used for upland agriculture had a slope gradient of 20 percent or more. Rice is the most important crop that accounts for more than 70% of the cultivated area (National Statistical Center, 1996). No tillage and inputs of fertilizers and chemicals are required. Land preparation consists of slashing secondary forest or shrub vegetation in January or February and burning the dry biomass in March or April. Rice, mostly glutinous, is planted with the onset of the monsoon rain in late May and June using a dibble stick (Roder et *al*, 1996). A single rice crop is usually followed by fallow periods of 2-8 years. Few farmers cultivate rice for two or more successive years. A variety of other crops are planted in combination with rice. These include, in approximate order of declining importance, maize, cucumber, chili, eggplant, taro, sesame, gourd, pumpkin, cassava, loofah, sorghum, cowpea, peanut, sweet potato, job's tear, yambean, pigeon pea, sun hemp, tobacco, mungbean, phaseolus bean, watermelon, and spices.

Casual observers have related specific slash-and-burn practices to particular ethnic groups, following the exampies from Northern Thailand given by Kunstadter and Chapman (1978). Ethnically and culturally the population of Laos has many commonalties with the population oi Northern Thailand, but recent quantitative observations of land-use systems did not support the association of distinct practices with ethnic categories (Roder et at, 1995 d). Practices used today are largely a function of land capability, climate, population pressures, and past political events. Except for changes caused by shorter fallow periods and the introduction of new weed species, the production system has changed little. Only traditional rice varieties are used and tools such as knife, dibble stick, and weeding blade are the same as those used genera-(ions ago.

FALLOW LENGTH AND ITS EFFECTS ON WEEDS, WEEDING REQUIREMENTS, AND SOIL FERTILITY

The primary functions of fallow periods in slash-and-burn systems are to restore soil fertility and to reduce weed pressure (Nye and Greenland, 1960; Warner, 1991; Kleinman et at, 1995). To maintain long fallow periods, large land resources and consequently low population densities are required. The population of Laos has increased from less than I million in 1920 to more than 4 million in 1994 (National Statistical Center, 1995). With a present population growth rate of 2.4%, further substantial increase is expected. The province of Luang Prabang has the greatest area used for slash-and-burn agriculture representing about 25% of the national area. At the same time, this province has a population density of 21.7 persons/km^2 which is substantially higher than the national average. To protect the remaining forest and/or to allow the forest to regenerate, the government is regulating land use and farmers are not given land tenure. Traditional users' rights are overruled if the fallow vegetation

TABLE 1

Trends in fallow length, weeding requirement. labor input, population density, and wage equivalent in rice

	1950s	1970s	l990s
Fallow period (yr)[1]	38	20	5
Weeding requirement (no.)[1]	1.9	2.3	3.9
Total labor requirement for upland rice(d/ha)[2]	226	239	290
Population (million)[3]	1.8	3.0	41
Population density (Nationally person/km^2)	7.6	12.5	17.6
Rice equivalent or wage for construction (kg/d)[4]	8.4	n,a.	5
Rice equivalent of labor wage for farm work (kg/d)[4]	6 + meal	6 + meal	4 + meal

[1]Household survey 1992-93 (Roder a at, 1994).

[2]Calculated from household survey data assuming labor requirement for weeding is propor-. tional to the number of weeding requirements.

[3] Caculated or 1950 using 1970 data and an annual increase of 2A%; Whitaker et *al*, (1972) for 1970 data; National Statistical Center (1991) for 1990 data.

[4] Halpern (1961) for 1950 data; authors for 1970 and 1990 data.

has passed a certain number of years or if the fields are near a national highway. The combined effects of increased population density and government policies limiting farmers' access to land, have reduced fallow periods from about 40 years in 1950 to an average of only 5 years in 1992-1993 (Table 1). Over the same period, the requirement for weeding has. more than doubled.

Weed control in upland rice production (Figure 2) requires about 140-190 d/ha or 40-50 % of the total labor input (Roder et all, 1994). In the survey, upland fanners considered weeds the single most important constraint in rice production (Table 2). With stagnant or, as some authors suggest, declining yields (Fujisaka, 1991), upland farmers' returns to labor inputs have declined substantially. One labor day presently produces about 5 kg rice in upland production systems and 13 kg rice in lowland production systems (Roder a all, 1992). In another study carried out in Luang Prabang province. Leacock a at. (1993) reported labor inputs of 268, 205, and 194 d/ha or returns to labor of 4.3 kg grain/d for upland rice, 8.6 for lowland rice, and 13.3 for maize production.

Traditional slash-and-bum systems are believed to optimize return to labor while using large land resources (Ruthenberg. 1980). While this theory may have been pertinent earlier, it is far from the realities faced by today's farmers in the hills of Laos. Introduction of tillage with animal power is often a key factor in the change from slash-and-bum to more intensive land-use systems. Because of the steep slopes!, however, tillage would not be a sustainable solution for most upland farmers in Laos. Given the hilly topography. the absence of markets, the strong preference for rice, and the lack of other employment opportunities- farmers have no option but to grow rice in slash-and-bum systems. Lack of alternatives, rather than return to labor, is the main reason why they continue using slash-and-bum systems for rice production. It is also interesting that labor wages relative to rice prices have declined substantially over the last decade (Table 4 In part this may be a reflection of the decline in labor

TABLE 2

Farmers' rating of major constraints to upland rice production based on household surveys [1]

	Respondents listing constraint (%)		
Constraint	Oudomxay (n=32) %	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	25
Soil fertility	31	22	2

[1] Oudomxay and Luang Prabang survey carried out in 1991-92, (Ruder a at, 1995b), Bokeo survey carried out in 1994 (LAO-IRRI, Annual Technical Report 1994, unpublished).

productivity in upland rice production systems. Nevertheless, it is also a strong indication of the limited alternative employment opportunities available to the hill population.

Changes in the crop-to-fallow ratio not only resulted in an overall higher weed pressure but also caused shifts in weed and pest populations. *Chromolaena odorata*, introduced to Laos in the 1930s, has become the most abundant weed and fallow species (Roder a at. 1995 a)- Elderly people interviewed could not recollect the dominant weed species prior to the introduction of C. *odorata*. It was suggested that C. *odorata* may have largely replaced tree species coppicing from old plants or growing from seeds. With increased cropping intensity a shift from C. *odorata* to Ageratum conyzoides was observed (LAO-IRRI, 1996). The same studies also revealed a strong association between the prevalence of N conyzoides and root knot nematode (*Mebidogine graminicola*). Present reduction in rice

TABLE 3

Relationship between soil fertility parameters, fallow period, weeds, nematodes, and ,ice yield

	Fallow period	Rice yield	Reference
Fallow period		No	1
Organic C	Some	Consistent but low	1
Soil pH	No	No	1
Available N	No	Some	1
Extractable P	No	No	1
Plant N at flowering	High	High	2
Chromolaena odorata	No	No	1,3
Ageratum conyzoids	Some	Some	1,3
Meloidogine graminicola	Some	Some	1

1) Roder et *al*, 1995b, 2) LAO-IRRI, Annual Technical Report 1995 (unpublished), 3) Roder et *al*, 1995a.

