Evaluation of Transplanting Date and Nitrogen Fertilizer Rate Adapted by Farmers to Toposequential Variation of Environmental Resources in a Mini-Watershed (Nong) in Northeast Thailand

Koki Homma¹, Takeshi Horie¹, Tatsuhiko Shiraiwa¹ and Nopporn Supapoj²

¹Graduate School of Agriculture, Kyoto University, Sakyo, Kyoto 606-8502, Japan;
²Ubon Rice Research Center, P.O. Box63, Ubon 34000, Thailand

Abstract: Environmental resources for rainfed rice production show large variability even within a small area in Northeast Thailand, and it is said that farmer’s management is well adapted to the variability. This study evaluated transplanting date and nitrogen (N) fertilizer rate in the management to improve rice productivity. The effect of transplanting date and N fertilizer rate on rice productivity was analyzed by investigating rice growth, and also by dividing rainfed rice fields located in a mini-watershed into 4 subecosystems: (1) medium deep water, waterlogged (MDW), (2) shallow water, favorable (SWf), (3) shallow water, drought- and submergence-prone (SWds), and (4) shallow water, drought-prone (SWd). Rice grew at almost a constant rate until maturity and the growth rate was higher at a lower field. The difference in productivity was derived from not only a water condition but also soil fertility, and was associated with the rate of N uptake. Small leaf area index was found to be one of the causes for low productivity in rice. Statistic analysis showed that earlier transplanting increased biomass production in all subecosystems. The biomass-increase resulted in a higher yield in SWds and SWd fields while it resulted in a reduced harvest index (HI) and did not increase yield in MDW and SWf fields. The effect of N fertilizer was apparent in the field where rice biomass was small due to later transplanting or unfertile soil, but the effect was generally small. Earlier transplanting in upper fields and later transplanting in lower fields in mini-watersheds were suggested to improve rice production, and proper distribution of N fertilizer use is considered necessary.

Key words: Farmer's management, Rainfed rice, Rice growth, Soil fertility, Subecosystem, Water availability.

Rainfed rice yield in Northeast Thailand is quite low and unstable, due to drought and low soil fertility (Fukai et al., 1998; Wade et al., 1999). Those two constraints are extremely variable depending on toposequential position of fields in mini-watersheds, which is a component unit of topography there and called Nong in Thai (Craig and Pisone, 1985; Miyagawa and Kuroda, 1988). Soil fertility and water availability were rich in the fields at the bottom of mini-watersheds, while they were poor in the uppermost fields (Homma et al., 2003, 2004). A farmer ordinarily has sequences of fields from bottom to uppermost in a mini-watershed, and his management seems to be well adapted to the sequences (Craig and Pisone, 1985; Fukui, 1993).

In 1980’s, farmers used several rice cultivars and scarcely used chemical fertilizers (Fukui, 1993; Mackill et al., 1996). They early-transplanted late-matured cultivars in bottom fields in mini-watersheds, and late-transplanted early-matured cultivars in uppermost fields. Rice yield under such a condition showed quite large variability, being explained to some extent by water condition, soil fertility and cultivars (Miyagawa and Kuroda, 1988). Miyagawa and Kuroda (1988) concluded that adoption of improved variety and establishment of irrigation facilities were useful for increasing rice yield. Recently, only two cultivars, KDML 105 and its glutinous mutant RD6, were famous for their eating quality, and they occupied more than half of rice fields (Miyagawa, 1995; Miyagawa et al., 1999). The amount of chemical fertilizer was also increasing as the economy developed (Pandy, 1998; Miyagawa et al., 1999). Although farmers might adapt their management to these changes, information on its effect on rice production is scarce.

In this study, rice growth under the farmer’s management in the rainfed paddy fields located within a mini-watershed was investigated in terms of plant nitrogen (N) uptake. The effect of the management was analyzed by dividing the mini-watershed into 4 subecosystems based on water availability, which was reported by Homma et al. (2004). Suitability
of the management and possibility of production improvement were also discussed.

