

Performance of Traditional and Improved Upland Rice Cultivars under Nonfertilized and Fertilized Conditions in Northern Laos

K. Saito,* G. N. Atlin, B. Linqvist, K. Phanthaboon, T. Shiraiwa, and T. Horie

ABSTRACT

Shortened fallows have reduced the productivity of traditional upland rice (*Oryza sativa* L.)-based slash-and-burn systems in northern Laos. New cultivars and management methods are needed for food security in the region. To assess their potential for increasing upland rice productivity, this study compared two improved and three traditional upland rice cultivars in three fertilizer treatments: no fertilizer, nitrogen (90 kg N/ha), and N plus phosphate (50 kg P/ha), in six trials over 2 yr. The two improved cultivars had consistently higher grain yields than the traditional cultivars across all fertilizer treatments (3.9 vs. 2.1 t/ha). The improved cultivars had greater total biomass and harvest index, more panicles, and were shorter than the traditional cultivars. They were also more responsive to N without applied P than traditional cultivars. Two of three traditional cultivars gave a response that was similar to the improved cultivars when both N and P were applied. In addition, on-farm trials were conducted at 13 locations to compare the productivity of the improved cultivars with fertilizer (N–P–K 60–26–50 kg/ha) to farmers' practice consisting of traditional cultivars without fertilizer. In these trials, the improved cultivars with fertilizer achieved much higher grain yields than farmers' practice (3.0 vs. 1.8 t/ha). Improved cultivars and moderate inorganic fertilizer application offer a new approach to increasing the productivity of upland rice in Laos.

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Abbreviations: ANOVA, analysis of variance; HI, harvest index; TDM, total dry matter.

GLOBAL RICE RESEARCH and development efforts have largely concentrated on lowland rice production systems, wherein rice is grown in banded fields that are kept flooded for most of the season. Improved rice cultivars, combined with inputs of fertilizer and irrigation, have contributed to great yield increases in lowland rice production systems in Asia (Evans, 1993). Although considerable research has been done on upland rice, the achievements and developmental impacts of this investment have been modest (Gupta and O'Toole, 1986; Roder, 1997; Piggin et al., 1998). This is particularly the case in Laos, which is a center of diversity for upland rice, and where upland rice is still a major staple food. While several improved lowland rice cultivars have been developed in Laos and are now widely grown on the Mekong floodplain, substantially improving farmers' livelihoods (Boualaphanh et al., 2001; Schiller et al., 2001), no improved upland rice cultivars have been released for the mountainous northern region of the country, where farmers continue to grow traditional cultivars. In this region, upland rice is typically grown without fertilizer in slash-and-burn systems by resource-poor farmers for subsistence

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purposes. It accounts for about half of the total rice area in the north, yielding 1.7 t/ha on average (National Statistical Center, 2004; Saito et al., 2006c). On-farm studies indicate that upland rice yields vary widely, ranging from almost nothing to more than 3 t/ha (Roder et al., 1995a; Saito et al., 2006c).

The low yield of upland rice has been attributed to infertile soils and heavy weed infestation due to increased cropping intensity, insufficient and irregular rainfall, and a lack of improved production technologies and high yielding cultivars (George et al., 2001; Piggin et al., 1998; Roder, 1997; Roder et al., 1997; Saito et al., 2006b). Rapid population growth and government policies aimed at protecting forests no longer permit traditional slash-and-burn management with long fallows and have resulted in increased cropping intensity. The result is that fallow periods of only 2 or 3 yr, which is in line with the current government land allocation policies, are common (Linguist et al., 2007). These short fallows are not sustainable using traditional management practices (Saito et al., 2006b) and the development of stable alternatives for these areas is necessary.

Traditional upland rice cultivars are generally tall, have few tillers, and are low yielding, but are suited to the long fallow slash-and-burn systems in northern Laos (Roder, 1997; Roder et al., 1996). Improved cultivars have not been considered to be feasible due to the greater amount of inputs required for high yields, as in the case for lowland rice in northeast Thailand (Wonprasaid et al., 1996). However, Saito et al. (2006a) reported that in both high- and low-yielding environments, improved upland rice cultivars performed better and had greater yield response to N than traditional cultivars that had been selected on the basis of yield and farmer preference in on-station and participatory variety selection trials from among more than 3,000 traditional accessions in northern Laos (Songyikhangsuthor et al., 2002). These improved cultivars were developed in Southeast Asia, and are often referred to as “aerobic rice” cultivars, because of their adaptation to nonsaturated soils. Aerobic rice cultivars are being developed for lowland environments with occasional water shortage or for favorable upland areas that receive high rainfall or supplementary irrigation (Atlin and Lafitte, 2002; Atlin et al., 2006; Bouman et al., 2005; George et al., 2002a). These rice cultivars are popular among farmers in other regions. For example, in Brazil, as a result of the development of aerobic rice cultivars, commercial, intensive upland rice-based cropping systems have spread widely (Pinheiro et al., 2006). Also, in mountainous regions of southern China, aerobic rice cultivars are grown on nonflooded terraces under intensive management, replacing the traditional upland rice-based slash-and-burn systems (Atlin et al., 2006). In Laos, the adoption of aerobic rice cultivars may be possible in favor-