TABLE 4

Priorities of development agencies wetting in the hilly areas of Laos[1]

	Agencies listing objective (no.)	
Objective	Primary	Primary and secondary
Improvement of living standard	7	9
Food security	7	8
Stabilization of upland agriculture	6	8
Increase in rice production	6	7
Cash income for farming population	3	8
Increase in livestock production	3	5
Improved nutrition of farming population	2	6
Reduction of ecological damage	1	6

[1]Agencies (n=12) were asked to list their primary and secondary objectives

yield with repeated cultivation could be caused partly by a strong increase of root knot nematodes.

Based on household surveys carried out in three provinces, upland farmers considered rodents the second most important constraint to rice production after weeds (Table 2). Drought and insect pests were also considered important in some locations. Soil fertility, however, was not perceived as a major limitation. Similarly, extensive soil and rice yield measurements did not reveal strong associations between soil parameters and rice yield (Table 3; Roder, 1995 b). Yet, many recent documents discussing the potential of upland agriculture in Laos refer to sail fertility as a major constraint (SUAN, 1990; Fujisaka, 1991; Lovelace, 1991). The only soil parameters showing some association with rice yield were organic C and available N (Table 3). Substantial yield increases with the application of N fertilizer have been established (LAO-IRRI, Annual Technical Reports, 1994 and 1995, unpublished).

Considerable declines in soil organic matter and soil nitrogen have been observed during the cropping and fallow periods (Roder et *al*, 1995 b). In a study of five sites, losses of 5.6 ± 2.7 t/ha for organic C and 0.4 ± 0.13 t/ha for organic N were observed over the cropping perico of 200 days from the soil interval of 0-25 cm. Simdarlv. in another study covering four sites, losses over 3 years (1 rice crop, 2 yr fallow) were 9 ± 2.6 t/ha for organic C and 2 ± 1.1 t/ha for organic N. Through repeated cycles of short fallow periods, the organic matter levels in the Lao upland soils are expected to decline further until an equilibrium has been reached. Most of the organic C loss was attributed to mineralization; only about 10% was found in eroded soil (Roder et *al*, 1995 b). Measures reducing erosion, although important, will therefore reduce the total C losses by only a small percentage. The fallow length required to maintain soil fertiliq~ especially organic C, at an optimal level depends on soil and climatic conditions. For Laos, it was estimated to be 15-20 years (Gourou, 1942; Whitaker a at, 1972). More rime would be required to restore organic C to its original levels. Brown and Lugo (1990) suggested that the time for recovery of soil organic C during succession would be about 40-50 years for tropical forests.

Loss of potential rice yield and contribution to the CO_2 load in the atmosphere are the most obvious results of soil organic C decline. However, the most harmful effect for the farmer may be the loss of other land-use options which will become available with better access to markets. Such options could include fruits, condiments, vegetables, and other cash crops.

OBJECTIVES AND PRIORITIES FOR DEVELOPMENT ACTIVITIES

The forestry. livestock, and agriculture departments under the Ministry of Agriculture all work with upland farmers and advise them on technical issues. In addition to these government agencies. there are a number of projects whose main emphasis is on hill agriculture Current government policies award high importance to rice self-sufficiency and food security. Similarly, the most important objectives of the projects of the development agencies included in the survey were improvement of living standard, food security stabilization of' upland agriculture, and increase in rice production (Table 4). With a strong preference for rice, food security is generally considered equivalent to increased rice production. Rice deficits are frequently reported 'as a major problem for upland regions (VanGansberghe. 1994). Such shortages are certainly not new (Gouron, 1942; Wall, 1975) and it is important to realize that farmers had no use for surplus rice production. Since their storage losses due to rats and insects increase substantially with extended storage periods, the production shortages observed largely reflect the farmers' attempt to optimize storage losses and problems of overproduction. Over 50 years ago, Gourou (1942) observed that the rice and 'maize harvested by upland farmers was used for daily food consumption and for conversion to alcohol; it was rare for them to have sufficient rice reserves until the next harvest. As upland farmers in remote areas have no incentive to produce surplus rice, even small fluctuations in production will immediately result in shortages.

If the main reasons for today's apparent rice shortages at the national level are drought stress (Roder et at., 1996), pricing, and market policies (World Bank, 1995), then the emphasis on rice production will not help to solve the problem for the upland households. Emphasis on other crops such as maize and cassava is more likely to improve food security in remote areas. Maize and cassava are not only less susceptible to drought, they are also used as livestock feeds; thus, surplus production can be used for livestock.

While high levels of self-sufficiency with rice will remain an important goal, economic realities have to be considered- According to a recent review of agricultural profitability, the returns to labor were US $0.14, 0.74, 1.65, and 11 .9/d for upland rice production. upland maize production. buffalo raising, and pig fattening, respectively (World Bank, 1995). Upland rice production is, by far, the least profitable enterprise for the hill farmer. Considering the limited market opportunities for annual crops and horticultural products. the relatively low population densities, and the hilly topography, in general. upland farmers have a comparative advantage for livestock and timber production (Roder et al,, 1995 c). Livestock products are already the most important source of cash income, contributing 68% of the annual cash income [or the farmers surveyed in 1992 and 1993 (Table 5). With high value per weight and being partly mobile, they are less dependent on road facilities.

TABLE 5

Sources of cash income[1]

	Cash income (US $)	
	1992	1993
Rice	15	5
Livestock	76	59
Forest products	3	10
Other crops	3	5
Wages and off farm	15	8
Total	112	88

[1] Sample sizes were 64 in 1992 and 126 households in 1993 (Roder et *al*, 1996).

EXTENSION AND DEVELOPMENT EFFORTS AND TECHNOLOGIES PROMOTED/ADOPTED

The development agencies interviewed listed "advice on farming practices" as the most important strategy used to achieve the objectives of improved food security and higher rice production (Table 6). Meaningful advice to farmers can be provided only if the technologies at hand are superior to those presently used. Furthermore, slash-and bum, no tillage systems may be the only sustainable method for rice production in hilly environments. Therefore, the choice of realistic technologies available to change or improve the system is very limited, especially if rice production is to remain a major focus.

While there is some agreement that the land-use options of upland farmers are limited by die absence or inaccessibility of markets, none of the agencies interviewed had listed the provision of market support as a primary strategy. The marketing of upland products is left to private individuals or companies who seek high profit margins and who do not hesitate to exploit the unprotected farmers to the maximum limit possible.

