Yields from Rice Plants Cultivated under Tree Canopies in Rainfed Paddy Fields on the Central Plain of Laos

Shuichi Miyagawa¹, Maki Seko¹, Mari Harada¹ and Sengdeaune Sivilay²

¹Faculty of Applied Biological Science, Gifu University, 1-1 Yanagido, Gifu 501-1193, Japan;
²National Agriculture and Forestry Research Institute, Vientiane, Lao P.D.R.

Abstract: Many trees are left uncut in the paddy fields of many villagers in central Laos. Yields of rice in rainfed paddy fields interspersed with trees in central Laos were investigated in relation to shading and soil fertility from trees. Grain yield of rice plants cultivated in close proximity to tree trunks (CTP) was higher than that of the plants cultivated far away from the tree trunks (FTP) in 5 fields but lower in 7 fields. The effects of individual trees on rice yield varied among trees of the same species over the course of the three-year study period. No relationship was observed between the changes in photosynthetic photon flux density (PPFD) due to interception by the tree and the ratio of grain yield of CTP to that of FTP. A significant negative relationship was observed between grain yield of FTP and the ratio of grain yield of CTP to that of FTP, suggesting that yield of CTP under some trees is not lower than that of FTP when the latter was low.

Key words: Distance from tree, Light intensity, Rice production forest, Shading, Yield components.

In Laos and Thailand, rainfed paddy fields occupied by trees left uncut are a characteristic feature of the landscape. This landscape, particularly that in Northeast Thailand, has attracted considerable attention from geographers (Pendleton, 1943). Takaya and Tomosugi (1972) described the “rice production forests” in Northeast Thailand as being a transitional phase of land reclamation from forest to paddy field. According to Watanabe et al. (1990), the tree density in these environments ranged from 30 to 149 ha⁻¹, and the average diameter at breast height (DBH) of trees ranged from 30 to 42 cm. Fifty-four tree species were identified by Grandstaff et al. (1986), and almost all of these species are used by villagers in some way to support their livelihood (Pendleton, 1943; Grandstaff et al., 1986; Prachaiyo, 2000). In addition, farmers believe that these trees also increase the fertility of the soil (Pendleton, 1943). Indeed, Vityakon and Danthaisong (2005) demonstrated that the leaf litter from the trees increased the supply of carbon (C), nitrogen (N), phosphorus (P), potassium (K), calcium (Ca) and magnesium (Mg) in the soil and that the organic matter content and total N, P and K in the topsoil were higher in paddies with a high tree density than in paddies with fewer or no trees. Sae-Lee et al. (1992) showed that soil fertility was higher near the base of the trees, while grain yield, biomass, tiller number, and quantity of mature grains were higher at positions farther from the tree due to shading by the tree. A similar increase in crop yield of plants far away from tree base was reported by Vityakon et al. (1993). However, the extent to which sunlight is intercepted by the tree canopies was not examined in these studies.

In Thailand, the rainfed paddies in central and southern Laos are also characterized by trees that stand singly or in small groups (Kosaka et al., 2006a; Miyagawa et al., 2007; Matsusita et al., 2011; Natuhara et al., 2011). Previous studies showed that paddies in three villages in central Laos and three villages in southern Laos had 137 and 61 woody species, respectively, and all of the trees were used by the villagers for a variety of purposes (Kosaka et al., 2006b; Natuhara et al., 2011). However, little information has been published to date on the effects of trees on rice growth and yield.

In the rainfed paddy fields in Laos, low soil fertility combined with fluctuations in annual rainfall and
variations in topography have resulted in low yields that vary considerably among field parcels (Sipaseuth et al., 2001; Tsubo et al., 2006; Adachi et al., 2010). When the trees in paddy fields become significant obstacles to rice yield, as reported in northeast Thailand (Sae-Lee et al., 1992; Vityakon et al., 1993), trees need to be thinned to advance rice production. National demand for lowland rice has increased recently in Laos, while the production of dry-season irrigated rice is decreasing, which has been expected to lead to increased rice production (Haefele et al., 2006). Almost all wet-season rice is still produced in rainfed paddy fields because the adoption of irrigation-based systems is typically very expensive (Adachi et al., 2010). Consequently, factors affecting rice growth and yield in rainfed paddy fields should be examined in order to improve the rice production in these areas. The objectives of the current study were therefore to clarify the effects that trees have on the growth and yield of rice in rainfed paddy fields in Laos.

**Materials and Methods**

1. **Study site**

   This study was conducted in Dong Khuai village (18°01’N, 102°48’E) in the Vientiane municipality, Lao P.D.R. from 2006 to 2009. The village, which is believed to be more than 150 years old, is typical of the rainfed rice-growing villages on the Vientiane Plain. The village occupies an area of 2528 ha, 820 ha of which are paddy fields (Adachi et al. 2010). A 134.8 ha (6883 field parcels) area of paddy fields located on gently sloping land near the village was selected for the present study. The paddy fields were partially surrounded by forest, with the main settlement located 171 – 175 m above sea level (ASL) on the higher areas of the plain. The lowest-lying paddy fields (166 m ASL) were close to a tributary of the Mekong River. A total of 837 trees with DBH greater than 10 cm were counted in the area (on average 6 trees ha⁻¹). A total of nine, seven and 14 rice cultivars were planted in the paddy fields of the study area in 2007, 2008 and 2009, respectively. Planting took place in early July – early August in 2007, and late June – late July in 2008 and 2009. Paddy fields were dressed with fertilizer in 64, 60 and 73% of the field parcels around trees investigated in 2007, 2008 and 2009, respectively. None of the farmers changed the amount of fertilizer based on the proximity of the trees to the rice plants. Table 1 shows the monthly precipitation measured at the National Agriculture Research Center, which is located about 10 km north of the village. In 2008, precipitation was greater than in other years, much in the early half of the rainy season and raised the water level of the Mekong River causing flooding in lower paddy fields near the tributary.

