Response of traditional and improved upland rice cultivars to N and P fertilizer in northern Laos

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Keywords: Fertilizer; Improved cultivar; Laos; Nitrogen; Slash-and-burn; Upland rice

1. Introduction

Upland rice is typically grown under slash-and-burn systems in the mountainous region of northern Laos by resource-poor farmers for subsistence. Upland rice cultivars are all traditional and no fertilizer inputs are used. In these systems, grain yields average only 1.7 t/ha. A multi-site experiment was conducted in Luang Prabang province to examine cultivar and fertilizer effects on grain yield. Three traditional and three improved cultivars were grown under four fertilizer treatments: no added fertilizer, nitrogen only (N; 90 kg N/ha), phosphate only (P; 50 kg P/ha), and N and P (NP) at three locations. No severe water stress developed at any location.

The two improved cultivars, IR55423-01 and B6144-MR-6-0-0 out-yielded traditional cultivars in all locations and fertilizer treatments. They had higher total dry matter and harvest index, lower plant height and more panicles than traditional cultivars. N fertilizer application increased grain yields of the two improved cultivars from 3.1 to 4.0 t/ha while increasing those of traditional cultivars from 1.6 to 1.9 t/ha. Applying only P gave no effect on grain yield, and applying P with N increased grain yield only by 0.5 t/ha over N application alone on average over all cultivars at all locations. However, there was cultivar and location difference in the yield response to P applied with N. Further studies are required on the genotype-by-environment interaction in the effect of P applied with N under upland conditions. These results indicate that upland rice cultivars with high HI, which have been selected under favorable conditions, can perform well under low fertility conditions but also respond well to applied N fertilizer.

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Abstract

Upland rice is typically grown under slash-and-burn systems in the mountainous regions of northern Laos by resource-poor farmers for subsistence. Upland rice cultivars are all traditional and no fertilizer inputs are used. In these systems, grain yields average only 1.7 t/ha. A multi-site experiment was conducted in Luang Prabang province to examine cultivar and fertilizer effects on grain yield. Three traditional and three improved cultivars were grown under four fertilizer treatments: no added fertilizer, nitrogen only (N; 90 kg N/ha), phosphate only (P; 50 kg P/ha), and N and P (NP) at three locations. No severe water stress developed at any location.

The two improved cultivars, IR55423-01 and B6144-MR-6-0-0 out-yielded traditional cultivars in all locations and fertilizer treatments. They had higher total dry matter and harvest index, lower plant height and more panicles than traditional cultivars. N fertilizer application increased grain yields of the two improved cultivars from 3.1 to 4.0 t/ha while increasing those of traditional cultivars from 1.6 to 1.9 t/ha. Applying only P gave no effect on grain yield, and applying P with N increased grain yield only by 0.5 t/ha over N application alone on average over all cultivars at all locations. However, there was cultivar and location difference in the yield response to P applied with N. Further studies are required on the genotype-by-environment interaction in the effect of P applied with N under upland conditions. These results indicate that upland rice cultivars with high HI, which have been selected under favorable conditions, can perform well under low fertility conditions but also respond well to applied N fertilizer.

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1. Introduction

Upland rice is typically grown without fertilization in slash-and-burn systems in the mountainous region of northern Laos by resource-poor farmers for subsistence. It yields an average of 1.7 t/ha versus 3.6 t/ha for wet season lowland rice, and accounts for about half of the total rice area in this region (National Statistical Center, 2004). Because of its low yield, upland rice is generally considered to be unsuitable for the intensive management practices aimed at high yields. However, the low yield of upland rice is largely a consequence of its production being limited to infertile or drought-prone uplands, and to low harvest index (HI) of traditional cultivars (George et al., 2001). Traditional cultivars are generally tall, have few tillers, and produce low but stable yields under unfavorable environments. They tend to lodge under favorable conditions and are thus not suited to high-input management. In northern Laos, no improved upland rice cultivars have yet been released. The Lao-IRRI project has screened over 3000 traditional accessions to identify those that are more productive and perform better under slash-and-burn systems with shortened fallow. Currently, through participatory varietal selection (PVS) trials conducted over 4 years, two traditional cultivars (Nok and Mak hin sung) have been identified which yield 0.3–0.5 t/ha more, on average, than local check cultivars (an 18–27% increase in yield) (Songyikhangsuthor et al., 2002;
Linquist et al., 2004). It is likely that little further improvement in yields can be achieved by selecting only among local traditional cultivars, and different approaches are required for further improving yields of upland rice. Improved, input-responsive upland rice cultivars have been developed in Southeast Asia which can achieve yields of more than 5 t/ha under relatively nutrient-rich and drought-free growing conditions (George et al., 2002). Improved upland cultivars have high HI relative to traditional cultivars (Atlin and Lafitte, 2002). But it is not known whether the cultivars are suitable for the uplands of northern Laos where traditional cultivars are considered to be adapted.