Rotation systems with legumes, and hedge row/alley cropping systems

These systems (or combinations of them) are the most widely recommended technologies to improve upland rice fields (Table 7). Species recommended in these systems. in order of preference, by the agencies interviewed are: pigeon pea, leucaena, ruzzi grass (*Brachiaria ruziensis*), *Calliandra callothyrsus*, *Stylosanthes guianensis*. and vetiver grass. There is good potential for increased livestock production by replacing the fallow vegetation with fodder species. Improved fallow systems, which combine the effects of fodder plants and grazing animals. may not only increase fodder availability but also suppress weeds and accelerate nutrient cycling (Roder et *al*, 1995 c). Further research, with farmers' participation, will be necessary to identify appropriate species and to develop suitable rotation systems and technologies to manage the introduced species and their residue cover during the rice crop.

Hedgerow and alley cropping systems have been promoted in northern Thailand for many years with very little adoption by fanners. At the same time, the benefits

TABLE 6
Major strategies used by development agencies surveyed[1]

Strategy	Agencies listing strategy (no.) Primary	Primary and secondary
Giving of advice on farming practices	7	10
Improvement of irrigation facilities	6	8
Vaccination of livestock	5	8
Setting up of revolving fund	4	8
Increase of area for lowland rice	4	7
Supply of seeds or fertlizers	3	8
Setting up of rice banks	3	4
Supply of fruit trees	1	7
Provision of marker support	-	2
Provision of market information	-	1

Agencies (n=12) were asked to list their primary and secondary strategies.

TABLE 7
Technologies recommended to improve upland via yields and extent of adoption

Technology	Number of agencies[1] (n=12)	Adoption [2] <10ha	Adoption [3] >l0ha
Rotation systems with legumes	9	4	1
Hedgerow system using trees	6	2	-
Improved varieties	5	3	-
Alley Cropping	5	4	-
Control of insect pests	3	-	-
Control of rodents	2	1	1
Fertilizer use	2	1	-
Terracing	1	-	-

[1]Agencies recommending technology as primary or secondary strategy (no.).
[2]Agencies reporting adoption at level c 10 ha (no.).
[3]Agencies reporting adoption at level> 10 ha (no-).

from alley cropping, especially in drier environments, have been seriously challenged (Coc, 1994; Ong, 1994). Although rotation benefits from pigeon pea have been demonstrated (LAG-IRRI, Annual Technical Report 1994, unpublished), its value is limited by the absence of a market for pigeon pea seed. While there may be some potential for modified hedgerow systems in parts of Laos, it is unlikely that any of the conventional systems with the Species presently recommended will ever be adopted by Lao upland farmers on a wider scale. Furthermore, there is presently no evidence that any of the species recoin-mended for fallow improvement would be superior to C. odonna, the prevalent fallow species (Roder a at, 1995 a).

Alternative crops

Earlier efforts to introduce fruit production had enjoy limited success because of lack of market opportunities (Roder et al, 1995 d). All participating farmers from Oudomxay Luang Prabang, and Sayabouly provinces in a recent research program preferred teak over fruit trees (Table 8). While fruit plantations increased only moderately in the Luang Prabang province, the area under teak has increased exponentially over the past few years. The sudden rise in the interest for teak planting was associated with changes in laws governing the use of timber (allowing farmers to own timber Plantedt departure from collectivized agriculture, and increased confidence of the farmers in the political stability of the country. Yet, investigations have shown that most of the teak plantation owners are farmers who own lowland rice areas, indicating that teak, although planted under upland conditions, is not an alternative crop for the upland farmers (Roder et at, 1995 d). Resource-poor families, representing the bulk of the slash-and-bum farmers, generally cannot risk the long-term investments (land, labor, fencing, planting material) required. In fact, promotion of teak may result in further deterioration of the upland farmers' resource base as upland farmers may lease out their land-use rights to lowland farmers or other investors. Efforts should be made to support resource-poor upland farmers through credit and other means to make it possible for them to plant teak. Modified plantation systems combining food,

TABLE 8

Choice of perennials and conservation measures adopted in farmer's participatory research projects (1994)

	Rate	Extent of adoption [2]
Choice of perennials		Tree (no.)
Planting of teak	100	380
Planting of mango	23	13
Other fruit: trees [3]	23	20
Conservation measures adopted		Area (ha)
Planting of:teak along contours	31	0.5
Planting of grass strips (vetiver or *Brachiaria* sp.)	15	< 0.1

[1] Percent of fanners (n = 13) choosing species or adopting soil conservation measures.
[2] Number or area per farmer planting a particular species or adopting a conservation measure.
[3] lncluding pomelo, longan, jack fruit, and custard apple.

TABLE 9

Technologies evaluated to maintain or macale rice yield ornduce weed biomass

Technology	Demonstrated effect: Yield increase	Demonstrated effect: Weed reduction	Limitations	Reference'
Increase rice yields	(%)	(%)		
Application of N fertilizer	0-150	0	Economic, input availability	a
Application of P fertilizer	0-15	0	Economic, input availability	a
Selection of improved varieties0	0			a
Crop rotation effects	0-50	(-)20-50	Additional labor, market	a
Planting density	(±)[2]0-40	(-)10-30	Yield reduction, grain qualities labor	a
Intercropping with legum	(±) 0-50	(-)10-40	Yield reduction, market, labor	a
Weed residue management				
Prepland glyphosate	0	30-50	Economic, input availability	b
Residue burning	0-70	0-30	Loss of organic C and N	a
Intercropping with maize	(-.)[3]l0...70	0-20	Yield reduction rice, market maize	a

[1] a) LAO-IRRI Annual Technical Reports 1991-96 (unpublished), b) Roder et al, l995e.
[2] lncrease and decrease in yield in the range indicated have been observed.
[3]Yield decreast

livestock, and timber production could be possible alternatives.

The farmers' assessments of marker opportunities for horticultural products reflect past experience. Improved communication networks, local fruit processing industries, and growing local markets may provide opportunities for increased fruit production. Fast growing markets in urban centers offer a range of new opportunities for nearby upland farmers to produce high-value vegetables and fruits. When provided with the necessary information on market potential and appropriate seeds, innovative farmers are very quick at adopting new crops and technologies (P. Hoare, Australian Upland Project, 1995, pers. Comm.).

Soil conservation practices

The greatest effort toward changing agriculture practices in the recent years focused on soil' conservation through terracing, and contour tillage (Fujisaka, 1989). A large FAO-sponsored project used a "food for work" program as incentive for the farmers to adopt their recommended methods. Early project reports were very enthusiastic over the high adoption rate and the impact of these activities (SUAN, 1990). Slash-and-bum practices were said to have been completely abandoned in 27 villages and reduced by 50-80 percent in 163 other villages (SUAN. 1990). Only a few years later, no evidence of these changes was traceable and the same project was quoted as an example of an approach that failed because the technique was neither necessary nor economical (Fujisaka. 1989).

PERTINENT RESEARCH FINDINGS AIMED AT INCREASING RICE YIELD AND/OR REDUCING WEED BIOMASS

Variety improvement and agronomic practices

Traditional varieties and farmers' management practires were found to be well adapted to the given conditions- The limited number of introduced varieties tested and variations in planting date and planting densities did not consistently improve yields. There was, however, increasing evidence that N availability limited Acids as implied by substantial response to N applications, especially applications after panicle initiation (Tables 3 and 9).