### Table 1. Monthly precipitation (mm) in rainy season measured at the National Agricultural Research Center.

| Year | April | May | June | July | August | September | October | November | Total |
|------|-------|-----|------|------|--------|-----------|---------|----------|-------|
| 2007 | 5     | 19  | 339  | 146  | 270    | 396       | 272     | 2        | 1448  |
| 2008 | 155   | 347 | 406  | 289  | 298    | 113       | 199     | 90       | 1966  |
| 2009 | 10    | 183 | 328  | 505  | 228    | 253       | 77      | 5        | 1589  |

### Table 2. Names of 10 tree species studied in Dong Khuai village, Lao P.D.R..

| Local name | Scientific name | Family | Abbreviation |
|------------|----------------|--------|--------------|
| Kokchan    | Butea monosperma (Lmk.) Taub. | Leguminosae | Bm |
| Koksabaeng | Dipterocarpus intricatus Dyer | Dipterocarpus | Di |
| Koksat     | Dipterocarpus obtusifolius Teysm. ex Miq. | Dipterocarpus | Do |
| Kokkoung   | Dipterocarpus tuberculatus Roxb. | Dipterocarpus | Dt |
| Kokpho     | Ficus religiosa L. | Moraceae | Fr |
| Kokbok     | Irvingia malayana Oliver ex A. Benn. | Irvingiaceae | Im |
| Koknyo     | Morinda tomentosa Heyne | Rubiaceae | Mt |
| Kokwaa     | Syzygium sp. | Myrtaceae | Sy |
| Koksueak   | Terminalia alata Heyne ex Roth | Combretaceae | Ta |
| Kokkham    | Tamarindus indica L. | Leguminosae | Ti |
with the crown size of trees from 4 m to 20 m. CTP was 1 m from the tree trunk. PPFD was measured once per tree around noon on 9 – 11 August 2007, 16 – 21 June 2008 and 25 – 28 June 2009 using a quantum light sensor (366816 Quantum Light 6 Sensor Bar connected to 3415FX Light Sensor Reader, Spectrum Technologies, Inc.), with eight replications on each location. The degree of canopy openness was calculated using a black-and-white hemispherical image captured by a camera fitted with a fisheye lens positioned at 1 m from the tree trunk in June 2009. The electrical conductivity (EC) of the topsoil around trees in paddy fields was measured in triplicate using an EC meter (EC110M, Spectrum Technologies, Inc.) at eight positions of CTP and at eight positions of FTP in June 2008, before the rice was planted. Yield surveys were conducted during the harvesting season from early to late October in 2007 and 2008 and from early October to early November in 2009. Rice was harvested from a 0.5 m × 0.5 m area at 4 sites of CTP and at 4 sites of FTP (Table 3). Grain yields from rice plants around 29, 20 and 35 trees were measured in 2007, 2008 and 2009, respectively. The yields of plants from flooded paddy fields were not assessed in 2008.

The locations, rice varieties and cultivation practices of the paddy fields all differed from each other, even when the same tree species were examined. Furthermore, because fewer than three sample trees could be examined for some species, statistical analysis was performed at the level of the tree which is shown as tree number in Table 4 – 6, and not at the level of the species. Significant differences between the average data of CTP and FTP in rice grain yield, the number of spikelets and percentage of ripening grains were tested by one-way analysis of variance for each tree or all trees in each year, where CTP and FTP were the factors and the data from 4 sites around tree were the sample.

Thirty farmers who had been engaged in rice cultivation for many years were interviewed to learn which trees they thought had good or bad effects on rice growth and yield in 2006.

Results and Discussion

1. Tree size and rice production

The sampled trees had an average height of 11.8 m, a DBH of 54.5 cm, a crown thickness of 9.6 m, a crown area of 58.1 m², and the degree of canopy openness was approximately 60.2% (Table 3). Of the trees surveyed, Tamarindus indica L. (Ti) and Syzygium sp. (Sy) were relatively small, and Ficus religiosa L. (Fr) were the largest. There was a significant correlation between tree height and DBH ($r = 0.573$, $p < 0.01$), but the correlation between tree height and crown area was a little weaker ($r = 0.486$, $p < 0.05$). While there was a significant correlation between crown area and the degree of canopy openness ($r = -0.648$, $p < 0.01$) in all sampled trees, this apparent correlation was not recognized whenFr was excluded ($r = -0.234$, $p > 0.05$). These findings suggest that, except for extremely large trees like Fr, size of crown area was not particularly well suited for use as an indicator of sunlight interception by trees.

Assuming that the DBH and canopy area of the sampled trees are equivalent on the average over those of all trees in the study area, the area occupied by tree trunk and canopy may be 1.4 m² ha⁻¹ (0.01%) and 348.6 m² ha⁻¹ (3.5%), respectively. Therefore standing trees do not seem to be severe obstacles to rice production in this village regarding the area of rice cultivation.

2. Yield and yield components

As Table 4 shows, the average yields of FTP were 243.8, 185.6 and 172.7 g m⁻² in 2007, 2008 and 2009, respectively, which were similar to the values obtained in the same village in 2005 (242.3 g m⁻²) and 2006 (154.1 g m⁻²) according to the yield survey for the evaluation of the level and variation of rice yield in paddy fields without trees (Adachi et al., 2010). More precipitation in August – October in 2007 resulted in a higher yield than in other years (Table 1). The total precipitation in those three months in 2009 was less than that in 2008.