Materials and Methods

1. Study fields and their classification into subecosystems

The study area was 9.3 ha of a closed mini-watershed in Hua Don Village, located at about 25 km northwest of the center of Ubon Ratchathani City, belonging to 10 farmers (Fig. 1). According to the soil map published by Department of Land Development, Thailand (Changprai et al., 1971; Kittayarak, 1971), soil in the study area is classified into Pimai series (USDA Taxonomy: Vertic Tropaquept) and Ubon series (Aquic Quartzipsamments). Precipitation data were collected at Ubon Rice Research Center, located at about 2 km northeast of the study area. The amount of precipitation was 1114 mm in 1997 and 1186 mm in 1998, both of which were smaller than normal (1506 mm, average of 1987−1996), but not so rare (1260 mm in 1988 and 1214 mm in 1993). The elevation difference between the highest and lowest paddy fields was 3.4 m in the study area. The paddy fields in the mini-watershed were classified into subecosystems according to elevation relative to the lowest paddy field.

Water availability and soil fertility in the study area changed with toposequence; superior in lower fields and inferior in upper fields (Homma et al., 2003, 2004). In this study, fields were classified into four subecosystems, according to the definition by International Rice Research Institute (IRRI) (Khush, 1984), that is, medium deep water, waterlogged (MDW), shallow water, favorable, (SWf), shallow water, drought- and submergence-prone (SWds), and shallow water, drought-prone (SWd). The fields classified into medium deep water, waterlogged subecosystem (MDW field) had standing water during rice cropping. The standing water depth sometimes exceeded 50 cm. These fields were at 0 to 0.16 m relative elevation in the study area. The fields classified into SWf were at 0.16〜1.0 m relative elevation, in which rice plants practically had no water stress. The fields classified into SWds were at 1.0〜1.9 m relative elevation, in which rice plants sometimes suffered water stress but were not seriously damaged. The fields classified into SWd were at 1.9〜3.4 m relative elevation, where rice plants were seriously damaged by water stress. These toposequential variations of water availability were reported by Homma et al. (2004) in detail. Table 1 shows the area, the number of fields and planted fields, the soil organic carbon content, clay content,
and number of flooded days in each subecosystem in the wet season in 1998. The difference in soil fertility was well represented by soil organic carbon content (Homma et al., 2003).

### Table 1. Area and the number of fields (total and planted), the number of flooded days, soil organic carbon (SOC) content and clay content in each subecosystem in the experimental mini-watershed area in the wet season in 1998 (Homma et al., 2003, 2004).

| Subecosystems               | RFE\(^1\) (m) | Area (ha) (%) | Number of fields | Flooded days | SOC\(^2\) (g kg\(^{-1}\)) | Clay\(^2\) (g g\(^{-1}\)) |
|-----------------------------|---------------|---------------|------------------|--------------|---------------------------|-----------------------------|
| **Medium deep water**       |               |               |                  |              |                           |                             |
| waterlogged (MDW)           | 0–0.16        | 1.8 (19.7)    | 14               | 14           | 115±9\(^a\)               | 17.7±3.1\(^a\)             | 0.34±0.19\(^a\)            |
| **Shallow water**           |               |               |                  |              |                           |                             |
| favorable (SWf)             | 0.16–1.0      | 3.5 (38.0)    | 85               | 83           | 81±3\(^a\)                | 8.6±2.6\(^a\)              | 0.18±0.11\(^a\)            |
| drought & submergence (SWds)| 1.0–1.9       | 2.3 (25.0)    | 87               | 78           | 40±3\(^a\)                | 5.5±3.1\(^a\)              | 0.04±0.02\(^a\)            |
| drought (SWd)               | 1.9–3.4       | 1.6 (17.3)    | 58               | 30           | 1±5\(^d\)                 | 3.3±0.8\(^d\)              | 0.03±0.01\(^d\)            |
| **Total**                   | 9.3           | 244           | 205              | 49±42        | 7.9±5.0                   | 0.13±0.14                   |

\(\pm\) indicates standard deviation.
Values within a column followed by the same letter are not significantly different at the 5% level.
\(^1\) RFE: Relative field elevation.
\(^2\) Numbers of sampled fields are 4, 12, 9 and 6 in MDW, SWf, SWds and SWd, respectively.

### Table 2. Differences in farmer’s management (a) and rice production (b) among the subecosystems in the study area in 1998.