Cropping systems

Rice yield increase and/or reduction in weed biomass through crop rotation and intercropping systems has been demonstrated (Table 9). These systems always require additional labor investments, but without adequate markets for by-products such as cowpea, pigeon pea, and maize, the additional rice produced does not compensate for the extra labor investment. Improved fallow systems most likely to succeed are those that include grazing and that optimize nutrient and moisture management. Most promising species for such systems presently tested on station and in farmer's fields include *Stylosanthes guianensis*, Leucaena leucocephata, Olivicidia sepium, and £radijaria species. Caution is needed to avoid, introducing new weed species, such as Mimosa invisa which was proinoted as a green manure plant in the 1950s (Poilane, 1952) and has now become a serious weed problem in some upland fields.

Weed and residue management strategies

Various weed and residue management strategies including mulching, residue burning, live mulch cover, and herbicides have been investigated but the results offered little promise for practical application (Table 9; Roder a al., 1995 e). Residue burning, as practiced by the farmer, reduced weed biomass in all experiments carried out and increased rice yield in some years. Application of glyphosate before rice planting reduces soil erosion and labor requirements for weeding (Roder et at, 1995 e).

Traditional rice production practices in the hills of Laos have changed little except for the dramatic reduction in fallow length. Shorter fallow periods resulted in excessive labor requirements for weeding but have had few visible effects on soil fertility and crop yields. Weeding requirement$ and soil fertility problems are likely to become more acute with repeated cycles of short fallow periods. Because of the unsatisfactory returns to labor and increased expectations, the Lao hill farmers are under great pressure to change their land-use practices and may reach a critical point where it Will be profitable for them to shift to a more intensive agricultural system (Boserup, 1965) However, lack of markets, credit facilities, or alternative employment opportunities leave them little choice but to continue producing upland rice for their own consumption.

Efforts by government and non-government agencies and projects focus largely on increasing food security and producdon by providing advice to farmers on new technologies. The range of technologies available to increase rice production under the given conditions, however, is limited at best. Farmers wilt adopt new technologies only if they are necessary, appropriate, and economical (Fujisaka, 1989). The solutions recommended today are similar to those advocated decades ago with emphasis on improved Callow/alley cropping, rotation systems, soil conservation measures, and planting of perennials. Many of the technologies recommended may not fulfill the criteria suggested by Fujisaka (1989). It must be acknowledged that technologies which are adopted under coercion, or with subsidy incentives, are unlikely to provide long-term solutions. There is a strong tendency for development pojects to be over-confident in advising farmers of new technologies, and to be too optimistic when reporting the success of their efforts.

Available markets, credit opportunities, and land tenure are the key factors that will affect the direction of future upland agriculture. One should be realistic and take these factors into consideration when planning development and extension activities and should place more emphasis on the following:

- Providing better and more stable market opportunities;
- Developing competitive marker systems and protecting farmers from exploitation by traders and middlemen;
- Helping farmers to improve their land-use rights or land tenure and to prevent them from giving away or selling their rights to parties interested in timber plantation;
- Providing realistic, affordable, and available credit systems;
- Focusing on realistic food security systems which will not depend on increased rice production in the uplands:
- Providing better access to health and education facilities and paying attention to nutritional problems which may arise with the change from traditional systems to a market economy; and
- Creating alternative employment opportunities that are dependent on the growth of other sectors of the national economy.

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Teak (*Tectona grandis*), fruit trees and other perennials used by kill farmers of northern Laos

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Key words: slash-and bum, upland rice, forest products

Abstract. Hilly topography and inaccessible markets leave limited alternatives for Lao upland farmers who grow rice in slash-and-burn systems. They plant banana, mango, papaya, coconut and other perennials and collect forest products, specially bamboo shoot, banana inflorescence, rattan, cardamom, and benzoin for home consumption and market. Teak is the most important perennial planted on upland fields but farmers having teak are more likely to belong to the lowland ethnic groups and own lowland rice fields. Farmers preferred teak over fruit trees and coffee because of the better market potential and 82% considered cash income or wood for constbruction and 18% the securing of land tenurc as major reasons for planting teak. Insufficient financial resources, non-availability of land, lack of seedlings, lack of labor and lack of experience were regarded as the main reasons for not planting teak by 41, 39, 35, 28 and 13% of non-teak growers, respectively. Plantations are often interplanted with rice for the first 1-3 years. Resource poor families generally cannot risk the long-term investments and credit or modified systems combining food, livestock, and timber production are necessary to allow them to take part in the potentially lucrative teak production.

Introduction

Slash-and-burn agriculture remains a dominant land-use system in many parts of the tropics. Depending on the perspective of the observer, the criteria applied, and the system used, slash-and-burn farmers have been either commended for having a harmonious relationship with their environment [Posey. 1985; Warner, 1991], or criticized for destroying the forest resources [Mackie, 1985; Singh and Singh, 1980]. Although systems used vary greatly, most s1ash and-burn farmers depend on perennials to suppress weeds and recover soil fertility in the fallow period, to provide fruits, substitutes for vegetables, emergency staple food, and hunting ground.

The population of Laos is made up of over 60 ethnic groups [Stuart-Fox, 1986]. Based on ethnicity, linguistics, and geographical characteristics, the ethnic groups are divided into three broad categories: Lao Loum (Lao of the lowlands), Lao Theung (Lao of the mountain slopes), and Lao Sung (Lao of the mountain summits). The population of Luang Prabang Province comprises of 39, 47 and 14% of Lao Loum, Lao Theung, and Lao Sung, respectively [Ethnographic survey 1985, Department of Ethnography, Vientiane, unpublished]. The Lao Theung and Sung categories consist mainly of the ethnic groups Kamu and Hmong, respectively. All major ethnic groups of the country are engaged in upland (upland refers to fields that are not bounded and usually not level) agriculture, but in proportion to their total numbers Lao Sung and Lao Theung farmers are more dependent on upland agriculture. Similarly, Lao Loum farmers are more likely to have lowland (lowland refers to fields that are level and bounded to retain surface water) rice fields. Most upland farmers use slash-and-burn fallow rotation systems to produce rice as their main crop.

Some of the ethnic groups prevalent in the north may have been traditional slash-and-bum farmers, whereas increasing population pressure pushed others from the lowlands into the hills [Halpern, 1961; Izikowitz, 1951]. Casual observers have related specific slash-an&burn practices to particular ethnic groups [Roder et al., 1991]. Kamu farmers are often credited for their appreciation of trees and environment [Hakangard et al., 1990; Tayanin 1992]. Hmong farmers, on the other hand, are frequently accused of using destructive practices (Hakangard et al., 1990]. Recent quantitative observations of land-use systems, however, did not support the association of positive or negative practices with ethnic categories [Roder et a!., 1991]. It appears that extrapolations of ethnic labels, coined by Kunstadter and Chapman [1978] for describing land-use systems in northern Thailand, have been applied repeatedly without validation in the Lao situation.