In 2007, the average grain yield of CTP in all the combined data was significantly lower than that of FTP, whereas there were no significant differences in other years. In fields with Terminalia alata Heyne ex Roth (Ta-3) the yield of CTP was significantly higher than that of FTP. In fields with Dipterocarpus intricatus Dyer (Di-3) and Dipterocarpus obtusifolius Teysm. ex Miq. (Do-1), the grain yield of CTP was lower than that of FTP. In 2008, in fields with Irvingia malayana Oliver ex A. Benn. (Im-1) and Ta-1, the grain yield of CTP was significantly higher than that of FTP. Conversely, in fields with Fr-1, grain yield of CTP was significantly lower than that of FTP. Similarly, in 2009, in fields with Manilaya tomentosa Heyne (Mt-1) and Sy-5 grain yield of CTP was significantly higher than that of FTP. In the fields with Di-2, Fr-1, Fr-2, Ta-2 and Ti-1, grain yield of CTP was significantly lower than that of FTP. Rice yields were consistently low in CTP in fields with Fr, but no consistent difference was observed in yields between CTP and FTP in the fields with other tree species examined over the three-year study period. The correlation coefficients between the grain yields of CTP and FTP of all trees were 0.510 ($p < 0.01$), 0.287 ($p > 0.05$) and 0.171 ($p > 0.05$), in 2007, 2008 and 2009, respectively. It suggested that rice yield of CTP was not so much related with that of FTP generally.

Table 5 shows the number of spikelets at each site. In 2007, the average number of spikelets of CTP as a whole was significantly lower than that of FTP, whereas there were no significant differences in other years. The significant
Table 3. Characteristics of trees and the distance of the farthest surveyed areas from the tree trunks.

| Tree species | Tree height (m)* | DBH (cm)* | Crown thickness (m)** | Crown area (m²) * | Degree of canopy openness (%) | Distance from tree trunk to the measuring sites (m)*** |
|--------------|-----------------|-----------|----------------------|------------------|-------------------------------|-----------------------------------------------|
| Bm           |                 |           |                      |                  |                               |                                               |
| N            | 5               | 5         | 5                    | 5                | 4                             | 5                                             |
| Mean         | 10.2            | 50.2      | 8.7                  | 42.8             | 55.2                          | 5.7                                           |
| Min.         | 8.6             | 37.5      | 6.1                  | 20.4             | 46.4                          | 4.0                                           |
| Max.         | 11.9            | 73.2      | 10.7                 | 72.9             | 67.0                          | 7.0                                           |
| Di           |                 |           |                      |                  |                               |                                               |
| N            | 6               | 6         | 6                    | 6                | 4                             | 6                                             |
| Mean         | 13.3            | 52.0      | 10.0                 | 68.6             | 64.7                          | 6.5                                           |
| Min.         | 10.1            | 20.7      | 8.1                  | 27.0             | 56.6                          | 5.0                                           |
| Max.         | 16.3            | 76.3      | 13.3                 | 150.5            | 73.8                          | 8.0                                           |
| Do           |                 |           |                      |                  |                               |                                               |
| N            | 5               | 5         | 4                    | 4                | 3                             | 5                                             |
| Mean         | 14.3            | 39.3      | 9.0                  | 17.5             | 66.1                          | 5.0                                           |
| Min.         | 11.2            | 27.8      | 6.2                  | 4.6              | 56.4                          | 4.0                                           |
| Max.         | 17.6            | 47.8      | 11.3                 | 24.7             | 71.0                          | 6.0                                           |
| Dt           |                 |           |                      |                  |                               |                                               |
| N            | 2               | 2         | 2                    | 2                | 2                             | 2                                             |
| Mean         | 13.0            | 28.3      | 9.5                  | 12.3             | 66.8                          | 4.5                                           |
| Min.         | 8.5             | 24.8      | 4.9                  | 9.1              | 60.5                          | 4.0                                           |
| Max.         | 17.5            | 31.8      | 14.0                 | 15.5             | 73.1                          | 5.0                                           |
| Fr           |                 |           |                      |                  |                               |                                               |
| N            | 2               | 2         | 2                    | 2                | 2                             | 2                                             |
| Mean         | 20.1            | 227.2     | 18.6                 | 452.6            | 32.3                          | 20.0                                          |
| Min.         | 19.4            | 200.6     | 18.2                 | 341.8            | 28.2                          | 20.0                                          |
| Max.         | 20.8            | 253.8     | 19.0                 | 563.3            | 36.5                          | 20.0                                          |
| Im           |                 |           |                      |                  |                               |                                               |
| N            | 4               | 4         | 3                    | 3                | 3                             | 4                                             |
| Mean         | 11.8            | 65.8      | 12.0                 | 26.8             | 58.8                          | 6.1                                           |
| Min.         | 7.5             | 31.8      | 11.5                 | 23.4             | 51.6                          | 5.5                                           |
| Max.         | 14.0            | 104.1     | 12.7                 | 30.8             | 65.1                          | 7.0                                           |
| Mt           |                 |           |                      |                  |                               |                                               |
| N            | 2               | 2         | 2                    | 2                | 2                             | 2                                             |
| Mean         | 13.8            | 41.7      | 13.1                 | 32.0             | 55.5                          | 7.0                                           |
| Min.         | 11.2            | 38.5      | 10.2                 | 27.2             | 51.7                          | 6.0                                           |
| Max.         | 16.4            | 44.9      | 16.1                 | 36.8             | 59.4                          | 8.0                                           |
| Sy           |                 |           |                      |                  |                               |                                               |
| N            | 4               | 4         | 4                    | 4                | 4                             | 4                                             |
| Mean         | 7.3             | 26.1      | 6.1                  | 30.9             | 70.7                          | 6.5                                           |
| Min.         | 5.9             | 20.0      | 4.3                  | 12.5             | 68.4                          | 5.0                                           |
| Max.         | 8.5             | 36.9      | 8.0                  | 44.9             | 74.4                          | 8.0                                           |
| Ta           |                 |           |                      |                  |                               |                                               |
| N            | 7               | 7         | 7                    | 7                | 5                             | 7                                             |
| Mean         | 11.2            | 49.3      | 9.2                  | 32.3             | 61.6                          | 5.1                                           |
| Min.         | 5.0             | 44.6      | 3.7                  | 12.2             | 52.6                          | 4.0                                           |
| Max.         | 15.0            | 57.3      | 14.3                 | 66.3             | 69.0                          | 6.0                                           |
| Ti           |                 |           |                      |                  |                               |                                               |
| N            | 2               | 2         | 2                    | 2                | 2                             | 2                                             |
| Mean         | 5.4             | 28.6      | 3.8                  | 16.0             | 56.1                          | 9.0                                           |
| Min.         | 3.2             | 18.6      | 1.3                  | 10.4             | 48.5                          | 8.0                                           |
| Max.         | 7.5             | 38.6      | 6.3                  | 21.7             | 63.8                          | 10.0                                          |

DBH = diameter at breast height, N = the number of individual trees of a species.