Nitrogen (N) and phosphate (P) deficiencies are the most important nutrient disorders in the upland conditions of northern Laos (Roder et al., 1995; George et al., 2001; Roder, 2001). Using traditional cultivars, various field fertilizer experiments have been conducted during 1991–2003 (Roder, 2001; Lao-IRRI, 1991–2003). These trials indicated that there was low response of traditional cultivars to N fertilizer application. Applying only P gave no effect on grain yields in spite of increased P uptake (George et al., 2001; Lao-IRRI annual report, 2003). These may indicate that the traditional cultivars are less responsive to N and P fertilizer application. However, little information is available on upland rice cultivar differences in response to N and P fertilization in Asia.

The objective of this study is to examine the effects of cultivar and N and P fertilization on grain yield in northern Laos, and to determine if improved, introduced upland rice cultivars differ from traditional cultivars in response to N and P fertilization. The experiment was conducted at three locations differing soil fertility in Luang Prabang province in 2004.

2. Materials and methods

Rainfed upland rice experiments were conducted at the Northern Agriculture and Forestry Research Center (Houay khot village in Xienggun district), and in two farmers’ fields (Somsanuck village in Pak Ou district and Houay hia village in Xienggun district) in Luang Prabang province in northern Laos. The experimental locations were typical of upland rice farming areas in northern Laos and general information for the three locations is presented in Table 1. Two of the three locations previously had a 3-year fallow, while at Somsanuck, upland rice was grown in the previous wet season. Each experiment was conducted on a level area to avoid soil erosion. The area in Somsanuck was terraced with bunds but rice was grown aerobically (i.e. dry-sown, in an unpuddled field without standing water). Average annual rainfall in this area is 1300 mm but has an erratic distribution. During 2004, rainfall was adequate without any extended dry spells. The amount of rainfall recorded from May 1 to October 31 at the Northern Agriculture and Forestry Research Center (Houay khot) was 1038 mm.

There were four fertilizer treatments (main-plot) and six upland rice cultivars (sub-plot) in a split-plot design within each location. Fertilizer treatments consisted of (1) no added fertilizer (control), (2) N fertilizer (90 kg N/ha; urea), (3) P fertilizer (50 kg P/ha; triple superphosphate), and (4) N and P fertilizer (NP; as in treatment 2 and 3). The full amount of P and one-third of N were applied at planting time. The remaining N was applied equally at 30 and 60 days after planting. N and P fertilizers were applied in 1–2 cm deep furrows along contours and between the rice hills and then were covered with soil to avoid fertilizer movement. The six cultivars included three traditional cultivars from northern Laos (Vieng, Nok, and Mak hin sung), two improved cultivars from the Philippines (IR71525-19-1-1 and IR55423-01), and one from Indonesia (B6144-MR-6-0-0). Vieng has historically been used as a variety check in northern Laos. As noted earlier, Nok and Mak hin sung have been identified as high-yielding traditional cultivars. IR71525-19-1-1 is an improved, drought-tolerant upland rice variety primarily of tropical japonica background, and performed well in an observation nursery in Luang Prabang in the 2003 wet season (Lao-IRRI, 2003). IR55423-01 is an elite indica-derived upland rice line developed at IRRI in the Philippines whose high yield potential has been previously reported (George et al., 2001; George et al., 2002). B6144-MR-6-0-0 is an improved indica cultivar developed in Indonesia (Atlin and Lafitte, 2002), and now widely grown as an upland rice cultivar in Yunnan province, southern China. These improved cultivars have all been selected under at least moderate levels of inputs (Atlin, G.N., personal communication, 2004).

There were three replications at each location, and sub-plot size was 1.5 m × 3 m. Hill spacing was 25 cm × 25 cm.