#### a) Farmer’s management.

| Subecosystems\(^1\) | Transplant (DOY)\(^2\) | Harvest (DOY)\(^3\) | N fertilizer (g m\(^{-2}\)) |
|---------------------|------------------------|----------------------|-----------------------------|
| MDW                 | 183±17\(^a\)           | 312±1\(^a\)          | 0\(^a\)                     |
| SWf                 | 195±9\(^b\)            | 314±2\(^a\)          | 3.7±1.8\(^b\)               |
| SWds                | 203±13\(^c\)           | 315±3\(^c\)          | 3.5±2.4\(^b\)               |
| SWd                 | 217±12\(^d\)           | 316±4\(^c\)          | 0\(^c\)                     |
| Mean                | 200±14                 | 315±3                | 2.9±2                       |

#### b) Rice production.

| Subecosystems\(^1\) | Biomass (g m\(^{-2}\)) | Yield (g m\(^{-2}\)) | HI\(^3\) (g g\(^{-1}\)) |
|---------------------|-------------------------|-----------------------|--------------------------|
| MDW                 | 997±280\(^a\)          | 234±59\(^b\)         | 0.25±0.06\(^c\)          |
| SWf                 | 778±192\(^d\)          | 273±67\(^c\)         | 0.35±0.05\(^c\)          |
| SWds                | 643±246\(^d\)          | 215±93\(^b\)         | 0.32±0.06\(^c\)          |
| SWd                 | 268±152\(^d\)          | 53±56\(^c\)          | 0.16±0.12\(^d\)          |
| Mean                | 673±284                | 219±104               | 0.31±0.09                 |

\(\pm\) indicates standard deviation.
Values within a column followed by the same letter are not significantly different at the 5% level.
\(^1\) The abbreviations are the same as in Table 1.
\(^2\) DOY: day of the year, for example, 183th±17 means 2nd July±17 days.
\(^3\) HI: harvest index.

2. Farmer’s crop management

Farmers transplanted one- to two-month-old seedlings between the end of June and mid-August. Some MDW fields were direct seeded. In all study
fields, either cultivar KDML 105 or its glutinous mutant RD 6 was cultivated. The two cultivars have almost the same developmental characteristics (Bunduang and Uchin, 1990) and head at almost the same day when they are seeded from May to mid-August and grown under no water stress conditions due to their strong sensitivity to photoperiod (Ohnishi et al., 1999; Homma et al., 2001). The combined chemical fertilizer of the 16–16–8% (N–P₂O₅–K₂O) type was used in all fields in both years except for the fields of the farmer No. II in Fig. 1 in 1997, where the 16–20–0% type was used. The application rates varied from 0 to 64.8 g m⁻² (N–P₂O₅–K₂O: 0–0–0 to 10.4–10.4–10.4 g m⁻²) in the study fields. SWd fields did not receive fertilizer because of the high risk of losing the fertilizer through floods. Irrigation by pumping and hand weeding was conducted only once at transplanting. Rice was harvested successively from the lower to the higher fields in November. These differences in transplanting date, harvesting date and fertilizer application rates among the subecosystems in 1998 are shown in Table 2a.

3. Plant sampling

Seven fields in 1997 and 12 fields in 1998 as denoted in Fig. 1 were selected for measurement of periodic rice sampling. Rice plants were harvested at transplanting time (TP) and every 10 days from 24 September to maturity (MT) in 1997 and at TP, panicle initiation (PI), heading (HD) and MT in 1998. On each harvesting occasion, 4 rice hills from each of 4 replication spots in each field were harvested. The harvested plants were measured for dry weight and nitrogen (N) content of each organ, and leaf area index (LAI). N content was determined by near infrared spectroscopic analysis method (Infra Analyzer 500, BRAN + LUEBBE, Hamburg) equipped with IDAS software, and calibrated by the Kjeldahl method.

Rice biomass and grain yields at maturity were measured in the 7 fields with 3 replications in 1997. In 1998, they were measured in 194 fields, which included the 12-periodically-rice-sampled fields, with 1-3 replications. Each reaping area was about 0.5 m². The data was averaged for each field and used for analysis.

Results

1. Growth and N uptake by rice

Fig. 2 gives biomass growth curves of rice at different relative field elevations under the same rate of fertilizer application in the mini-watershed in 1997. Rice grew at almost the same rate until maturity and the growth rate was higher in lower fields. Similar results were obtained in 1998 (data not shown). The difference in growth rate was derived from not only water condition.
but also by soil fertility. For example, biomass production at the field on 0.67 m relative elevation was much less than that on 0.23 m, in spite of adequate water availability (details about water availability at these fields were described in Homma et al., 2004). Under a similar condition of water availability and soil fertility, earlier transplanting date tended to increase biomass because of a similar growth rate (data not shown).