It is widely accepted that trees and other perennials are better adapted to adverse and unstable environments than annual crops [Felker and Bandurski, 1979]. Agroforestry systems have thus been promoted as an alternative to replace slash-and-burn systems [Robison and McKean, 1992]. Various products from trees and perennials of high value but low density have traditionally served as important trade commodities in northern Laos. Such products included sticklac produced by the insect Laccifer lacca feeding on pigeon pea [Malpuech, 1924], benzoin, a resin of Styrax sp. [Mouhot, 1864], cardamom, and various medical plants. Perennials have a specific significance for the Lao upland farmer because a large percentage of the land presently used for slash-and-burn agriculture has slope gradients over 40%, and will therefore not be suited to the production of annual crops such as rice in a permanent system [Roder et al., 1992]. Present government policies and on-going development programs, however, generally give priority to rice production and food self-sufficiency- Perennial crops have unfortunately not been given due recognition or priority by policy makers and donor agencies.

Lack of market is a serious constraint to horticultural production, except for villages around small urban areas such as provincial capitals [Roder et al., 1992] and opportunities for upland farmers to integrate trees and other perennials into their farming systems are limited. Over the past decade, teak (Tecrona grandis) was the most widely planted perennial, second only to fruit species planted for home use. Under similar ecological conditions but less favorable legislation in neighboring Thailand, teak has become a favorite cash crop for farmers [Hoare and Patanapongsa, 1988] and a lucrative investment opportunity for small investors [P. Ngarmpring, In: Shift into Teak land, Bangkok Post, November 1, 1993].

During 1992 and 1993 the LAO-IRRI project carried out various investigations in the Luang Prabang Province (northern Laos) to quantify and/or qualify: (1) the importance of fruit trees and plantation crops for individual farmers, (2) the importance of forest products in the household economy and market, (3) the motivation and circumstances that lead farmers to plant perennials, especially teak, and (4) the importance of upland rice in the manage ment of teak plantations.

Materials and methods

Household and village survey

Data pertaining to trees and perennials were obtained in the following surveys conducted during 1992 and 1993:

a) Village surveys were conducted in Viengkham, Pakseng, and Xiengngeun districts in 1992 (Luang Prabang province has a total of 11 districts). In each district 10 villages were chosen randomly from a list of all villages. The sample of 943 households represented about 7-10% of the total population of the districts. Information on all individual households pertaining to land, livestock and tree use and ownership was recorded.
b) Household surveys (Survey 1, 1992) were conducted in the same villages. In each village 2-4 individual households were visited and additional questions asked relating to land use problems and ownership of perennials (coconut and papaya).
c) Household surveys (Survey 2, 1993) focusing on rice economics were conducted in Xiengngeun and Viengkham districts in 10 villages; interviews were conducted in 10-20% of the households in each village. The total number of households used was 72. Questions relating to tree ownership and the use of forestry products were included in this survey.

Records available with district authorities

Village level data for household numbers, ethnic identity, lowland area, upland area, livestock figures. distance from road, and teak area were obtained and analyzed for Xiengngeun, Viengkham and Nambhak district of Luang Prabang Province. All 382 villages were included, but since teak plantations are only ‘found for Lao Loum and Lao Theung villages the data was only summarized for these two ethnic categories.

Market survey

The town of Luang Prabang (Capital of the Luang Prabang Province) has two daily markets for fresh products. Some farmers sell their products directly, while others use a intermediary. A survey was conducted during September to December 1992 to appraise the importance of products of perennial species, prices, and distance of producers from the market. Markets were visited once, a week and 15-25 randomly chosen vendors were interviewed. The volume, source (distance of village) and price of the goods sold were recorded.

Survey of teak

A survey was conducted in 1993 in Xiengngeun and Viengkham districts in 17 villages having teak plantations. Villages were chosen randomly from all 55 villages that had teak. In each village 2-5 households with teak plantations and 2-5 households with no teak were selected with the help of the village headman. Interviews were conducted using a formal questionnaire. Questions asked included: extent of plantation, motivation for planting teak, why teak was preferred against other perennials, source of planting material, plantation management, and major problems.

Results and discussions

Tree species: and their importance

The farmers: surveyed use a large variety of trees and other perennial plants. Mango and 'banana are the most important fruits, followed by papaya, and jackfruit (Tables 1 and 2). The introduced papaya has become an important component of the daily diet of many Laotian families. A preparation ('mak hong tam som') made from shredded green papaya fruits, fermented fish paste and spices is frequently eaten with sticky rice. The average number of trees and other perennials available per household is small and many families reported having none (Table 1). Most of the households listed as not having fruit species may harvest banana and papaya and other fruits from plants growing wild on fallow land or in the forest. The list of perennial species in Tables 1 and 2 is far from complete. Less important species used occasionally by the Lao farmer include: jujube (*Zizyphus jujuba*), custard apple (*Annona squamosa*), star apple (*Chrysophylluni Cain ito*), starfruit (*Averrhoa carambola*), lychee (*Nephelium litchi*). and 'mak monkhay' (*Diospyros decandra*).

Apparent ethnic differences in choice and importance of tree species used are largely a result of environment and available resources. Mango and coconut are the most important fruit species for Lao Loum, while banana and

Table 1. Frequency and average number of fruit trees and other perennials for the ethnic categories.[a]

	Lourn (n = 115)[b]		Theung (n = 604)		Sung (n = 224)	
	Frequency (%)	Average[c] (no.)	Frequency (%)	Average (no)	Frequency (%)	Average (no.)
Mango	44	11	25	6	24	11
Banana	29	9	25	21	56	21
Papaya[d]	25	5	11	8	30	12
Orange	4	2	7	11	11	4
Coconut[d]	33	8	14	5	0	0
Coffee	0	0	3	80	4	8
Teak	21	92	5	39	1	2

[a]Data pooled from household and village surveys.
[b] n - number of households.
[c] Average of households having a particular species.
[d] For coconut and papaya the sample size was 24, 103, and 27 households for Lao Loum, Lao Theung. and Lao Sung, respectively.
[e]Mostly *Coffea arabica*.

Table 2. Frequency and number of less important fruit tree species[a]

Species	Frequency (%)	Average numbers and range[b]
jackfruit	17	10 (2-57)
Pornelo	7	8 (1-20)
Lemon	6	3(2-4)
Tamarind	3	7(6-7)
Peach	3	4 (3-5)
Mak lot (*Floe gnus conferta*)	2	2
Guava	2	3

[a]Data from household survey 2, 72 households.
[b]Average for households having the particular species.

papaya are more important for Lao Sung farmers. This is clearly influenced by climatic conditions, since mango and coconut are not suited to the high elevations generally inhabited by the Lao Sung farmers. Age of settlement may be another factor affecting choice of species. Banana and papaya can both be harvested within one year after planting and may therefore be the preferred species in newer settlements.