Table 1
Description of the experimental locations in Luang Prabang province, Laos

<table>
<thead>
<tr>
<th>Site information</th>
<th>Location</th>
<th>Somsanuck</th>
<th>Houay hia</th>
</tr>
</thead>
<tbody>
<tr>
<td>Elevation (m)</td>
<td>Houay khot</td>
<td>330</td>
<td>320</td>
</tr>
<tr>
<td>Recent cropping history</td>
<td>Three-year fallow</td>
<td>Upland rice in the previous 2003 wet season</td>
<td>Three-year fallow</td>
</tr>
<tr>
<td>Situation</td>
<td>Hillside</td>
<td>Terrace at the foot of mountain</td>
<td>Upper part of mountain</td>
</tr>
<tr>
<td>Land preparation</td>
<td>Burning and tillage</td>
<td>Tillage</td>
<td>Burning</td>
</tr>
<tr>
<td>Mean grain yields of traditional cultivars under no fertilization (t/ha)</td>
<td>1.1</td>
<td>1.5</td>
<td>2.3</td>
</tr>
</tbody>
</table>

* Traditional cultivars include Vieng, Nok, and Mak hin sung.
Approximately six seeds were placed in 3–5 cm deep holes made with a dibble stick following the traditional planting method. Planting date varied among locations from 10 to 19 May. Rice seedlings were transplanted into missing hills where rice did not germinate until 20 days after planting. Weeds were controlled when required.

At maturity, grain yields were measured from whole plots after removing one border row on each side of the sub-plot (grain yields are reported at 14% moisture). Six selected rice hills were sampled from inside the harvested area for determination of plant height, panicle number, and dry weight of grain and straw. There were no pest outbreaks, but brown spot disease did affect one replication of the N fertilizer application treatment in Somsanuck.

Soil samples were taken to a depth of 0–15 cm in each field at the time of rice planting. The samples were air-dried and sieved for soil analysis. Measurements were made of pH in a 1:1 ratio of soil/water and extractable P (Bray-2). Total carbon and N contents were analyzed with a tracer mass spectrometer (Tracer MAT, Thermo Quest Co. Ltd., Tokyo). Available N as NH₄-N was determined by the indophenol method (Hidaka, 1997) and as NO₃-N by Griess–Ilosvay method after reduction to NO₂ (Hidaka, 1997).

Analyses of variance were conducted for combined data across three locations for grain yield, total dry matter (TDM), HI, days to flowering, plant height, panicle number, and single grain mass using IRRISTAT 4.4 (IRRI, 2003). In this analysis, we considered the effects of location, cultivar, and fertility treatment to be fixed.

### 3. Results

The soil in Houay khot was the least fertile and in Houay hia the most fertile (Table 2). Total carbon content in Houay khot was relatively low. Total N content in Houay hia was higher than that in the other two locations. Extractable P content ranged widely from 4 to 30 mg/kg; such a large variation is consistent with previous observations in upland fields in northern Laos (Roder et al., 1995; George et al., 2001). Available N content in Houay hia was the highest, followed by Somsanuck. The mean grain yield of traditional cultivars (Vieng, Nok, and Mak hin sung) with no fertilizer inputs ranged from 1.1 to 2.3 t/ha between locations (Table 1). Such variation in grain yields of traditional cultivars has been previously observed in the uplands under slash-and-burn systems (Roder et al., 1995; Lao-IRRI, 2000, 2001), and can largely be attributed to soil fertility conditions. Grain yields in Houay hia, which had the most fertile soil, were higher than those in Houay khot, where soil fertility was the poorest, and Somsanuck, where rice was grown in the previous year. Roder et al. (1995) reported that soil organic matter and available N showed consistent association with grain yield of traditional upland rice. George et al. (2001) indicated that Mehlich-1 extractable P correlated with grain yield. Our results agree with those previous findings.

Results of analyses of variance combined for the three locations for grain yield, total dry matter (TDM), HI, days to flowering, plant height, panicle number, and single grain mass are shown in Table 3. The effects of fertilizer (F), cultivar (C), location-by-cultivar (L × C) and fertilizer-by-cultivar (F × C) on grain yield were highly significant. The effect of F on grain yield was smaller than that of C. The pattern for TDM was similar to that for grain yield with significant effect of C and L × C, while the effect of F × C was not significant (p = 0.065). For HI, L, C, and L × C effects were significant. Strong effects of C for days to flowering, plant height, panicle number, and grain mass were observed.