able areas where soil moisture is adequate, the risk of soil erosion is less, and the response to fertilizer is high.

In the Laos study discussed above (Saito et al., 2006a), improved cultivars were only evaluated in a single year over three locations. The genotype by environment interaction for grain yield is often large relative to the effect of genotype in low yielding environments (Cooper et al., 1999). Thus, quantitative data across locations and years are required to evaluate the productivity and stability of these cultivars. Furthermore, there is little information available on the on-farm performance of improved cultivars with fertilizer inputs using farmer management. To address these issues, experiments were conducted with the following objectives: to identify cultivars with high yield potential under a range of fertility conditions; to describe the features of high yielding cultivars; and to determine if improved upland rice cultivars differ from traditional cultivars in response to fertilizer.

MATERIALS AND METHODS

Experiment 1

Rainfed upland rice experiments were conducted at three locations in Luang Prabang province in northern Laos in both 2004 and 2005 (Table 1). Weather data were only recorded at the Northern Regional Agriculture and Forestry Research Center (NAFRc). The management and results of the 2004 experiments were previously reported by Saito et al. (2006a). The 2005 trial conducted at NAFRc was adjacent to the location of the 2004 experiment and both trials were conducted on a hillside. The 2004 and 2005 experiments in Houayhia, both located on an upper part of a mountain, were within 1 km of each other. Each trial was conducted on a level area to minimize soil erosion that resulted in fertilizer losses. The experimental plots in Somsanuck (2004) and Mout (2005) were originally developed for lowland rice cultivation and represent relatively favorable lower-toposequence fields; however, lowland rice was not grown in them in the year before the experiment and the soil was never flooded during the experimental period. At NAFRc, Somsanuck, and Mout the soils were tilled before planting.

Experiments were designed with three fertilizer treatments (main plot) and five upland rice cultivars (subplot) in a split-plot design with three replications in each location. Fertilizer treatments were: (i) no added fertilizer (control), (ii) N fertilizer (90 kg N/ha; urea), and (iii) N and P fertilizer (50 kg P/ha; triple superphosphate) (NP; N as in treatment 2). The full amount of P and one-third of the N was applied at planting. The remaining N was applied equally at 30 and 60 d after planting. Nitrogen and P fertilizers were applied in 1- to 2-cm deep furrows along contours and between the rice hills and then covered with soil to minimize fertilizer losses. The five cultivars included three traditional cultivars from northern Laos (Vieng, Nok, and Makhinsung), one improved cultivar from the Philippines (IR55423-01) and one from Indonesia (B6144F-MR-6-0-0). Subplot size was 1.5 by 3 m. Rice was planted with a dibble stick, as is the traditional practice, at a hill spacing of 25 by 25 cm with about six seeds in each hill. Planting date varied and

Table 1. Description and soil properties of the Exp. 1 environments in Luang Prabang province, Laos.

Information	Location name (year of study)					
	NAFR _e C [†] (2004)	NAFR _e C [†] (2005)	Houayhia (2004)	Houayhia (2005)	Somsanuck (2004)	Mout (2005)
District name	Xiengngun	Xiengngun	Xiengngun	Xiengngun	Pak Ou	Xiengngun
Elevation (m)	330	330	605	630	320	325
Recent cropping history	3-yr fallow	Upland rice in the previous 2004 wet season	3-yr fallow	3-yr fallow	Upland rice in the previous 2003 wet season	Maize in the previous 2004 wet season
Landscape position	Hillside	Hillside	Upper part of mountain	Upper part of mountain	Terrace at the foot of mountain	Lowland rice paddy at the foot of mountain
Land preparation	Burning and tillage	Burning and tillage	Burning	Burning	Tillage	Tillage
Soil properties						
pH	5.9	5.4	5.5	5.7	5.8	6.0
Total C (g/kg)	13	13	21	25	23	12
Total N (g/kg)	1.9	1.9	2.3	2.2	1.9	1.6
Extractable P (mg/kg)	3.9	4.5	30.1	60.6	4.7	57.9
Available N (mg/kg)	11	17	34	26	21	14
Mean grain yields of traditional cultivars without fertilizer (t/ha) [‡]	1.1	1.1	2.3	2.1	1.5	3.3

[†]Northern Regional Agriculture and Forestry Research Center.