* Mean values for 2008 and 2009.

** Difference between tree height and the height of the lowest branch.

*** Mean values for PPFD and rice-yields for sites farthest away from tree trunks in 2007 to 2009.
Table 4. Difference in rice grain yields (g m\(^{-2}\)) at sites closest\(^1\) to and farthest\(^2\) from trees in 2007, 2008 and 2009.

| Species | Tree number | Mean ± SE Close\(^1\) | Mean ± SE Far\(^1\) | Close\(^2\) | Mean ± SE | Far\(^2\) | Mean ± SE | † Significant difference between close and distant spots at the 5% (\(*\)) and 1% (\(**\)) probability levels. ns means nonsignificant. |
|---------|-------------|-----------------------|---------------------|------------|-----------------|------------|-----------------|-----------------------------------------------------------|
| Bm      | 1           | 167.3 ± 98.5          | 156.0 ± 38.4  ns    |            | 112.5 ± 29.7    | 176.4 ± 35.7  ns    |                                              |
|         | 2           | 165.2 ± 17.3          | 150.0 ± 34.7  ns    |            | 124.3 ± 53.6    | 82.5 ± 30.0    ns    |
|         | 3           | 148.0 ± 28.2          | 241.1 ± 82.9  ns    | 190.0 ± 85.8 | 186.8 ± 54.2 ns  |                                |
|         | 4           | 125.1 ± 57.6          | 169.1 ± 70.7  ns    |            | 147.6 ± 17.9    | 117.3 ± 39.0  ns    |
|         | 5           |                       |                     |            | 237.4 ± 33.6    | 117.8 ± 63.3  ns    |
|         | 6           |                       |                     |            | 140.1 ± 60.3    | 164.8 ± 47.2  ns    |
| Di      | 1           | 200.6 ± 61.0          | 276.0 ± 49.9  ns    | 152.0 ± 62.3 | 121.5 ± 43.0 ns  |                                |
|         | 2           | 93.0 ± 48.4           | 211.4 ± 111.7 ns   | 187.5 ± 68.9 | 247.7 ± 85.7 ns  |                                |
|         | 3           | 148.8 ± 45.3          | 299.0 ± 60.0  *      |            | 191.8 ± 22.3    | 170.2 ± 101.8 ns    |
|         | 4           | 438.0 ± 85.8          | 240.5 ± 77.4  ns    |            | 172.0 ± 24.6    | 223.8 ± 53.4  ns    |
|         | 5           | 226.6 ± 91.4          | 219.8 ± 85.4  ns    |            | 148.6 ± 111.2    | 133.9 ± 72.5  ns    |
|         | 6           |                       |                     |            | 140.1 ± 60.3    | 164.8 ± 47.2  ns    |
| Do      | 1           | 66.1 ± 21.3           | 160.0 ± 58.2  *      |            | 110.7 ± 50.4    | 241.3 ± 18.2  ns    |
|         | 2           | 169.8 ± 111.0         | 287.2 ± 181.1 ns   |            | 207.6 ± 70.1    | 242.3 ± 19.8  ns    |
|         | 3           | 210.0 ± 24.5          | 336.4 ± 104.5 ns   | 158.9 ± 50.3 | 188.1 ± 89.7 ns  |                                |
|         | 4           | 234.0 ± 101.0         | 219.7 ± 152.0  ns    |            | 163.6 ± 22.9    | 180.7 ± 44.2  ns    |
|         | 5           | 226.6 ± 91.4          | 219.8 ± 85.4  ns    |            | 148.6 ± 111.2    | 133.9 ± 72.5  ns    |
|         | 6           |                       |                     |            | 140.1 ± 60.3    | 164.8 ± 47.2  ns    |
| Dt      | 1           | 159.7 ± 22.8          | 257.8 ± 80.8  ns    | 207.3 ± 153.9 | 196.0 ± 76.9 ns  |                                |
|         | 2           | 182.5 ± 38.1          | 215.3 ± 55.1  ns    |            | 200.7 ± 6.3     | 228.3 ± 50.6  ns    |
| Fr      | 1           | 53.3 ± 20.1           | 213.0 ± 89.9  ns    | 48.7 ± 25.6 | 185.9 ± 105.4 ** |                                |
|         | 2           | 179.2 ± 43.6          | 260.6 ± 80.2  ns    |            | 97.4 ± 39.7     | 282.5 ± 86.2  *      |
| Im      | 1           | 143.4 ± 26.2          | 185.3 ± 77.2  ns    | 255.5 ± 82.4 | 126.7 ± 63.0 ** |                                |
|         | 2           | 199.6 ± 57.0          | 256.8 ± 59.0  ns    |            | 208.4 ± 36.9    | 223.5 ± 46.5  ns    |
|         | 3           | 317.9 ± 139.6         | 166.2 ± 51.3  ns    | 167.5 ± 64.0 | 150.5 ± 45.7 ns  |                                |
|         | 4           | 209.5 ± 32.0          | 360.2 ± 70.8  ns    |            | 230.1 ± 60.8    | 170.1 ± 61.2  ns    |
| Mt      | 1           | 356.8 ± 77.5          | 344.0 ± 93.6  ns    | 168.5 ± 71.1 | 157.6 ± 115.7 ns  |                                |
|         | 2           | 348.8 ± 164.3         | 399.6 ± 147.1 ns   | 163.4 ± 81.7 | 152.4 ± 66.9 ns  |                                |
|         | 3           | 295.9 ± 94.5          | 303.1 ± 70.3  ns    |            | 166.1 ± 11.2    | 151.7 ± 9.2  ns    |
|         | 4           | 254.8 ± 38.1          | 314.5 ± 74.3  ns    |            | 88.5 ± 20.7     | 119.3 ± 27.9  ns    |
| Sy      | 1           | 192.3 ± 9.7           | 314.5 ± 74.3  ns    | 129.0 ± 49.5 | 178.1 ± 44.6 ns  |                                |
|         | 2           |                       |                     | 181.9 ± 38.6 | 246.8 ± 89.7 ns  |                                |
|         | 3           |                       |                     | 192.6 ± 47.8 | 188.4 ± 122.5 ns  |                                |
|         | 4           | 197.4 ± 48.1          | 336.8 ± 159.3 ns   | 224.2 ± 42.1 | 225.2 ± 40.4 ns  |                                |
|         | 5           | 217.5 ± 61.7          | 201.4 ± 45.4  ns    | 221.9 ± 112.9 | 201.3 ± 90.7 ns  |                                |
|         | 6           |                       |                     | 180.1 ± 40.9 | 153.8 ± 64.6  ns    |
| Ti      | 1           | 291.9 ± 70.4          | 203.4 ± 53.1  ns    | 115.1 ± 6.4 | 237.7 ± 52.0  *      |
|         | 2           | 204.0 ± 64.0          | 243.3 ± 102.7 ns   | 172.4 ± 34.8 | 149.5 ± 54.8 ns  |
| Average |             | 195.8                 | 243.8 **           | 181.7       | 185.6       ns    | 160.6       172.7       ns    |