Grain yield, TDM, HI, days to flowering, plant height, panicle number and single grain mass of six cultivars under four fertilizer treatments grown at three locations are shown in Table 4. For the location main effect, grain yields and TDM were the highest in Houay hia, followed by Somsanuck. In the combined analysis over locations, N

### Table 2

<table>
<thead>
<tr>
<th>Source of variation</th>
<th>Houay khot</th>
<th>Somsanuck</th>
<th>Houay hia</th>
</tr>
</thead>
<tbody>
<tr>
<td>pH</td>
<td>5.9</td>
<td>5.8</td>
<td>5.5</td>
</tr>
<tr>
<td>Total C (g/kg)</td>
<td>13</td>
<td>23</td>
<td>21</td>
</tr>
<tr>
<td>Total N (g/kg)</td>
<td>1.9</td>
<td>1.9</td>
<td>2.3</td>
</tr>
<tr>
<td>Extractable P (mg/kg)</td>
<td>3.9</td>
<td>4.7</td>
<td>30.1</td>
</tr>
<tr>
<td>Available N (mg/kg)</td>
<td>11</td>
<td>21</td>
<td>34</td>
</tr>
</tbody>
</table>

### Table 3

<table>
<thead>
<tr>
<th>Source of variation</th>
<th>d.f.</th>
<th>Grain yield</th>
<th>TDM</th>
<th>HI</th>
<th>Days to flowering</th>
<th>Plant height</th>
<th>Panicle number</th>
<th>Single grain mass</th>
</tr>
</thead>
<tbody>
<tr>
<td>Location (L)</td>
<td>2</td>
<td>8.46*</td>
<td>6.12*</td>
<td>25.85**</td>
<td>17.19**</td>
<td>2.96 ns</td>
<td>2.74 ns</td>
<td>5.81*</td>
</tr>
<tr>
<td>Fertilizer (F)</td>
<td>3</td>
<td>7.64**</td>
<td>13.2*</td>
<td>1.80 ns</td>
<td>2.12 ns</td>
<td>21.45**</td>
<td>19.63**</td>
<td>1.26 ns</td>
</tr>
<tr>
<td>L × F</td>
<td>6</td>
<td>1.77 ns</td>
<td>1.43 ns</td>
<td>2.64 ns</td>
<td>2.16 ns</td>
<td>2.82*</td>
<td>2.95*</td>
<td>2.25 ns</td>
</tr>
<tr>
<td>Cultivar (C)</td>
<td>5</td>
<td>78.24**</td>
<td>26.23**</td>
<td>94.78**</td>
<td>147.37**</td>
<td>89.24**</td>
<td>168.37**</td>
<td>411.47**</td>
</tr>
<tr>
<td>L × C</td>
<td>10</td>
<td>12.75**</td>
<td>6.31**</td>
<td>6.97**</td>
<td>6.94**</td>
<td>3.49**</td>
<td>4.72**</td>
<td>8.68**</td>
</tr>
<tr>
<td>F × C</td>
<td>15</td>
<td>2.25*</td>
<td>1.67 ns</td>
<td>1.64 ns</td>
<td>1.48 ns</td>
<td>1.30 ns</td>
<td>1.36 ns</td>
<td>2.53**</td>
</tr>
<tr>
<td>L × F × C</td>
<td>30</td>
<td>0.90 ns</td>
<td>0.56 ns</td>
<td>2.13**</td>
<td>1.20 ns</td>
<td>1.16 ns</td>
<td>1.37 ns</td>
<td>0.74 ns</td>
</tr>
</tbody>
</table>

* Indicate significance of the F test at p = 0.05.

** Indicate significance of the F test at p = 0.01.
and NP fertilizer applications significantly increased grain yields by 29 and 51%, respectively. However, there was no significant difference in grain yield between the N and NP treatments (the difference was only 0.5 t/ha). Applying only P had no effect on grain yields. When the results of the locations were analyzed as single experiments, the effect of only N or P fertilizer application on grain yield did not reach significance at \( p = 0.05 \) at any location and the effect of NP fertilizer application was significant at only one location (Houay khot) (Table 5). The response of grain yields to N and NP applications was the highest in Houay khot. While applying only N gave a small effect on grain yields, NP fertilizer applications increased grain yields by 71% in Somsanuck (\( p = 0.19 \)). There was no significant difference in grain yields among four fertilizer treatments in Houay hia. These indicate that the response of grain yields to N and NP applications was probably affected by soil fertility. For example, there was a small response of grain yields to N and NP applications in Houay hia where soil fertility was the highest, and the higher response was observed in Houay khot where the soil fertility was the poorest. In Somsanuck, the low response of grain yields to N application might be affected by higher total C content and relatively high available N content. However, the location-by-fertilizer interaction on grain yield was only significant at \( p = 0.16 \), and some of the apparent differential response across sites may have been due to random plot error, which is high in upland rice trials. Little response of grain yields to only P application was consistent across all locations.