[‡]Grain yields were averaged over three traditional cultivars grown in three replications in each environment.

ranged from 10 May to 1 June. Weeds were controlled by hand when necessary.

At maturity, grain yields were measured from each plot after removing one border row on each side of the subplot (grain yields are reported at 14% moisture). Six rice hills were sampled from inside the harvested area for determination of plant height (culm and panicle length), panicle number, and grain and straw dry weight.

Soil samples were taken to a depth of 15 cm in each location at the time of rice planting. The samples were air-dried and sieved for soil analysis. Soil pH was determined in a 1:1 ratio of soil/water; extractable P using the Bray-2 method (Nanjo, 1997); total carbon and N using a trace mass spectrometer (Tracer MAT, Thermo Quest Co. Ltd., Tokyo); available NH₄-N by the indophenol method (Hidaka, 1997); and available NO₃-N by Griess-Ilosvay method after reduction to NO₂ (Hidaka, 1997).

An analysis of variance (ANOVA) was conducted on the combined data set across six environments (three trials × 2 yr) for grain yield, total dry matter (TDM), harvest index (HI), days to flowering, plant height, and panicle number using IRRI-STAT 4.4 (IRRI, 2003). In this analysis, we considered the effects of cultivar and fertilizer treatments fixed and the effect of environment random. The fixed effects of cultivar and fertilizer treatments, and their interaction, were tested against their respective interactions with environment. The mean square for the main effect of fertilizer treatment was partitioned into two single degree of freedom contrasts comparing the unfertilized control treatment with the N and NP treatments, and comparing the N treatment with the NP treatment. The mean square for the main effect of a cultivar was partitioned into a single degree of freedom contrast comparing traditional cultivars with improved cultivars. The mean square for cultivar × fertilizer interaction was partitioned into single degree of freedom contrasts for determining if response of improved cultivars to N and NP treatments differs from that of traditional cultivars

(control vs. N × traditional cultivars vs. improved cultivars; control vs. NP × traditional cultivars vs. improved cultivars), and if response of improved cultivars to P differs from that of traditional cultivars under N fertilized conditions (N vs. NP × traditional cultivars vs. improved cultivars).

Experiment 2

A traditional system (traditional cultivar without fertilizer) was compared to an improved cultivar (IR55423-01 or B6144F-MR-6-0-0) plus fertilizer in 11 farmers' fields in Luang Prabang Province (Xiengngun and Pak Ou districts) and in two fields at NAFReC in 2005. Treatments were not replicated within each field. Plot size ranged from 64 to 100 m². Fertilizer (N-P-K 60-26-50 kg/ha) was applied to improved cultivars once at 38 to 49 d after rice planting (after weeding). The fields were managed by the farmer (or at NAFReC according to farmers' normal practices), except for plot layout and fertilizer application. At maturity, rice was harvested from the whole plot to determine grain yield. Analyses of variance were conducted for combined data across the 13 locations for grain yield, using locations as replications.

RESULTS

Experiment 1

Average annual rainfall in the region is 1300 mm but has an erratic distribution. Rainfall was slightly lower than average in June 2005, but overall, rainfall was adequate during both the 2004 and 2005 growing seasons (Table 2). Minimum and maximum temperatures differed little between the 2 yr, but sunshine hours were low in August 2005.

The soils at both Houayhia locations were the most fertile, while the NAFReC soils were the least fertile (Table 1). Total soil carbon and N were lowest in NAFReC and Mout, and extractable soil P ranged from 4 to 61

Table 2. Wet season weather data expressed as means of daily values (temperature) or cumulative daily values (sunshine hour and rainfall) at the Northern Regional Agriculture and Forestry Research Center in Luang Prabang province, Laos, for 2004 and 2005.

Month	Temperature		Sunshine hour	Rain
	Min	Max		
	— °C —			mm
Wet season 2004				
May	23	33	131	241
June	23	32	93	182
July	23	31	102	221
August	23	32	93	190
September	22	31	112	175
October	19	29	115	31
Wet season 2005				
May	23	35	182	174
June	24	32	92	129
July	23	32	135	276
August	23	30	46	261
September	22	31	118	327
October	20	30	198	12

mg/kg. Large variation among upland soils is consistent with previous observations in northern Laos (Roder et al., 1995a,b). The mean grain yield of traditional cultivars with no fertilizer inputs ranged from 1.1 to 3.3 t/ha across environments (Table 1). Such variation in grain yield has been previously observed in the uplands and has been attributed to variation in soil fertility (Roder et al. (1995a,b); Saito et al., 2006b). High grain yields were associated with high extractable soil P, a finding that is consistent with others (George et al., 2001; Saito et al., 2006b).