The difference in the biomass productivity was associated with that in nitrogen (N) uptake by rice (Fig. 3). The dry weights of the above-ground part and panicle were proportional to their N content at all phenological stages in spite of differences in year and field elevation. Change with the lapse of time in N uptake by rice both in 1997 and 1998 showed features similar to that in biomass until around heading (mid-October) (Fig. 4). Although the values were slightly scattered, N uptake rate was higher in the lower field, and increased almost linearly until heading reaching a plateau and then appeared to stop increasing.

Leaf area index (LAI) was also proportional to N uptake by the plant. The maximum LAI among the study fields during the period from panicle initiation (PI) to heading was as low as about 2. Such an insufficient leaf expansion was obviously one of the causes of low productivity in the farmers’ fields.

2. Toposequential difference in rice biomass and yield at maturity

Since upper fields had severer water stress, less fertile soil and later transplanting date, rice biomass declined with ascending the field elevation (Fig. 5). Table 2b shows the differences in rice biomass and yield among the subecosystems in 1998. While rice biomass was the largest in the MDW field, yield was the highest at the favorable subecosystem because of low harvest index (HI) in the MDW field. Lodging in the MDW field seriously reduced HI. In the SWd field, rice biomass and yield were extremely small, 268 and only 53 g m$^{-2}$, respectively, on the average. The difference of the productivity between the SWf field and the SWds field was distinctly smaller than that between the SWd and SWd fields.

The correlations of biomass with transplanting date and N fertilizer application rate in 1998 also indicated that rice biomass was associated with transplanting date, while the association with N fertilizer was relatively weak (Table 3a). The application rate of N fertilizer had a stronger correlation with yield. As farmers did not apply chemical fertilizer in the fields which would have flood and drought, decline of yield in such a field made the correlation between N fertilizer and yield higher than that between N fertilizer and biomass. Moreover, since one of the major causes of the correlations in Table 3a appears to be the field elevation, the coefficients may not properly represent the effects of transplanting date and N fertilizer application rate. Therefore, we analyzed the effects in each subecosystem in the next section to reduce the toposequential difference.

3. Effects of transplanting date and N fertilizer application in each subecosystem (MDW field)

A major constraint for production was lodging in this subecosystem. Medium deep water (sometimes exceeding 50 cm) produced excessive plant height, which reached 2 m in some fields, and caused severe lodging. Excess of biomass production may also play the same role as medium deep water, which fact was indicated by the strong negative correlation between
HI and biomass (Table 3b). Thus, earlier transplanting tended to produce a larger biomass but not to give a higher yield. No significant difference in biomass or yield was observed between direct seeding and transplanting (data not shown).

(2) **Shallow water, favorable subecosystem (SWf field)**

The negative correlation between HI and biomass was also observed in this subecosystem (Table 3c). Although both earlier transplanting and large amounts
of fertilization increased biomass, yield was not significantly correlated with transplanting date but with N fertilizer rate. This suggests that earlier transplanting increased plant height and slightly decreased yield by lodging. The regression equation of N fertilizer rate against yield indicated that 1 g of N fertilizer increased only 10 g of grain (data not shown).

(3) Shallow water, drought- and submergence-prone subecosystem (SWds field)
Transplanting date had stronger correlation with both biomass and yield than N fertilizer application rate did in this subecosystem (Table 3d). One-day-earlier transplanting increased about 4.5 g-grain. Difference in the effect of N fertilizer between the SWf and SWds fields was not significant, but that in the SWds and the SWd fields indicates that biomass production is insufficient there. Long growth duration makes it possible to produce large biomass with small leaf area. The duration is also necessary to absorb nitrogen under such an unfertile condition (Wada and Cruz, 1989; Evans, 1993).

Earlier transplanting was sometimes avoided due to a lack of standing water (Fukui, 1993; Kono et al., 2001). However, in this study, earlier transplanting increased yield even under a severe water stress condition in the SWd field, where standing water was available for less than one month during crop season. The planted cultivars, KDML105 and RD6, have high ability of recovering from water stress during vegetative growth, which is advantageous to earlier transplanting (Wade et al., 2000). The disadvantage of earlier transplanting may happen only when drought is so long and severe. The duration of rain intermission in the rainy season, so called dry-spell, was about 2 weeks in 1997 and 1998, and a dry-spell of more than 2 weeks rarely happens in rainy season in Northeast Thailand (Vorasoot et al., 1985; also cf. Polthanee, 1996). Irrigation with small pump is also becoming common (Miyagawa et al., 2002). On the contrary, the strong correlations among transplanting date, biomass production and yield in both the SWds and the SWd fields indicate that biomass production is insufficient there. Long growth duration makes it possible to produce large biomass with small leaf area. The duration is also necessary to absorb nitrogen under such an unfertile condition (Wada and Cruz, 1989; Evans, 1993).