IR55423-01 and B6144-MR-6-0-0 were the highest-yielding cultivars averaged over locations and fertilizer treatments, followed by IR71525-19-1-1. Grain yields of these three improved cultivars were significantly higher than traditional cultivars (Vieng, Nok, and Mak hin sung). Superiority of these improved cultivars can be seen when the grain yield of each cultivar is plotted against the mean grain yield of the 12 environments (three locations and four fertilizer treatments); traditional cultivars performed poorly in all the environments (Fig. 1). The regression coefficient of 1.55 for the improved cultivars is particularly suitable for high-yielding environments, but these cultivars also are highest-yielding in the least productive environments.

Days to flowering varied from 93 to 109, but except for Mak hin sung and IR71525-19-1-1, there was no large

**Table 4**
Grain yield, total dry matter (TDM), harvest index (HI), days to flowering, plant height, panicle number and single grain mass of six cultivars under four fertilizer treatments grown at three locations in Luang Prabang province in Laos

<table>
<thead>
<tr>
<th>Location</th>
<th>Grain yield (t/ha)</th>
<th>TDM (t/ha)</th>
<th>HI</th>
<th>Days to flowering</th>
<th>Height (cm)</th>
<th>Panicle number per ha (x10^4)</th>
<th>Single grain mass (mg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Houay khot</td>
<td>2.1 a</td>
<td>5.4 a</td>
<td>0.33 b</td>
<td>97 a</td>
<td>87 a</td>
<td>162 a</td>
<td>31 a</td>
</tr>
<tr>
<td>Somsanuck</td>
<td>2.5 a</td>
<td>7.7 ab</td>
<td>0.27 a</td>
<td>101 b</td>
<td>97 a</td>
<td>109 a</td>
<td>29 b</td>
</tr>
<tr>
<td>Houay hia</td>
<td>3.5 b</td>
<td>8.3 b</td>
<td>0.33 b</td>
<td>102 b</td>
<td>97 a</td>
<td>184 a</td>
<td>30 ab</td>
</tr>
</tbody>
</table>

**Fertilizer**
- Control 2.2 a 5.9 a 0.32 a 101 a 87 a 157 a 30 a
- N 2.9 bc 7.9 b 0.30 a 101 a 99 b 184 b 30 a
- P 2.3 ab 6.1 a 0.32 a 101 a 88 a 159 a 30 a
- NP 3.4 c 9.2 c 0.31 a 99 a 103 b 192 b 31 a

**Cultivar**
- Vieng 1.7 a 5.6 a 0.26 a 103 d 98 d 126 b 32 d
- Nok 2.1 b 5.9 a 0.30 b 98 b 95 c 127 b 37 f
- Mak hin sung 2.1 b 7.1 b 0.25 a 109 e 110 e 112 a 35 e
- IR71525-19-1-1 3.0 c 7.4 b 0.35 c 93 a 91 b 190 c 29 c
- IR55423-01 3.6 d 8.8 c 0.35 c 100 c 80 a 242 d 24 a
- B6144-MR-6-0-0 3.7 d 8.9 c 0.36 c 99 bc 91 b 241 d 25 b

**LSD0.05 (location main effect)**
- 0.86 2.44 0.023 2.2 ns ns 1.1

**LSD0.05 (fertilizer main effect)**
- 0.57 1.28 ns ns 4.9 12.0 ns

**LSD0.05 (cultivar main effect)**
- 0.27 0.77 0.014 1.3 2.9 12.8 0.7

**Table 5**
Grain yield at four fertilizer treatments averaged over six cultivars (above) and that of six cultivars averaged over four fertilizer treatments (below) at three locations in Luang Prabang province in Laos

<table>
<thead>
<tr>
<th>Location</th>
<th>Grain yield (t/ha)</th>
<th>Fertilizer Treatment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Houay khot</td>
<td>2.1 a</td>
<td>Control</td>
</tr>
<tr>
<td>Somsanuck</td>
<td>2.5 a</td>
<td>N</td>
</tr>
<tr>
<td>Houay hia</td>
<td>3.5 b</td>
<td>P</td>
</tr>
</tbody>
</table>

**Fertilizer**
- Control 1.4 2.0 3.3
- N 2.6 2.3 3.8
- P 1.3 2.3 3.4
- NP 3.1 3.3 3.6

**Cultivar**
- Vieng 1.8 1.6 1.7
- Nok 1.7 2.0 2.5
- Mak hin sung 1.5 2.3 2.4
- IR71525-19-1-1 2.2 2.6 4.2
- IR55423-01 2.8 3.4 4.7
- B6144-MR-6-0-0 2.6 3.1 5.5