Table 3. F ratios from the combined analysis of variance over six environments for grain yield, total dry matter (TDM), harvest index (HI), days to flowering, plant height, and panicle number for five rice cultivars evaluated under three fertilizer treatments in Exp. 1.

Source of variation	Degrees of freedom	Grain yield	TDM	HI	Days to flowering	Plant height	Panicle number
Environment	5	9.59**	11.38**	10.72**	54.79**	48.47**	7.19**
Fertilizer	2	4.31*	12.13**	3.89*	1.73ns	17.47**	7.90**
Control vs. N	1	2.27ns†	9.22*	7.30*	1.26ns	20.02**	9.62*
Control vs. NP	1	8.61*	23.79**	3.83ns	0.52ns	31.17**	13.72**
N vs. NP	1	2.04ns	3.39ns	0.56ns	3.40ns	1.23ns	0.36ns
Environment × fertilizer	10	1.74ns	1.31ns	1.83ns	1.74ns	1.73ns	2.19ns
Cultivar	4	21.25**	9.78**	25.02**	26.58**	53.61**	99.58**
Traditional cultivars vs. improved cultivars	1	82.29**	33.20**	85.27**	31.25**	140.65**	390.13**
Environment × cultivar	20	8.05**	5.75**	6.21**	8.37**	3.95**	3.21**
Fertilizer × cultivar	8	2.22*	4.31**	0.69ns	1.90ns	0.90ns	3.02*
Control vs. N × traditional cultivars vs. improved cultivars	1	10.30**	27.77**	2.78ns	5.98*	0.01ns	12.03**
Control vs. NP × traditional cultivars vs. improved cultivars	1	3.82ns	2.94ns	0.40ns	2.79ns	1.04ns	7.10*
N vs. NP × traditional cultivars vs. improved cultivars	1	1.58ns	12.64**	1.07ns	0.60ns	0.86ns	0.65ns
Environment × fertilizer × cultivar	40	1.21ns	0.59ns	2.02**	0.87ns	1.30ns	0.97ns

*Indicates significance of the F test at $p = 0.05$.

**Indicates significance of the F test at $p = 0.01$.

†ns, not significant.

Results of a combined ANOVA over the six environments for grain yield, TDM, HI, days to flowering, plant height, and panicle number are shown in Table 3. Fertilizer, cultivar and fertilizer × cultivar effects on grain yield, TDM, HI, plant height and panicle number were all significant; except for the effects of F on days to flowering, and fertilizer × cultivar on HI, days to flowering and plant height. The effect of cultivar was larger than that of fertilizer on all parameters except TDM.

There was a significant difference in grain yield between control and NP treatments, averaged over all cultivars. Differences in grain yields between control and N and between the N and NP treatments were not significant (Tables 3 and 4). Failure to detect these differences is due to a large cultivar × N interaction (Table 3); high soil variability [a common feature of slash-and-burn fields, as reported by Roder (2001)]; and environment × fertilizer interaction (environments where grain yields were high without fertilizer had a lower response to applied fertilizer) (Table 5). Nevertheless, there was a positive effect of fertilizer treatment on grain yield averaged over environments. In the combined analysis over environment and cultivar, N and NP fertilizer applications increased grain yields by 15% (a 0.4 t/ha increase) and 29% (a 0.7 t/ha increase), respectively. The difference in grain yields between the N and NP treatments was only 0.3 t/ha.

Grain yields of the two improved cultivars (IR55423-01, B6144F-MR-6-0-0) ranged from 1.8 to 6.0 t/ha (Fig. 1) and were, on average, 1.7 t/ha (82%) higher than traditional cultivars (Vieng, Nok, and Makhinsung), averaged over fertilizer treatments (Tables 3 and 4). Improved cultivars differed signifi-

cantly from traditional cultivars in all measured traits (Tables 3 and 4). Averaged over environments and fertilizer treatments, improved cultivars had higher TDM (9.0 vs. 6.6 t/ha), higher HI (0.37 vs. 0.28), higher panicle number (245 vs. 127 per m²) and were shorter than the traditional cultivars (115 vs. 131 cm). Contributions of TDM and HI to yield increases were analyzed using a $\ln(\text{Yield}) = \ln(\text{TDM}) + \ln(\text{HI})$ model. The analysis produced the relationship $\ln(\text{Yield}) = 1.01\ln(\text{TDM}) + 0.94\ln(\text{HI}) + 0.06$ ($p < 0.01$, $n = 5$). The standardized partial regression coefficients were 0.58 and 0.48 for TDM and HI, respectively, and the effects were independent, suggesting that TDM had a greater effect on grain yield than HI. Highly positive correlations between panicle number and grain yields were also found ($r^2 = 0.71$, $p < 0.01$, $n = 90$). The improved cultivars used in this study flowered, on average, 5 d earlier than the traditional cultivars.