Discussion
In the mini-watershed, relative elevation, which dominated the distribution of soil fertility and water availability, was closely related with rice productivity. The strong negative correlation of transplanting date with rice production was possibly derived from earlier transplanting at a lower elevation. Categorization of toposequence in this study decreased the effect of variation in environmental resources, which was confirmed by the relatively small correlation between rice production and field elevation (Table 3b–c), and revealed the effect of farmer’s crop management. Earlier transplanting tended to produce a larger biomass of rice, but it increased plant height often resulting in severer lodging in MDW and SWf fields. Although the effect of nitrogen (N) fertilizer was generally small, the efficiency was apparent in the fields where rice biomass was small due to later transplanting or unfertile soil.

Too large biomass production with long growth duration usually does not increase yield (Akita, 1989; Evans, 1993). This phenomenon was observed in MDW and the SWI fields in this study. Introduction of modern high yielding cultivars must be one method of improving rice productivity in SWI. Although medium deep water (e.g. 50cm) was hardly coped by such modern cultivars with short stature, some hopeful lines were recently developed (Gregorio et al., 2002). On the contrary, the strong correlations among transplanting date, biomass production and yield in both the SWds and the SWd fields indicate that biomass production is insufficient there. Long growth duration makes it possible to produce large biomass with small leaf area. The duration is also necessary to absorb nitrogen under such an unfertile condition (Wada and Cruz, 1989; Evans, 1993).

Earlier transplanting was sometimes avoided due to a lack of standing water (Fukui, 1993; Kono et al., 2001). However, in this study, earlier transplanting increased yield even under a severe water stress condition in the SWd field, where standing water was available for less than one month during crop season. The planted cultivars, KDML105 and RD6, have high ability of recovering from water stress during vegetative growth, which is advantageous to earlier transplanting (Wade et al., 2000). The disadvantage of earlier transplanting may happen only when drought is so long and severe. The duration of rain intermission in the rainy season, so called dry-spell, was about 2 weeks in 1997 and 1998, and a dry-spell of more than 2 weeks rarely happens in rainy season in Northeast Thailand (Vorasoot et al., 1985; also cf. Polthanee, 1996). Irrigation with small pump is also becoming common (Miyagawa et al., 1999). These facts support the advantage of earlier transplanting.

Many investigators reported that the farmer’s management is relatively well adapted to toposequential distribution of environmental resources (Fukui, 1993; Craig and Pison, 1985). The results of this study indicated that farmers can still improve their management for higher rice yield. Farmers commonly delay transplanting in upper fields in mini-watershed in a droughty year, but earlier transplanting (e.g. in early July), is advantageous if pumping irrigation is
available. Although a differing transplanting date is required due to labor shortage in a sufficient-rainfall year, the seedlings should be transplanted earlier in upper fields and later in lower fields on the contrary to the present management. Direct seeding is also acceptable in the deep-water zone in the case of labor shortage. Many investigators reported the difference in productivity was small between transplanting and direct seeding where abundant water was supplied (Naklang et al., 1996; Miyagawa et al., 1998). Efficiency of chemical fertilizer application may also be improved by reducing the amount of fertilizer in the SWf field and by increasing it in the SWd fields.

In northeast Thailand, new rice cultivars (Somrith, 1996; Supapoj, 1996) and new crop management (Herrera et al., 1997; Whitbread et al. 1999) were suggested to improve rice production, but have not been common yet. Since farmers have fields belonging to different subecosystems in which effects of management are totally different as this study showed, it is important to pay attention to what subecosystem is the target when new cultivars and new managements are introduced. Moreover, since boundaries of subecosystems may change depending on weather condition, it is important to give the simple and flexible guide along the toposequence for the introduction of new techniques.

References

Akita, S. 1989. Improving yield potential in tropical rice. In Progress in Irrigated Rice Research. IRRI, Los Banos. 41-73.

Bunduang, R. and Uchin, S. 1990. Introduction to Rice and Cereals in Temperate Countries. Department of Agriculture, Bangkok. 1-31.