**LSD0.05 (L × F interaction)**
- ns

**LSD0.05 (L × C interaction)**
- 0.48

*Significant level at \( p = 0.16 \).
difference among other cultivars. IR71525-19-1-1, IR55423-01, and B6144-MR-6-0-0 produced higher TDM than traditional cultivars did, and higher dry matter partitioning to grain in the three improved cultivars can be seen (Table 4, Fig. 2). For example, when TDM was 8 t/ha, predicted grain yield from fitted regression was 2.9 t/ha in Nok, 2.3 t/ha in Mak hin sung and 3.3 t/ha in IR71525-19-1-1, IR55423-01, and B6144-MR-6-0-0, respectively. In Fig. 2, there was no indication that HI declined at higher TDM levels either in traditional or improved cultivars. Although traditional cultivars generally tend to lodge under favorable conditions, and especially under well-fertilized conditions, no traditional cultivars lodged in this study, while B6144-MR-6-0-0 lodged in only two plots at three locations. IR71525-19-1-1, IR55423-01, and B6144-MR-6-0-0 which produced higher TDM and had higher HI, lower plant height, more panicles, and smaller grain mass than did traditional cultivars. Traditional cultivars, Nok and Mak hin sung produced higher grain yield than Vieng did. Nok had higher HI than Vieng, while there was no difference in TDM between these two cultivars. There was no difference in HI between Mak hin sung and Vieng, however, Mak hin sung produced higher TDM than Vieng did.

Grain yields of six cultivars on average for four fertilizer treatments are shown for the three individual locations in Table 5. Grain yield of B6144-MR-6-0-0 was not different from IR71525-19-1-1 and IR55423-01 in Houay khot, but was significantly higher in Houay hia. While grain yield of Vieng was similar to that of Nok and Mak hin sung in Houay hia, it was less in Houay hia.

There was a significant cultivar difference in response to N and NP applications (Table 6). Traditional cultivars were less responsive to N application, and grain yields of the traditional cultivars were increased by only 16% with N application (a 0.1–0.4 t/ha increase in grain yield). Grain yields of improved cultivars (IR71525-19-1-1, IR55423-01, and B6144-MR-6-0-0) were increased by 37% with N application (a 0.9–1.2 t/ha increase in grain yield).

The more responsive cultivars to NP application were Nok, IR71525-19-1-1, IR55423-01, and B6144-MR-6-0-0 (a 1.3–1.5 t/ha increase in grain yield) and the less responsive were Vieng and Mak hin sung (a 0.8 and 0.6 t/ha increase in grain yield, respectively). The increase in grain yield was associated with HI; the more responsive cultivars had higher HI than the others did (0.3–0.36 versus 0.25–0.26) (Table 3). While there was no significant difference in grain yields among traditional cultivars under no fertilizer and N application conditions, Nok produced higher grain yield with NP application than did Vieng and Mak hin sung. Comparing with N and NP applications, grain yields of the two improved cultivars (IR71525-19-1-1 and IR55423-01) with NP application were similar to those with N application but grain yields of B6144-MR-6-0-0 significantly increased with P application under N fertilization.

Table 6
Grain yield of six cultivars under four fertilizer treatments on average for three locations in Luang Prabang province in Laos

<table>
<thead>
<tr>
<th>Grain yield (t/ha)</th>
<th>Control</th>
<th>N</th>
<th>P</th>
<th>NP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vieng</td>
<td>1.3</td>
<td>1.7</td>
<td>1.7</td>
<td>2.1</td>
</tr>
<tr>
<td>Nok</td>
<td>1.8</td>
<td>1.8</td>
<td>1.6</td>
<td>3.2</td>
</tr>
<tr>
<td>Mak hin sung</td>
<td>1.8</td>
<td>2.1</td>
<td>2.0</td>
<td>2.4</td>
</tr>
<tr>
<td>IR71525-19-1-1</td>
<td>2.4</td>
<td>3.6</td>
<td>2.4</td>
<td>3.6</td>
</tr>
<tr>
<td>IR55423-01</td>
<td>3.0</td>
<td>4.0</td>
<td>3.2</td>
<td>4.3</td>
</tr>
<tr>
<td>B6144-MR-6-0-0</td>
<td>3.2</td>
<td>4.0</td>
<td>3.1</td>
<td>4.6</td>
</tr>
</tbody>
</table>