There was a significant cultivar difference in response to N when P was not applied (Tables 3 and 6). Traditional cultivars were less responsive to N (grain yields increased by 7%) than were improved cultivars (grain yields increased by 22%). Nitrogen application increased TDM and panicle number of the improved cultivars by 35 and 18%, respectively, while increasing those of traditional cultivars by only 15 and 10%. For HI, there was no significant cultivar difference in response to N, suggesting that the increased grain yield of improved cultivars due to N application was associated with increased TDM and panicle number. Similar results have been reported for lowland rice (Khuntasuvon et al., 1998). There were no differences in response of improved and traditional cultivars to NP application relative to the control (no fertilizer) except for in panicle number (Tables 3 and 6). The yield response of two of the three traditional cultivars (Vieng and Nok) to the NP application was similar to that of the improved cultivars. The traditional cultivars had a significant TDM response to the addition of P under N-fertilized conditions, whereas the improved cultivars did not (Tables 3 and 6). The 22% increase in TDM in response to P application resulted in a 22% increase in grain yield in the traditional cultivars, although this increase was not significant at $p = 0.05$. Despite this, the improved cultivars had higher yield and TDM than traditional cultivars both with and without addition of P.

Table 4. Grain yield, total dry matter (TDM), harvest index (HI), days to flowering, plant height, and panicle number of six rice cultivars under three fertilizer treatments grown in six environments (Exp. 1).

	Grain yield	TDM	HI	Days to flowering	Plant height	Panicle number per m ²
	— t/ha —				cm	
Fertilizer						
Control	2.5	6.3	0.33	103	116	157
N	2.8	7.8	0.30	104	127	180
NP	3.2	8.7	0.31	103	130	185
Cultivar						
Vieng	1.8	5.9	0.26	105	125	129
Nok	2.3	6.5	0.31	99	129	133
Makhinsung	2.3	7.4	0.26	111	140	118
IR55423-01	3.9	8.9	0.38	100	109	234
B6144F-MR-6-0-0	3.9	9.2	0.36	100	120	255
LSD _{0.05} (fertilizer main effect)	0.54	1.11	0.024	ns	5.4	16.5
LSD _{0.05} (cultivar main effect)	0.62	1.38	0.032	2.70	4.6	19.3

Experiment 2

On-farm grain yields of the traditional system (traditional cultivar without fertilizer) ranged from 0.4 to 3.6 t/ha, compared to 1.8 to 4.5 t/ha for improved cultivar with fertilizer. Averaged over the 13 locations, the grain yield of improved cultivars with fertilizer was significantly higher than that of traditional system (3.0 vs. 1.8 t/ha; $p < 0.01$). The difference in grain yield between these two systems tended to be larger when grain yield of the traditional system was lower (Fig. 2). The largest yield differences (up to 2.5 t/ha) occurred when grain yields of the traditional system were lower than 1 t/ha, an effect similar to that found in Exp. 1. In Mout, where traditional cultivars had high grain yields under nonfertilized conditions, the yield difference between traditional cultivars and improved cultivars with fertilization was smaller than in the other five environments (Fig. 2). The difference in grain yields between traditional cultivars without fertilizer and improved cultivars with fertilizer in the other five environments in Exp. 1 was somewhat larger than that observed in Exp. 2, even when the yield level

Table 5. Grain yield at three fertilizer treatments averaged over five rice cultivars in six environments (Exp. 1).

	Grain yield						Mean
	NAFRcC (2004) [†]	NAFRcC (2005)	Houayhia (2004)	Houayhia (2005)	Somsanuck (2004)	Mout (2005)	
	— t/ha —						
Control	1.4	1.9	3.2	2.7	1.7	3.8	2.5
N	2.4	2.3	3.5	3.4	2.2	3.2	2.8
NP	3.2	3.4	3.4	3.4	2.3	3.5	3.2
PR > F	0.04	0.45	0.71	0.02	0.23	0.19	0.04
LSD _{0.05}	1.26	ns [‡]	ns	0.46	ns	ns	0.54

[†]The results of each environment were analyzed as single experiments using ANOVA. In this analysis, we considered the effects of cultivar and fertility treatments fixed.