Over the last decade teak has become by far the most important tree planted, except by Lao Sung farmers. While numbers and area increased only moderately with other species, an exponential increase was observed for teak (Fig. 1). The increase in teak plantations started in 1975 and gained phenomenal momentum in 1985. Although various factors may have contributed to an increased interest in teak, changes in the laws governing use

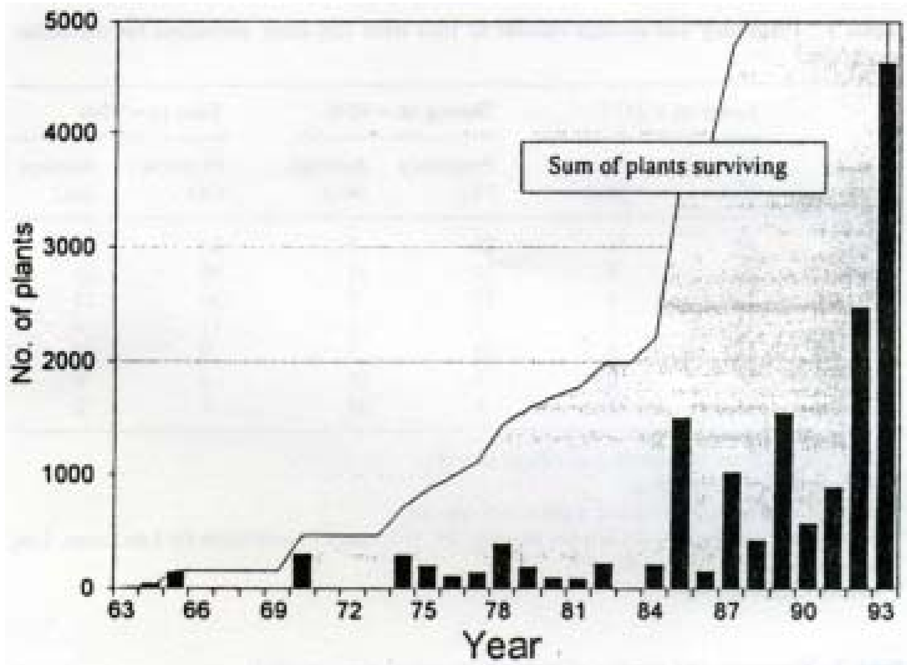

Fig. 1. Number of teak planted (bar) and the total number of teak plants that survived from the 62 households interviewed

of timber, departure from collectivized agriculture, and increased confidence of farmers in political stability are probably the most important factors.

A large variety of wild plants, animals and insects are collected and used by the rural population. Many of these are collected from fallow land (rice slash-and-burn rotation) or from the forest. In the household interview conducted during 1992, bamboo shoot was the most important commodity collected for home consumption and sale (Table 3). Other forest products including benzoin, cardamom, and 'posa' (Broussonetia papyrzjfera) are collected for cash income only.

Non-timber products from trees and other perennials in the market of Luang Prabang

Luang Prabang town with about 20,000 inhabitants, although relatively small, is the most important local market in northern Laos. Products from trees and other perennials sold in the market are seasonal. The list in Table 4 indicates the main products available during September to December. Species important for the rural population such as banana, papaya and coconut are also the most important species in the urban marker. Mango did not appear because its season was already over at time of the survey.

Table 3. Forest products collected, volume and use[a]

Product	Frequency [b]	Volume [c]	Use
Bamboo shoot	27	220 kg	Home and market
Banana infiorescence	7	230 no.	Home and marker
'Posit' (*Broussonetia papyrifera*)	6	73 kg	Market
Cardamom (*Amomum* sp.)	4	2 kg	Market
'Mak kha' (*Pahudia cochinchinensis*)	4	20 kg	Market
Rattan	3		Home and marker

[a]Data from household survey 2, 72 households.
[b]Percent of households reporting collection of the product.
[c]Average per household.

Table 4. Products from perennials in the market of Luang Prabang and distance of producers:[a]

Species	Frequency [b] (%)	Average distance (km)	Average Price (US$ kg^{-1})
Cultivated			
Banana[c]	71	11	0.18
Papaya	71	12	0.14
Lemon	57	15	1.38
Orange	43	150[d]	0.18
Coconut	29	16	0.49
Tamarind	21	4	0.06
Wild			
Bamboo shoot	43	3	0.48
Trumpet flower (*Oroxylum indicum*)	36	14	0.97
'Some pone' (*Acacia rugata*)	29	18	0.71
Pepper wood (*Piper ribesoides*)	21	90[d]	0.93
'Mak kok' (*Spondias man gifera*)	14	3	0.24

[a]Data from market survey.
[b]Frequency based on the presence in the weekly samples during 14 weeks.
[c]Includes leaves and inflorescence which may often be harvested from banana growing wild in shifting cultivation fields.
[d] These products need special conditions not available in the vicinity of Luang Prabang

A large variety of products from wild growing plants collected from the forest or fallow land (fallow progresses into forest and no clear separation exists) are very important in the market. The list in Table 4 includes the most important species, but is far from complete. Interestingly the prices for products from wild species are quite high. Although the rural population may use forestry products mainly during scarcity of rice, this is no longer the case for the urban population, which has acquired a taste for these fancy' products. Many of the products sold are carried to the market by producers and/or collectors from the surrounding villages. The average distance from the production or collection site is generally less than 20 km and is the same for products from cultivated and wild species.

Motivation of farmers and circumstances that favor teak plantation

Most of the teak growers in the area surveyed are Lao Loum farmers in spite of them representing only 10-30% ‘of the population in the districts surveyed (Tables I and 5). Compared to Lao Theung households they are about 4 times more likely to have teak (Table 1) and have a much higher number of teak plants per household. Lao Sung farmers generally live at elevations above 800 m which is outside the adaptation range for teak. According to village level data provided by district authorities, villages having teak are generally much closer to the roads or rivers, are more likely to have lowland rice, have larger areas of lowland rice, and higher numbers of buffalo per household (Table 5). This pattern is the same for Lao Loum and Lao Theung farmers. Availability of lowland area and the number of buffalo are both indicators of the farmer’s’ wealth. Furthermore, under Lao conditions the production of rice from lowland areas may require about 60% less labor compared to upland rice [Roder et al., 1994]. It may therefore be argued that rather than ethnicity it is the resources and the proximity to the road that are the major determinants whether a family will plant teak or not. This argument is strongly supported by the reasons cited for not having teak by families who were interviewed in the same village as the teak plantation owners. Poverty, lack of land, lack of seedlings, lack of Labor, no experience, and being a newcomer were mentioned as the main reasons for not planting teak by 41, 39, 35, 38, 13, and 7% of the households interviewed (n = 42), respectively. The four most important reasons are all resource related. Investments made in teak plantations consist mainly of labor and land. Some farmers may buy planting material and barbed wire for fencing. Financial returns from the sale of timber can be expected after 15-20 years. Families that need to use all their labor resources to produce food may therefore not be in a position to make any labor investments in teak plantations.