LSD0.05 (F × C interaction) 0.55
4. Discussion

While there were significant location-by-cultivar and fertilizer-by-cultivar interactions for grain yield, two improved cultivars, IR55423-01 and B6144-MR-6-0-0, out-yielded traditional cultivars including Nok and Mak hin sung, which have been identified as high-yielding cultivars (Songyikangauthor et al., 2002; Linquist et al., 2004), across all locations and fertilizer treatments (Tables 4–6, and Fig. 1). Grain yields of traditional cultivars ranged from 1 to 3 t/ha in this study, similar to the current yield level on farm with no fertilization (Roder et al., 1995; Lao-IRRI, 2000, 2001). Therefore, our results suggest that cultivars selected under favorable conditions (under at least moderate levels of inputs) would perform well under most conditions in northern Laos. This result is consistent with Romyen et al. (1998), who found consistent cultivar ranking for grain yield in most lowland rice environments in Thailand, particularly under high yielding conditions. Grain yields of IR55423-01 and B6144-MR-6-0-0 approached 5 t/ha when water was not limiting (Fig. 1). Good performance of IR55423-01 under nutrient-rich and drought-free growing conditions has been already demonstrated in the Philippines (George et al., 2001, 2002; Lafitte et al., 2002). The high grain yield of B6144-MR-6-0-0 in this study is contrast with Atlin and Lafitte (2002) and Lafitte et al. (2002) in the Philippines, but is consistent with results obtained in southern China (Atlin et al., in press). Several authors have also reported upland rice yields of 5 t/ha or more in Brazil (Pinheiro and de Castro, 2000), northern China (Wang et al., 2002) and southern China (Atlin, G., personal communication, 2004). Case studies in northern China showed that grain yields of improved cultivars varied from 4.5 to 6.5 t/ha, which was about double that of traditional upland cultivars (Wang et al., 2002). While irrigation is common in upland rice production in Brazil and northern China, upland rice in northern Laos is grown under rainfed condition. Water stress is one of the main production-limiting factors for upland rice productivity (Roder et al., 1996; Schiller et al., 2001), and it is not known how IR55423-01 and B6144-MR-6-0-0 would perform under water stress.

Higher grain yields of IR55423-01 and B6144-MR-6-0-0 compared with traditional cultivars were associated with a 43% increase in average TDM and a 31% increase in average HI (0.36 versus 0.27) compared to traditional cultivars (Table 4 and Fig. 1). However, HI of IR55423-01 and B6144-MR-6-0-0 is still lower than 0.50, which is usually observed for high-yielding lowland paddy. More research is necessary for identifying improved germplasm with higher partitioning of dry matter to grain for increasing rice yields. In addition, IR55423-01 and B6144-MR-6-0-0 had lower plant height, more panicles and smaller grain mass than did traditional cultivars. These characters together with higher HI are considered to be important for cultivars to respond positively to higher soil fertility conditions. This agreed with results on rainfed lowland rice reported by Inthapanya et al. (2000), who suggested that cultivars with high HI are likely to perform well in different soil fertility conditions. Vose (1990) indicated that modern cultivars with high HI are often more efficient in nutrient use (the ratio of grain yield to nutrient uptake), and hence, may perform better than traditional cultivars in all environments including low input conditions. High-yielding upland cultivars under high-input conditions are characterized by moderate panicle number in Philippine (300 panicles/m²) and tillering number in Brazil (250 tillers/m²), and by higher HI and intermediate height in Philippine, Brazil, and northern China (Atlin and Lafitte, 2002; Pinheiro and de Castro, 2000; Wang et al., 2002). Their results and ours suggest that these characters are important for cultivars which can adapt not only to high-input irrigated systems but also to conventional low-input systems which produce 1–3 t/ha of grain yield with traditional cultivars.

There was significant cultivar difference in response to N application. Improved cultivars with higher HI tended to be more responsive to N application. This result confirms previous reports (De Datta et al., 1968; Gupta and O’Toole, 1986; Romyen et al., 1998), showing greater responsiveness of improved cultivars to N fertilizer application than traditional cultivars.