[‡]ns, not significant.

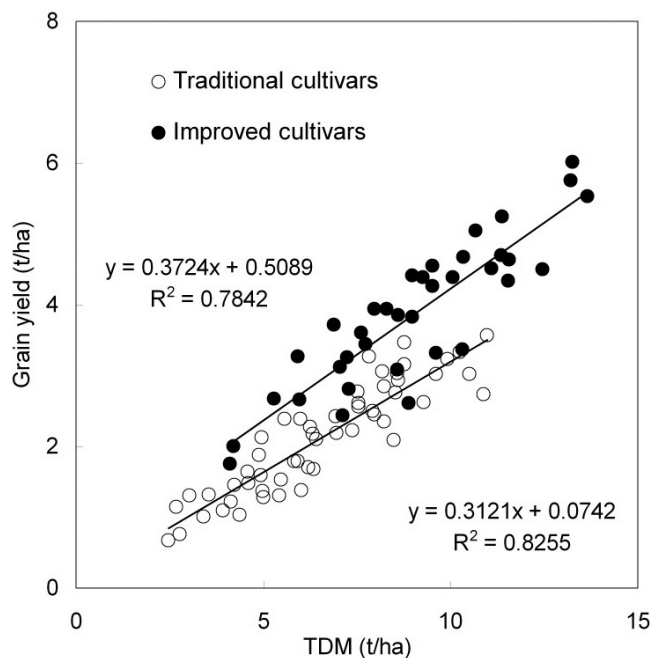


Figure 1. The relationship between grain yield and total dry matter (TDM) of two improved and three traditional cultivars grown under three fertilizer treatments in six environments. The regression lines are for averages of two improved and three traditional cultivars.

of traditional cultivars under nonfertilized conditions was similar between the two experiments. This may be partly due to differences in the amount of fertilizer applied, application method, timing of the application, and geographic conditions; Exp. 1 was conducted on flat fields, whereas most fields in Exp. 2 were sloping, which may have made fertilizer application less effective.

DISCUSSION

Improved cultivars, IR55423-01 and B6144F-MR-6-0-0, produced higher yields than traditional cultivars in both high and low fertility conditions, and the ranking for traditional and improved cultivars was stable across environments. These findings are in direct contradiction to the commonly-held belief that traditional cultivars are better-adapted to low-fertility conditions, and that high-yielding improved cultivars only outperform adapted traditional varieties in the presence of sufficient inputs. However, our results are consistent with results reported for upland rice in the Philippines by Atlin et al. (2006), for irrigated lowland rice in the Philippines by De Datta et al. (1968), for rainfed lowland rice in Laos by Inthapanya et al. (2000), and for lowland rice in Thailand by Romyen et al. (1998). The results of our study are also confirmed by on-farm participatory upland rice varietal selection in northern Laos, which showed that improved cv. IR55423-01 B6144F-MR-6-0-0 outyielded traditional local cultivars by about 50% under nonfertilized conditions (1.9 vs. 1.3 t/ha, unpublished data, 2005). Good performance of IR55423-01 in this study is consistent with previous