\(^1\) 1 m away from the tree trunk.

\(^2\) 4 – 20 m away from the tree trunk as in Table 3.
| Trees | Close<sup>1)</sup> | Far<sup>2)</sup> | Close<sup>1)</sup> | Far<sup>2)</sup> | Close<sup>1)</sup> | Far<sup>2)</sup> |
|-------|------------------|------------------|------------------|------------------|------------------|------------------|
|       | Species          | Tree number      | Mean ± SE        | Mean ± SE        | Mean ± SE        | Mean ± SE        |
|       |                  |                  | Close           | Far             | Close           | Far             |
|       |                  |                  | Mean ± SE       | Mean ± SE       | Mean ± SE       | Mean ± SE       |
|       |                  |                  | 2007            | 2008            | 2009            | 2008            |
|       |                  |                  |                  |                  |                  |                  |
| Bm    |                  |                  | 6935 ± 4321     | 7331 ± 1330     | 4623 ± 1238     | 7889 ± 1291     |
|       |                  | 2                | 5110 ± 593      | 7367 ± 1653     | 5376 ± 1780     | 4462 ± 1106     |
|       |                  | 3                | 8141 ± 2070     | 12934 ± 4593    | 8486 ± 3492     | 8443 ± 1822     |
|       |                  | 4                | 8141 ± 2070     | 12934 ± 4593    | 8486 ± 3492     | 8443 ± 1822     |
|       |                  | 5                | 11645 ± 1623    | 5639 ± 2424     | 11645 ± 1623    | 5639 ± 2424     |
| Di    |                  | 1                | 6822 ± 1536     | 9641 ± 1433     | 7127 ± 2372     | 6291 ± 2166     |
|       |                  | 2                | 3932 ± 1788     | 7631 ± 5692     | 9078 ± 2345     | 10165 ± 3611    |
|       |                  | 3                | 6930 ± 1721     | 12858 ± 2067    | 7712 ± 620      | 6499 ± 3601     |
|       |                  | 4                | 16569 ± 2690    | 9285 ± 2689     | 5810 ± 981      | 7345 ± 1363     |
|       |                  | 5                | 8229 ± 3426     | 5545 ± 3377     | 6369 ± 3497     | 6264 ± 2248     |
|       |                  | 6                | 6512 ± 2799     | 7574 ± 2130     | 7036 ± 820      | 8131 ± 823      |
| Do    |                  | 1                | 2954 ± 786      | 6947 ± 2089     | 8226 ± 1487     | 8476 ± 1034     |
|       |                  | 2                | 7254 ± 4834     | 1143 ± 6581     | 7701 ± 1503     | 9156 ± 3344     |
|       |                  | 3                | 9372 ± 1434     | 14258 ± 4236    | 9280 ± 2545     | 11043 ± 544     |
|       |                  | 4                | 16057 ± 2994    | 9548 ± 6822     | 7811 ± 1399     | 7863 ± 1940     |
|       |                  | 5                | 11800 ± 2674    | 11912 ± 4932    | 6926 ± 1398     | 7474 ± 1441     |
|       |                  | 6                | 6512 ± 2799     | 7574 ± 2130     | 7036 ± 820      | 8131 ± 823      |
| Dt    |                  | 1                | 8702 ± 1323     | 13240 ± 3154    | 8509 ± 5907     | 10639 ± 1238    |
|       |                  | 2                | 8520 ± 2308     | 9366 ± 1686     | 7895 ± 373      | 9133 ± 1887     |
| Fr    |                  | 1                | 2815 ± 1034     | 7423 ± 1366     | 3218 ± 1495     | 6868 ± 3638     |
|       |                  | 2                | 9036 ± 2020     | 11640 ± 3505    | 6373 ± 2581     | 12598 ± 2579    |
| Im    |                  | 1                | 5349 ± 1236     | 8531 ± 3380     | 9438 ± 2812     | 5909 ± 2128     |
|       |                  | 2                | 10502 ± 323     | 12541 ± 1724    | 8989 ± 2066     | 8920 ± 1870     |
|       |                  | 3                | 12442 ± 5855    | 7688 ± 1722     | 7250 ± 2831     | 6556 ± 1257     |
|       |                  | 4                | 10263 ± 1906    | 15828 ± 2507    | 9158 ± 2300     | 7196 ± 2224     |
| Mt    |                  | 1                | 14130 ± 2418    | 12740 ± 3480    | 7362 ± 2694     | 6654 ± 4081     |
|       |                  | 2                | 16355 ± 5416    | 16145 ± 5328    | 7953 ± 3271     | 7789 ± 2295     |
|       |                  | 3                | 13228 ± 3474    | 12920 ± 2513    | 7586 ± 711      | 7205 ± 465      |
|       |                  | 4                | 8833 ± 674      | 14760 ± 4824    | 6534 ± 2049     | 8243 ± 1926     |
|       |                  | 5                | 6954 ± 2216     | 9528 ± 3183     | 13145 ± 1995    | 8244 ± 1125     |
| Ta    |                  | 1                | 8411 ± 2054     | 7716 ± 4340     | 8156 ± 3121     | 5655 ± 1825     |
|       |                  | 2                | 10236 ± 3057    | 14075 ± 5735    | 5444 ± 744      | 8341 ± 990      |
|       |                  | 3                | 1665 ± 534      | 574 ± 238       | 3154 ± 80       | 5090 ± 156      |
|       |                  | 4                | 9202 ± 1517     | 14424 ± 6176    | 11994 ± 2922    | 10350 ± 2133    |
|       |                  | 5                | 12174 ± 5201    | 9112 ± 2121     | 9945 ± 4606     | 9080 ± 4159     |
|       |                  | 6                | 12495 ± 3319    | 7893 ± 1797     | 6190 ± 154      | 10020 ± 1425    |
|       |                  | 7                | 9301 ± 2843     | 10816 ± 3961    | 7358 ± 1242     | 6906 ± 2207     |
|       |                  |                  | 8764 ± 1040     | 8283 ± 8167     | 7362 ± 7847     | 7362 ± 7847     |
|       |                  |                  | **              | **              | **              | **              |
|       |                  |                  |                  |                  |                  |                  |
| Ti    |                  | 1                | 12495 ± 3319    | 7893 ± 1797     | 6190 ± 154      | 10020 ± 1425    |
|       |                  | 2                | 9301 ± 2843     | 10816 ± 3961    | 7358 ± 1242     | 6906 ± 2207     |