Slash-and-burn farmers have no ownership of the land they use for rice production, but they can claim ownership of perennials planted on the land. Planting of teak thus is almost equivalent to longderm land tenure and many outside observers expected that securing land tenure would be the most important motivation for teak plantation. When asked to rate motives for planting teak, 82% of the households interviewed mentioned ‘expected cash income and availability of timber for house construction’ as the main motive. ‘Securing land tenure’ was only mentioned by 18% as the most important criteria. The limited importance given to land tenure perhaps reflects the fact that individual land ownership is not part of the culture for most ethnic groups;

Teak has ‘the potential to produce excellent returns. Logs of medium size trees are presently sold in the local market for US$100 per in3. Assuming

Table 5. Distance from road or river, availability of lowland ricefields[c] and number of buffaloes for villages without and with teak.[a]

Category	Xiengngeun		Nambhak		Viengkham		Average	
	No teak	Teak	No teak	Teak	No teak	Teak	No teak	Teak
Lao Loum								
Distance (km)[b]	18.0	0.1	1.9	0.8	12.7	2.9	10.9	1.3
Lowland (ha hh^{-1})[c]	0	0.30	0.54	0.67	0.18	0.02	0.24	0.33
Lowland frequency (%)	0	100	100	100	88	38	63	79
Buffalo (no. hh^{-1})	1.0	1.0	2.7	3.0	2.0	1.7	1.9	1.9
Frequency (no. of villages)	2	14	13	17	26	13	41	44
Lao Theung								
Distance (km)	5.6	4.0	3.8	0.5	14.6	2.9	8.0	2.5
Lowland (ha hh^{-1})	< 0.01	0.10	0.04	0.12	< 0.01	< 0.01	0.01	0.07
Lowland frequency (%)	11	60	22	65	3	38	12	54
Buffalo (no. hh^{-1})	0.3	0.5	0.9	1.1	1.0	1.4	0.7	1.1
Frequency (no. of villages	46	20	64	20	82	8	192	48

[a] Following village level statistics made available from the districts of Xiengngeun, Viengkham, and Nambhak districts.
[b] Distance of village from road or river.
[c] hh = household.

modest growth rates of 6 m^3 per year the value of the annual production per hectare would be US$600. The same family may grow 1 hectare of upland rice with a' labor input of 300 days producing 1.5 t of rice at a value of about US$150.

The reason for the large increase in the popularity of teak is probably due to the lack: of other alternatives. Farmers are familiar with other tree species but many 'of them have had disappointing experience in marketing the products. Most farmers cite the absence of market as the main criterion for the preference of teak over fruit tree or coffee plantations (*Coffea arabica* and *C. canephora*, Table 6). Farmers assessment reflects past experience. Local processing: and market promotions may make some products such as coffee more attractive. Some farmers may also be willing to experiment with other timber species but they may require planting material and expertise. Farmers, however, rightly fear that most other timber species may take much longer to provide them with a marketable product.

Up to 1990 over 90% of the farmers interviewed had to rely on their own source of planting material by collecting teak seedlings in plantations or in the forest or by raising teak in their own nursery (Table 7). In the last few years nurseries maintained by the government or by various development projects provided substantial numbers of teak plants. This availability

Table 6. Farmers' response to the question 'Why is teak preferred over: 1) fruit trees, 2) coffee and 3) timber species.[a]'

Reason (%)	Fruit trees (%)	Coffee (%)	Timber species (%)
No market	94	55	-
No planting material	3	15	45
No experience		21	32
Long period to get marketable product	-	-	31
No land	6	6	3
Not adapted to environment	3	31	-

[a]Data from teak survey, n = 62 households.

Table 7 Source of teak plants.[a]

Source	Percent of households		
	1965-85 (n = 25)	1986-90 (n = 27)	1991-93 (n = 40)
Seedlings from plantations or forest	100	84	41
Government or project	-	6	40
Fanners' nursery	-	10	19

[a]Data from teak survey, n = 62 households

of planting material undoubtedly contributed to the large ‘increase in teak planting in 1992 and 1993. Teak seeds used in the nurseries are collected indiscriminately from any teak tree available. Unfortunately none of the nursery operators has made any efforts to identify their seed sources or select superior provenances.

Planting and management of teak

Damage by livestock is a major problem in the initial years of the plantations. Control and protection are very important and most farmers considered proximity to the village as the main reason for field selection (Table 8). The land used for teak plantations is generally closer to the road and village than the upland rice fields. Often the most fertile land with lesser slope gradients is used for the plantations. Over 90% of the farmers reported that they did not receive any advice in field selection, layout or planting of their teak. Planting distances of 3 x 3 in are very common. Most farmers plant teak in the rice crop about 1-2 months after planting rice (Table 9). Field preparations for the rice crop provide a good environment for teak; but competition from rice can reduce teak growth substantially in the first year, especially if planting of teak is delayed and if the rice crop is vigorous. Nevertheless planting teak in a rice crop is probably the best method for upland farmers because no extra labor for field preparation and weeding is required. Intercropping with rice or other crops remains important through the first 3 years of the plantation. Farmers generally burn the crop residues every spring. before planting a new intercrop. Depending on the heat intensity during the burning the young teak plants can suffer substantially from this practice. Weeding methods and intensity are largely dependent on the intercrop. As long as intercrops are used weeding will be done 2-3 times per season using a hoe or a weeding blade. Without intercrop weed control mostly consists of slashing with a knife.

Table 8. Criteria applied by farmers for site selection of teak plantations.[a]

Criteria	Respondents (%)[b]
Near village	68
Good soil	13
Near road	10
Near river	8
Inherited	8
No other option	2
Unsuitable for cropping	2

[a]Data from teak survey, n = 62 households.
[b]Sum < 100% because some respondents gave two reasons.

Table 9. Management of teak plantations in the first 4 years after planting.[a]

Management (intercropping & weeding)	Percent of respondents			
	Year 1	Year 2	Year 3	Year 4
Intercropping,				
Rice	52	20	5	-
Bananas	5	2	-	-
Rice + bananas	4	5	-	-
Sugar cane	7	16	18	3
Bananas + sugar cane	4	5	5	-
Pineapple	3	2	2	-
Fruit trees	2	2	2	3
Other annual crops [b]	9	5	5	-
No intercrop	14	43	63	93
Weeding				
Hoe or blade	100	58	23	3
Slashing	0	42	77	86
No weed control	0	0	0	11

[a] Data from teak survey, n = 62 households.
[b] Others annual crops include maize, cotton, sesame, peanut, chilli and other vegetables.

Summary and conclusions

Agroforestry systems (including slash-and-burn systems), fruit and timber plantations are the only sustainable land use systems for slopes above 40%. Lao upland>farmers presently use tree products mainly for home consumption. Market inaccessibility is a major constraint for increased fruit production. Improved communication, fruit processing industries and growing local markets may provide opportunities for increased fruit production in the near future. In the absence of other opportunities teak has become the most important plantation crop in Luang Prabang Province.