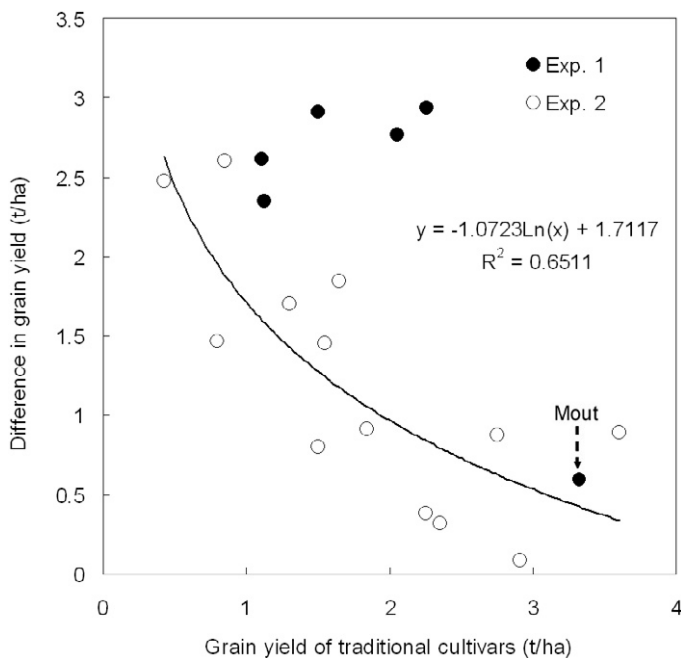


Figure 2. Relationship between the grain yield of traditional cultivars without fertilizer and the grain yield difference between improved cultivars with fertilizer and traditional cultivars without fertilizer. There were six environments in Exp. 1 (2004 and 2005) and 13 in Exp. 2 (2005). The regression line is for Exp. 2 data. The amount of fertilizer applied to improved cultivars was 90 kg N/ha plus 50 kg P/ha in Exp. 1. In Exp. 2, 60-26-50 kg/ha of N-P-K were applied.

studies in the Philippines (Atlin et al., 2006; George et al., 2001, 2002a; Lafitte et al., 2002; Bouman et al., 2005; Zhao et al., 2006). The high grain yield of B6144F-MR-6-0-0 is in contrast with Atlin and Lafitte (2002) and Lafitte et al. (2002) in the Philippines, but is consistent with results obtained in the Philippines (Zhao et al., 2006) and southern China (Atlin et al., 2006). The reason for contradictory results with this cultivar is probably its susceptibility to lodging. When it was grown under highly fertile, well-watered conditions, it lodged severely (Atlin and Lafitte, 2002). Similarly, in Exp. 1 in Mout, B6144F-MR-6-0-0 severely lodged in most of plots receiving N and NP fertilizer.

Higher grain yields of improved cultivars compared with traditional cultivars were associated with a 38% average increase in TDM and a 33% average increase in HI compared to traditional cultivars. The TDM had a greater effect on grain yield than HI in this study. This finding is in contrast with previous studies on lowland rice comparing semi-dwarf and traditional cultivars, which attributed improvement in yield potential to the increase in HI rather than to biomass production (Evans et al., 1984). Kawano (1990) noted, however, that although grain yield may be closely related to HI in high yielding environments, the importance of total biomass is greater in low yielding ones.

The HI of improved cultivars in this study is still lower than 0.50, which is usually observed for high-yielding

lowland rice. Also, there are reports that the high-yielding semi-dwarf hybrid Magat had higher HI (0.40–0.43) in aerobic experiments in the Philippines whereas its TDM was not significantly different from that of IR55423-01 (George et al., 2002a,b). This indicates that further improvement in grain yield might come from improving HI. Together with higher HI, the reduced plant height and greater panicle number of improved cultivars, compared with traditional cultivars, are important for high yield over the range of fertility conditions

observed in this study. This is consistent with Inthapanya et al. (2000), who showed that cultivars with higher HI tended to have high nutrient (N and P) use efficiency, and indicated that they are likely to perform well in different fertility conditions, including poor soils. Similarly, Atlin et al. (2006) reported that improved upland rice cultivars consistently had higher HI and panicle number than traditional tropical upland *japonica* cultivars across different water and fertility conditions, and that the improved cultivars outyielded the traditional ones. It seems possible that the reduced plant height of improved cultivars compared with traditional cultivars may make the cultivars less competitive against weeds, and that therefore the use of improved cultivars may increase labor input for weeding, which is one of major constraints to upland rice production in northern Laos (Roder et al., 1997). However, a recent study in the Philippines (Zhao et al., 2006) showed that improved cultivars, including IR55423-01 and B6144F-MR-6-0-0, tended to be more weed competitive than tropical *japonica* types under upland conditions. Caton et al. (2003) also showed the early vigor of B6144F-MR-6-0-0 under severe weed competition. Thus, introduction of improved cultivars like B6144F-MR-6-0-0 and IR55423-01 would not increase labor input for weeding and might reduce it, although further evaluation is needed to test this hypothesis.

There were significant cultivar differences in response only to N. Fertilizer N increased TDM, panicle number and grain yields of improved cultivars, but did not increase the grain yields of traditional cultivars. Others (De Datta et al., 1968; Gupta and O'Toole, 1986; Romyen et al., 1998) have also reported that improved cultivars are more responsive to N fertilizer than traditional cultivars. However, when comparisons were made between traditional and improved cultivars, there was no significant difference between the NP treatments and the control. This suggests that cultivar differences in response to N fertilizer depend on P availability. The lack of response of the traditional cultivars to only N, coupled with their response to NP, suggest that either P only or both N and P are responsible for the yield increase of the traditional cultivars when NP fertilizers are applied. Although we cannot

Table 6. Grain yield, total dry matter (TDM), and panicle number of five rice cultivars under three fertilizer treatments averaged over six environments (Exp. 1).