† Significant difference between close and distant spots at the 5% probability level. ns means nonsignificant.

1) 1 m away from the tree trunk.
2) 4 – 20 m away from the tree trunk as in Table 3.
| Species | Tree number | 2007 Close \(^1\) | 2008 Close \(^1\) | 2007 Far \(^2\) | 2008 Far \(^2\) |
|---------|-------------|----------------|----------------|----------------|----------------|
| Bm      | 1           | 68.5 ± 5.2    | 68.6 ± 12.1    | ns             |                |
|         | 2           | 58.8 ± 7.7    | 57.2 ± 7.5     | ns             |                |
|         | 3           | 50.9 ± 8.4    | 53.3 ± 15.2    | ns             |                |
|         | 4           | 47.0 ± 18.0   | 74.3 ± 11.9    | *              |                |
|         | 5           | 71.7 ± 10.1   | 74.9 ± 10.4    | ns             |                |
| Di      | 1           | 78.3 ± 18.4   | 57.8 ± 11.7    | ns             | 58.9 ± 11.0    |
|         | 2           | 58.5 ± 10.0   | 51.0 ± 10.9    | ns             | 64.3 ± 8.5     |
|         | 3           | 42.3 ± 12.9   | 61.8 ± 5.1     | ns             | 42.7 ± 3.7     |
|         | 4           | 56.0 ± 4.7    | 64.3 ± 11.8    | ns             | 61.7 ± 9.1     |
|         | 5           | 76.1 ± 4.8    | 75.3 ± 3.6     | ns             |                |
|         | 6           | 67.5 ± 10.2   | 69.1 ± 8.0     | ns             |                |
| Do      | 1           | 58.1 ± 12.5   | 64.3 ± 15.7    | ns             |                |
|         | 2           | 70.1 ± 2.7    | 67.2 ± 17.2    | ns             |                |
|         | 3           | 52.0 ± 10.2   | 62.7 ± 2.5     | ns             | 58.5 ± 9.4     |
|         | 4           | 57.9 ± 11.7   | 59.6 ± 3.4     | ns             | 61.7 ± 9.1     |
|         | 5           | 60.2 ± 16.8   | 70.2 ± 10.0    | ns             |                |
| Dt      | 1           | 47.9 ± 4.2    | 49.7 ± 4.8     | ns             | 69.2 ± 15.1    |
|         | 2           | 41.9 ± 2.6    | 41.1 ± 1.8     | ns             | 65.1 ± 9.0     |
| Fr      | 1           | 22.4 ± 15.3   | 57.8 ± 19.5    | ns             | 28.9 ± 14.6    |
|         | 2           | 58.7 ± 5.2    | 69.2 ± 9.3     | ns             | 75.5 ± 11.4    |
| Im      | 1           | 57.8 ± 4.4    | 57.0 ± 5.3     | ns             | 75.1 ± 7.4     |
|         | 2           | 49.1 ± 21.0   | 69.2 ± 5.1     | ns             | 60.8 ± 10.8    |
|         | 3           | 40.0 ± 8.2    | 43.4 ± 15.9    | ns             | 61.9 ± 25.5    |
|         | 4           | 59.0 ± 8.3    | 73.3 ± 7.1     | ns             | 62.2 ± 13.4    |
| Mt      | 1           | 61.7 ± 8.8    | 75.6 ± 11.9    | ns             | 58.8 ± 16.1    |
|         | 2           | 48.1 ± 16.1   | 62.1 ± 2.4     | ns             | 54.2 ± 9.2     |
| Sy      | 1           | 52.2 ± 12.2   | 69.3 ± 8.8     | ns             | 62.5 ± 12.5    |
|         | 3           | 62.8 ± 5.2    | 65.3 ± 11.7    | ns             | 65.1 ± 11.6    |
|         | 4           |                | 57.6 ± 15.7    | ns             |                |
|         | 5           |                | 62.5 ± 12.5    | ns             |                |
| Ta      | 1           | 53.9 ± 10.4   | 54.0 ± 11.0    | ns             | 65.5 ± 23.9    |
|         | 2           | 36.8 ± 9.8    | 41.1 ± 9.0     | ns             | 73.7 ± 18.2    |
|         | 3           | 61.8 ± 9.8    | 35.8 ± 7.7     | *              |                |
|         | 4           | 54.8 ± 9.7    | 60.5 ± 8.0     | ns             | 44.5 ± 7.4     |
|         | 5           | 52.4 ± 10.5   | 64.8 ± 3.8     | ns             | 66.3 ± 15.6    |
| Ti      | 1           |                | 61.1 ± 4.9     | ns             | 67.5 ± 5.1     |
|         | 2           |                | 73.6 ± 4.0     | ns             | 74.5 ± 9.0     |
| Average |              | 54.8 ± 9.8    | 60.0 ± 9.8     | *              |                |