Our results indicate that the response of upland rice cultivars to P application depends on N status. The lack of grain yield response to P application alone is consistent with George et al. (2001), who reported that application of P only had little effect on grain yield in spite of increased P uptake. In contrast, the cultivar differences in response to additional P under N application condition in this study is consistent with those studies in Brazil (Fageria et al., 1988) and West Africa (Sahrawat et al., 1995). Fageria et al. (1988) indicated that genotypic variation in total P uptake and physiological P use efficiency existed among upland rice cultivars, and that total P uptake was related to TDM. The study on rainfed lowland rice showed that additional P application (K was also applied with P in the study) under N fertilized condition increased total N uptake as well as grain yield, and indicated that genotypic variation in yield response to applied N, P, or NPK fertilizer was closely related to the variation in the total N more than P uptake response (Inthapanya et al., 2001). Inthapanya et al. (2000) indicated that cultivar difference in physiological nutrient use efficiency contributed to that in grain yield. George et al. (2001) reported that yield increases from P application were not always large even for improved upland cultivars (including IR55423-01) grown at high N input despite increased P uptake, which may indicate low physiological P use efficiency in these cultivars. These results suggest that the genotypic difference in response of grain yields to P application in this study may be attributed to the difference in nutrient uptake (N and P) and physiological nutrient use efficiency. However, in the current study, no data are available on plant N and P uptake or on soil N and P dynamics in upland rice culture in northern Laos. Therefore,
the exact mechanism that brought the genotypic difference in yield response to P is the subject for further studies.

Grain yield responded to N fertilizer application at the rate of 2.8 and 11.6 kg grain/kg N applied for traditional and improved cultivars in this study, respectively (Table 6). Estimate of N/rice price ratio in Laos is about 6.3 ($ 0.76/kg fertilizer N and $ 0.12/kg unhulled rice), and thus, the application of N appears profitable only for improved cultivars. Grain yield responded to NP application with a 0.6–1.5 t/ha increase, depending on cultivars in this study (Table 6). From the current price of N and P fertilizer, the application can be economical if grain yield is increased by 1.3 t/ha ($ 1.74/kg fertilizer P). Thus, P fertilizer application in addition with N is profitable for Nok and B6144-MR-6-0-0. Although NP application is less profitable than N application alone except for Nok, the economics of P application with N would be even better if the increased residual P fertilizer is accounted for in the analysis. Upland rice grown in the subsequent season responded to residual P fertilizer applied in the previous year (George et al., 2001; Sahrawat et al., 1997). Our experiment was conducted in the leveled areas to avoid fertilizer movement. In northern Laos, however, most upland fields are situated on slopes of 15–60% (Roder, 2001) and upland farmers with limited resources may not afford to purchase fertilizer, which make fertilizer application difficult under such situations. It may be more practical to increase soil N and P by introducing fallow crops of fast-growing leguminous species in place of natural fallow than to apply fertilizers. They should not normally be used in northern Laos but dry spells often occur in early growing season. Such water stress may make fertilization ineffective. However, Boonjung and Fukai (1996) showed, in an upland rice experiment in Australia, that when drought occurred during vegetative stages, it had only a small effect on subsequent development and grain yield under high fertilized condition. Prasertsak and Fukai (1997) reported that rice plants at high N application suffered from severe water stress during vegetation stage, but after rewatering they took up N rapidly and produced a higher yield than those at lower N application. Although there is such information from the experiments in relatively dry conditions, further research is needed on quantification of profitability of fertilizer application to highly fertilizer-responsive cultivars in northern Laos where the physical (climate, soil) environments are diverse.

It should also be pointed out that glutinous rice with specific grain quality is preferred by upland rice farmers in northern Laos (Roder et al., 1996; Songyikhangsauthor et al., 2002; Linquist et al., 2004). While the traditional cultivars used in this study were glutinous and large grain type, the improved cultivars were non-glutinous and small grain type. Further research will be needed to examine if these improved cultivars are acceptable for farmers. If they are not, they may be used as parents in upland rice breeding programs to ensure that high yielding cultivars also meet the high grain quality standards.

5. Conclusions

In northern Laos, grain yield of upland rice can be increased with cultivar improvement and fertilization if water stress does not develop. IR55423-01 and B6144-MR-6-0-0 out-yielded traditional cultivars in all locations and fertilizer treatments, indicating that upland rice cultivars which have been selected under favorable conditions are likely to perform well not only under high input management but also different soil fertility conditions with low-input. They had higher total dry matter and harvest index, lower plant height and more panicles than traditional cultivars. These characters are considered to be important for cultivars with increased yields. Further approaches are required to test these cultivars under unfavorable conditions, such as water limited condition.

In the combined analysis over locations, the improved cultivars responded better to N application than the traditional cultivars did, which confirmed the previous studies on the rice crop. There was a significant cultivar difference in response to NP application while P only application gave no effect on grain yields. The results indicate that the response of upland rice cultivars to P application depends on N status. The cause for the cultivar-by-fertilizer interaction for grain yield is not known, and should be identified for developing improved germplasm with greater responsiveness to P application.

Reference