Cultivar	Grain yield			TDM			Panicle number		
	Control	N	NP	Control	N	NP	Control	N	NP
	t/ha						m ²		
Vieng	1.5	1.8	2.2	4.8	5.7	7.1	119	129	140
Nok	2.0	2.1	2.8	5.4	6.3	7.7	127	132	140
Makhinsung	2.1	2.2	2.4	6.6	7.2	8.5	104	124	126
IR55423-01	3.2	4.2	4.2	6.9	10.0	9.8	197	255	249
B6144F-MR-6-0-0	3.4	3.9	4.3	7.6	9.6	10.3	239	260	267
LSD _{0.05} (Fertilizer × cultivar interaction)	0.41			0.74			17.8		

distinguish between these alternatives based on the results of the present study (there was no “P only” treatment), previous research in northern Laos has shown only small yield responses of both traditional and improved upland rice cultivars to P fertilizer alone (George et al., 2001; Roder, 2001; Saito et al., 2006a). Thus, both N and P are likely to be limiting nutrients for the traditional cultivars while N appeared to be more limiting than P for the improved cultivars.

Large variability in on-farm grain yields of the traditional system had a strong influence on the efficiency of fertilizer applied with improved cultivars. The combination of improved cultivar with fertilizer inputs was more effective in fields where the traditional system produced poor yields, whereas it had much less effect at high-yielding locations (Fig. 2). This suggests that grain yields of traditional cultivars at low-yielding locations are strongly limited by low soil fertility, or that improved cultivars are more adapted to the low-yielding locations than traditional cultivars even without fertilizer. However, since there was not an “improved cultivar without fertilizer” treatment, we cannot distinguish between these two hypotheses.

Taken together, the results of these experiments suggest that improved cultivars can improve productivity either with or without fertilizer, a finding that is particularly important for resource-poor farmers who cannot afford fertilizers. Using improved cultivars with fertilizer would be most prudent in relatively flat locations as there is less risk of fertilizer loss due to erosion and soil water conditions may be more favorable. However, such areas in northern Laos are limited because most crops are grown on steep lands. An alternative to cropping on steep slopes is the construction of terraces, as has been done in parts of southern China (Atlin et al., 2006), however, this requires a significant investment in time and labor. Another issue is that an increase in grain yields achieved with the use of improved cultivars can result in greater nutrient withdrawal from the soil reserves and therefore a more rapid decline in soil fertility, since grain yields are often closely related to nutrient content of grain and total biomass (e.g., George et al., 2001;

Ohnishi et al., 1999). However, this is not always the case, as Fukai et al. (1999) and Inthapanya et al. (2000) reported that some high-yield lowland rice cultivars did not have greater nutrient uptake but higher internal nutrient use efficiency. Finally, the use of improved cultivars and fertilizer inputs should only be seen as a component to improved upland rice based cropping systems. Several researchers have reported that growing upland rice at high frequency or continuously in rotations, particularly on light-textured soils, has resulted in yield declines that cannot be mitigated either by fertilizer or improved cultivars (e.g., Bouman et al., 2005; George et al., 2002a; Pinheiro et al., 2006). Therefore, land-use management practices need to be developed for effective use of improved cultivars and fertilizer that take into account these potential problems.

It should also be noted that the improved cultivars evaluated in this study are nonglutinous, a quality type with limited acceptability to the major ethnic groups in northern Laos. For the potential productivity gains resulting from improved cultivars to be widely available to poor farmers in the region, improved glutinous cultivars with reasonable quality must be developed.

CONCLUSIONS

Improved upland rice cultivars consistently outyielded traditional cultivars in both high yielding and low yielding environments in northern Laos, where farmers have faced difficulty in maintaining or improving rice productivity in short-fallow slash-and-burn systems. Differences in yield response to N fertilizer between the improved and traditional cultivars depended on P availability. Improved cultivars were more responsive to N fertilizer without P fertilizer than traditional cultivars, whereas two out of three traditional cultivars responded similarly as the improved cultivars when both N and P were applied. These results suggest that the use of improved cultivars is a prerequisite for increased grain yields beyond the present levels as well as for increased efficiency of N fertilizer. Improved cultivars had greater total biomass and HI, more panicles, and were shorter than traditional cultivars. Using improved cultivars and moderate fertilizer inputs, Lao upland farmers could produce the same amount of rice on less land, thus freeing up marginal lands for more sustainable uses. However, for broad adoption of improved cultivars in northern Laos appropriate land-use management practices to sustain long-term soil quality and glutinous cultivars of acceptable quality must be developed.

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