\(^1\) Significant difference between close and distant spots at the 5% (\(*\)) and 1% (\(\**\)) probability levels. ns means nonsignificant.

\(^2\) 1 m away from the tree trunk.

4 – 20 m away from the tree trunk as in Table 3.
difference in the number of spikelets between CTP and FTP was observed for the same trees with a significant difference of grain yield shown in Table 4. In addition, in 2007, in the fields with Fr-1, the number of spikelets of CTP was significantly lower than that of FTP. In 2009, in the fields with Butea monosperma (Lmk.) Taub. (Bm-5) the number of spikelets of CTP was significantly larger than that of FTP. In the fields with Bm-1 and Ta-3, the number of spikelets of CTP was significantly smaller than that of FTP. The fields with other tree species did not show any significant differences in the number of spikelets between CTP and FTP.

The percentages of ripened grains are shown in Table 6. No data are available for 2009 due to extensive damage caused by mice while grains were stored before measurement. In 2007 and 2008, the average percentage of ripened grains of CTP was significantly lower than that of FTP. In 2009, in the fields with Bm-5, the number of spikelets of CTP was significantly larger than that of FTP. In the fields with Bm-1 and Ta-5, the number of spikelets of CTP was significantly smaller than that of FTP. The fields with other tree species did not show any significant differences in the number of spikelets between CTP and FTP.

A significant correlation was observed between the ratios of the grain yield of CTP to that of FTP (C/F ratio of grain yield, GYR) and the C/F ratio of the number of spikelets (NSR) (Fig. 1). In addition, a significant correlation was observed between GYR and C/F ratio of ripened grains \( r = 0.756 \) (\( p < 0.01 \)) and \( r = 0.614 \) (\( p < 0.01 \)) in 2007 and 2008. According to Tables 4, 5 and 6, the significant differences in grain yield between CTP and FTP may be due to the significant differences in the numbers of spikelets over the three years. The higher grain yields of CTP in the fields with Ta-3 in 2007 and in the fields with Im-1 in 2008 may be because CTP had larger spikelets and a higher percentage of ripening grains than FTP.

The relationships between GYR and grain yield of FTP in 2007, 2008 and 2009 are shown in Fig. 2. A significant negative correlation was observed between these two items in all three years: \( r = -0.571 \) (\( p < 0.01 \)) and \( r = -0.570 \) (\( p < 0.01 \)) in 2007 and 2008. According to Tables 4, 5 and 6, the significant differences in grain yield between CTP and FTP may be due to the significant differences in the numbers of spikelets over the three years. The higher grain yields of CTP in the fields with Ta-3 in 2007 and in the fields with Im-1 in 2008 may be because CTP had larger spikelets and a higher percentage of ripening grains than FTP.

3. Effects of trees on rice yield
The relationships between the PPFD ratio of CTP and
FTP (PPFR) and the GYR for the years 2007, 2008 and 2009 are shown in Fig. 3. Despite the marked variation in PPFR, no clear relationship was observed between PPFR and GYR in any of the years ($r = -0.239, p > 0.05; r = -0.492, p > 0.05; r = 0.161, p > 0.05$ for 2007, 2008 and 2009, respectively). According to Fig. 3(a) and (c), the low grain yield of CTP in the fields with Fr was attributable to the extremely low PPFD under this tree, which would have restricted spikelet development and grain ripening. Conversely, in the fields with Im in 2007 to 2009, Ta in 2007 and 2008, Sy in 2009, and Bm in 2009, GYR was higher when PPFR < 0.6, which implies that shady trees in paddy fields may not adversely affect rice yield, except for trees with extremely large crowns, such as Fr.

The ratio in EC measurements between CTP and FTP showed a positive but weak correlation with GYR ($r = 0.112, p > 0.05; r = 0.607, p > 0.05$ and $r = 0.492, p < 0.05$ in 2007, 2008 and 2009, respectively) and NSR ($r = 0.140, p > 0.05; r = 0.625, p > 0.05$ and $r = 0.601, p < 0.01$ in 2007, 2008 and 2009, respectively). Trees may change the soil fertility under trees, which could in turn affect the growth and yield of rice. Nutrients derived from tree litter, especially from leguminous trees (Sae-Lee et al., 1992; Vityakon and Dangthaisong, 2005) or from termite mounds (Miura et al., 1990), may affect soil EC, although such changes were not examined in this study.