The investigations have shown that:

1. *Fruit trees, except for home consumption, are inappropriate if markets do not exist*;
2. *Farmers are willing to invest in considerably long-term strategies;*
3. *Change in policies and regulations provided a strong incentive to plant teak.* The exponential increase in the number of teak planted observed from 1985 onwards coincided with major changes in land use law;
4. *Presently promoted teak plantation systems are not viable options for upland farmers.* Investigations have shown that most of the teak plantation owners are farmers having lowland rice areas, indicating that teak although planted under upland conditions is not an alternative crop for the upland farmers;

5. *Promotion of teak may result in further deterioration of upland farmers resource base.* Since resource-poor families, representing the bulk of the slash-and-burn farmers, cannot risk the long-term investments (land, labor, fencing material, planting material) required, lowland farmers will continue to be the main beneficiaries of any teak promotion scheme. In the extreme case, these efforts aimed at helping upland farmers could result in lowland farmers permanently occupying more and more prime upland areas for the production of non-food crops.

Efforts should be made to support resource-poor upland farmers through credit and other means to make it possible for them to plant teak. Modified plantation systems combining food, livestock, and timber production could be possible alternatives. Although such systems would not optimize teak production, cash could be available from the beginning of the plantation. Joint plantations by groups of farmers could help to reduce costs for fencing and if necessary building access roads at the time of harvesting.

Development projects working in upland conditions should strongly emphasize the promotion of perennials rather than annual crops. Furthermore the importance of planting these perennials before soil fertility has been depleted through inappropriate annual cropping can never be overemphasized. Although farmers generally know the techniques of simple nursery management or fruit tree propagation, it will be important to support them by providing high quality plants of adapted and suitable cultivars.

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Future directions

The government of the Lao PDR is committed to improving the social and economic conditions of the rural population, while maintaining or improving the biophysical resources of the country. In the Ministry of Agriculture and Forestry's strategic vision paper (Lao PDR 1999), separate approaches were suggested for (1) the flat land along the Mekong corridor and (2) the sloping land. In the same document, shifting cultivation is seen as an unsustainable land-use practice that needs to be replaced through more stable and productive agricultural systems. Strategies listed include (1) land-use zoning based on biophysical and socioeconomic parameters, (2) participatory land allocation and land-use occupancy entitlement, (3) farming systems diversification and agroforestry development through adaptive research, (4) community management of natural resources, (5) expansion and intensification of small -scale community-managed irrigation systems, (6) farmer demand-driven research and extension, (7) sustainable land management with soil erosion control, reforestation, and conservation management, (8) credit systems, and (9) improved communication systems providing better access to markets.

Planners and policymakers clearly expect a change from the current subsistence production system emphasizing rice production to a market-oriented system. A change in this direction is anticipated. but the speed of the transformation will depend on many factors, especially on the availability of (or accessibility to) markets, credit opportunities, and land tenure. The most promising options are the planting of perennials and improved fallow systems with components of food and livestock production. These options have become more realistic through growing markets and changes in regulations relating to land ownership and the use of forest products. When speculating on the pace of change and on the type of system that may evolve, we have to consider the following:

1. Change in land-use practices would require that slash-and-bum households (1) produce their food requirements using different production technologies, (2) change their food habits, or (3) produce products sold outside the rural economy. Research efforts by the Lao-IRRI project spanning more than a decade have not identified realistic technologies to change the production technologies for rice production in upland environments given their socioeconomic circumstances. As long as rice production for home consumption remains the main objective, Lao slash-and-bum farmers will have only limited options to change their land-use practices.
2. The biophysical and socioeconomic environment in the Lao uplands is extremely heterogeneous. This paradoxical situation, with limited resources for research in a highly heterogeneous environment, requires rigorous priority setting. In spite of the wide range of conditions, many problems are universal, such as access to resources, access to markets, the challenge to change from slash-and-burn to mulching, and optimizing synergistic effects from integrating livestock and leguminous fallow/fodder

species. The limited resources for research should concentrate' on areas that will provide technologies that are widely applicable.

3. A high degree of self-sufficiency in food grains and high food security remain important objectives of the Ministry of Agriculture. ft will be important to maintain a realistic balance between efforts aimed at achieving food security and efforts aimed at providing equitable income for the rural population. When implementing subsidy systems and extension programs emphasizing food security, caution must be exercised to avoid long-term negative: effects on the evolution of production systems adapted to the given socioeconomic and 'biophysical conditions.
4. We have to be aware that technologies that are adopted under coercion, or with subsidy incentives, are unlikely to provide long-term solutions.
5. Future changes in land use will most probably be made based on economic incentives rather than on long term ecological concern by the individual farmers. Thus, economic incentives that promote ecological sustainability need to be provided.
6. To reduce environmental and market-related risks, emphasis will have to be given to production systems with high diversity.
7. Farm typology, using socioeconomic indicators (size of farm holding, slope classes, soil type, water availability, livestock, access to markets and inputs, and access to alternative sources of income) rather than ethnic identity, should be Used in discussions, for policy formulation,~ and in the planning and execution of development activities focusing on hill areas.
8. Although indigenous knowledge needs to be respected and incorporated into future activities, one has to also be aware of it limitations. Indigenous knowledge on slash-and-bum practices or on survival techniques during food shortages will be of limited help in the change to more sustainable production systems.

Key issues that need to be addressed to hasten the pace of transition and to achieve the goals of equitable income levels and better nutrition without hampering the biophysical resources include

- Policy issues, especially land tenure
- Human resource development (farmers, extensionists, and researchers)
- Identification/generation and transmission of technologies

Both research and extension will play important roles in transforming the existing production systems. Development options and research needs and priorities will differ according to local conditions. Future research programs need to be flexible, realistic, and simple. Depending on .the pace of changes, research needs and priorities may change rapidly. Most research will need participatory methods, yet there will be needs for other more conventional research methods.

Socioeconomic issues need to be given high priority. Some examples are

- How to empower the rural population to optimize benefits from changes in land tenure.
- Changes in cattle herding to allow the introduction of new production systems.
- Developing village-level associations for credit management, input procurement, and marketing.

Fahrney (1999) made recommendations for future research, focusing on rice production systems. Options are limited to increase rice production or labor productivity for rice production in the upland environment. Furthermore, in an evolving market-oriented system, rice will play a minor role at best and research on rice variety improvement, agronomy, or weed and pest management will yield limited benefits. Considering the limited resources, rice-related work should be limited. Improvements to rice-based systems such as increased rice yield and increased labor productivity will accrue through the incorporation of other components (especially forage/livestock rotations).

Soil conservation, soil fertility, residue management, and water management, all strongly interdependent, are the key issues to be addressed by interdisciplinary teams consisting of socioeconomists, agronomists, livestock specialists, soil scientists, and hydrologists. The key issue in the transformation of the existing system to an environmentally sound, market-oriented system is not the change from rice production using slash-and-burn methods to a plantation system, but the transition from burning biomass to a system of using the biomass for mulching or livestock production.

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