### 4. Compatibility between tree utilization and rice cultivation

Interviews of farmers revealed that they believed the leaf
litter from Ta, Sy, Mt, Samanea saman (Jacq.) Merrill and Im trees enhanced soil fertility (Table 7). In addition, the farmers also believed that the trees improved rice growth, yield and grain quality. However, Do, Di, Dipterocarpus alatus Roxb., Peltophorum dasyrhachis (Miq.) Kurz and D. tuberculatus Roxb. (Dt) trees were believed to have a negative effect on rice growth and yield due to production of resin by trees and because they took up soil nutrients. However, observation for a longer period is required to more accurately clarify this “tree effect” in fields, because we could not confirm the difference of specific effects among tree species during 3 years. Although Fr trees were associated with decreased rice yield during the study period, farmers did not perceive this to be a problem because this species had significance in the Buddhist faith. Other trees were used for food and to provide materials for building and making furniture, farming implements, medicines, dyes and charcoal in the village as well as other villages investigated by Kosaka et al. (2006b) and Natuhara et al. (2011) in Laos. It therefore seems that tree utilization combined with rice cultivation is currently compatible in this village considering the rice yield and area occupied by trees. Indeed, the number of trees in paddy fields is likely to decrease as they are used and not replanted, or if they are removed for land consolidation or to facilitate the operation of plowing machines, as has occurred in the villages of northeastern Thailand. Kosaka et al. (2006a) pointed out that the number of trees in paddy fields in Laos has already decreased. Actually the trees are distributed only in the old paddy fields around the main settlements of Dong Khuai village in contrast to the paddy fields near a forest where the area occupied by trees may be more than the average values estimated above. It is also important to examine the role that paddy fields with trees play within the context of biodiversity of these areas.

Acknowledgements

The authors thank Dr. M. Chanphengxay, the former director of the National Agriculture and Forestry Research Institute, Lao PDR (NAFRI) for supporting this study. Thanks are also extended to the staff of NAFRI and to the villagers for their assistance, to Dr. Y. Kosaka, Graduate School of Asian and African Area Studies, Kyoto University, Japan (ASAFAS) for species identification of trees.

References

Adachi, Y., Miyagawa, S., Seko, M., Kamiya, K., Sivilay, S. and Ono, E. 2010. Analysis of effects of environmental factors and cultivation practices on variation in rice yield in rainfed paddy fields of the central plain of Laos. Trop. Agric. Dev. 54: 35-43.

Grandstaff, S.W., Grandstaff, T.B., Rathakette, P., Thomas, D.E. and Thomas, J.K. 1986. Trees in paddy fields in Northeast Thailand. In G.G. Marten ed., Traditional Agriculture in Southeast Asia. Westview Press, London. 273-292.

Haefele, S.M., Nivong, S., Sengxua, P., Phengsouvanna, V., Vongsoonthi, S. and Linquist, B. 2006. Soil fertility management in the lowland rice environments of Laos. In J.M. Schiller, M.B. Chanphengxay, B. Linquist and S. Appa-Rao eds., Rice in Laos. IRRI, Manila. 369-389.

Inthaphany, P., Siyavong, P., Sihatthep, V., Chanphengsay, M., Schiller, J.M., Linquist, B. and Fukai, S. 2001. Agronomic practices for improving yields of rainfed lowland rice in Laos. In S. Fukai and J. Basnayake eds., Increased Lowland Rice Production in the Mekong Region. ACIAR Proceedings No. 101. 31-40.

Kosaka, Y., Takeda, S., Pitrax, S., Sithirajvongsa, S. and Xaydala, K. 2006a. Species composition, distribution and management of trees in rice paddy fields in central Lao, PDR. Agroforest. Syst. 67: 1-17.

Kosaka, Y., Takeda, S., Sithirajvongsa, S. and Xaydala, K. 2006b. Land-use patterns and plant use in Lao villages, Savannakhet Province, Laos. Tropics 15: 51-63.

Matsusita, Y., Hoshikawa, S., Miyagawa, S. and Kosaka, Y. 2011. Geographical distribution of tree-rice system in paddy fields at Vientiane Plains – case of study in Dong Khuai village of Laos –. Ann. Environ. Sci. Shinshu Univ. 33: 8997*.

Miura, K., Subjiasaram, T., Tawinthung, N., Noochan, N. and Shiraiishi, K. 1990. Effects of termite activity on soils in Northeast Thailand. Jpn. J. Tropical Agric. 34: 40-47.

Miyagawa, S., Seko, M., Adachi, Y., Kamiya, K., Sivilay, S. and Takenaka, C. 2007. Relationships between forest and rice growth in a rainfed rice growing village of Vientiane Plain, Laos. Trop. Agric. Dev. 51 (Extra 1): 25-26*.

Natuhara, Y., Imanishi, A., Kanzaki, M., Southavong, S. and Duangvongsa, I. 2011. Uses of trees in paddy fields in Champasak Province, southern Lao PDR. Landscape Ecol. Eng. 8: 115-122.

Pendleton, R.L. 1943. Land use in northeastern Thailand. Geogr. Rev. 33: 15-41.

Prachaiy, B. 2000. Famers and forests: A changing phase in Northeast Thailand. SE.A. Stud. 58: 271-446.

Sae-Lee, S., Vityakon, P. and Prachaiy, B. 1992. Effects of trees on paddy bond on soil fertility and rice growth in Northeast Thailand. Agroforest. Syst. 18: 213-223.

Takaya, Y. and Tomosugi, T. 1972. Rice lands in the upland hill regions of Northeast Thailand – A remark on “rice producing forest”. SE. As. Stud. 10: 77-85**.

Tsobo, M., Basnayake, J., Fukai, S., Sihatthep, V., Siyavong, P., Sipesuth and Chanphengsay, M. 2006. Toposequential effects on water balance and productivity in rainfedlowland rice ecosystem in Southern Laos. Field Crop Res. 97: 209-220.

Vityakon, P. and Danghthaisong, N. 2005. Environmental influences on nitrogen transformation of different quality tree litter under submerged and aerobic conditions. Agroforest. Syst. 63: 225-236.

Vityakon, P., Sae-Lee, S. and Sripong, S. 1993. Effects of tree leaf litter and shading on growth and yield of paddy rice in Northeast Thailand. Kasetsart J.(Nat. Sci.) 27: 219-222.

Watanabe, H., Abe, K., Hoshikawa, T., Prachaiy, B., Sahumalu, P. and Khenmark, C. 1990. On trees in paddy fields in Northeast Thailand. SE. As. Stud. 28. 45-54.

* In Japanese.

** In Japanese with English abstract.