Changprai, C., Chotimon, A., Thuduan, V., Thipsuwan, C., Lepananontha, J. and Kittivarak, S. 1971. Detailed reconnaissance soil map of Ubon Ratchathani province. Soil Survey Division, Department of Land Development, Bangkok. 1-14.

Craig, I.A. and Pison, U. 1985. Overview of rainfed agriculture in Northisest Thailand. In Rainfed Agriculture in Northeast Thailand. KKF Cooperative Research Project, USDA/USAID Dryland Agriculture Project. 24-36.

Evans, L. T. 1993. Crop Evolution, Adaptation and Yield. Cambridge University Press, Cambridge. 1-500.

Fukai, S., Sittisuang, P. and Chanphengsay, M. 1998. Increasing production of rainfed lowland rice in drought prone environment. Plant Prod. Sci. 1 : 75-82.

Fukai, H. 1993. Food and Population in a Northeast Thai Village. Translated by P. Hawkess. University of Hawaii press. Honolulu. 1-421.

Gregorio, G.B., Senadhir, D., Mendoza, R.D., Manigbas, N.L., Roxas, J.P. and Guerta, C.Q. 2002. Progress in breeding for salinity tolerance and associated abiotic stresses in rice. Field Crops Res. 76 : 91-101.

Herrera, W.T., Garity, D.P. and Veijas, C. 1997. Management of Sesamia nonatata green manure crops grown prior to rainfed lowland rice on sandy soils. Field Crops Res. 49 : 259-268.

Homma, K., Horie, T., Ohnishi, M., Shiraiwa, T., Supapoj, N., Matsumoto, N. and Kabaki, N. 2001. Quantifying the toposequential distribution of environmental resources and its relationship with rice productivity. In S Fukai, and J. Basnayake eds., Increased Lowland Rice Production in the Mekong Region. ACIAR Proceedings, 101. ACIAR, Canberra. 281-291.

Homma, K., Horie, T., Shiraiwa, T., Supapoj, N., Matsumoto, N. and Kabaki, N. 2003. Toposequential variation in soil fertility and rice productivity of rainfed lowland paddy fields in mini-watershed (Nong) in Northeast Thailand. Plant Prod. Sci. 6 : 147-153.

Homma, K., Horie, T., Shiraiwa, T., Srirodok, S. and Supapoj, N. 2004. Delay of heading date as an index of water stress in rainfed rice in mini-watersheds in Northeast Thailand. Field Crops Res. 88 : 11-19.

Khush, G.S. 1984. Terminology for rice growing environments. In Terminology for Rice Growing Environment. IRRI, Los Baños. 5-10.

Kittayarar, S. 1971. Soil Series Description of the North East. Soil Survey Division, Department of Land Development, Bangkok. 1-43.

Kono, Y., Tomita, S., Nagata, Y., Iwama, K., Nawata, E., Junthotai, K., Katawatin, R., Kyuma, K., Miyagawa, S., Niren, T., Noichana, C., Sakurathani, T., Siributa, A. and Watanabe, K. 2001. GIS-based crop modelling approach to evaluating the productivity of rainfed lowland paddy in North-East Thailand. In : S Fukai and J. Basnayake eds., Increased Lowland Rice Production in the Mekong Region. ACIAR proceedings 101. ACIAR, Canberra. 301-318.

Mackill, D.J., Coffman, W.R. and Garrity, D.P. 1996. Rainfed Lowland Rice Improvement. IRRI, Manila. 1-211.

Miyagawa, S. and Kuroda, T. 1988. Effects of environmental and technical factors on rice yield in rain-fed paddy fields of Northeast Thailand. Jpn. J. Crop Sci. 57 : 773-781.

Miyagawa, S. 1995. Expansion of an improved variety into rainfed rice cultivation in Northeast Thailand. Southeast Asian Studies 33 : 187-203.

Miyagawa, S., Koncham, S. and Kono, Y. 1998. Yielding ability in direct seeding rice culture in Northeast Thailand. Jpn. J. Trop. Agr. 42 : 248-256.

Miyagawa, S., Kono, Y., Nagata, Y. and Nawata, E. 1999. Technical changes in rainfed rice cultivation in Northeast Thailand. In T. Horie, S. Geng, T. Amano, T. Inamura and T. Shiraiwa eds., Proc. Int. Symp. World Food Security and Crop Production Technologies for Tomorrow. Kyoto. 169-172.

Naklang, K., Fukai, S. and Nathabut, K. 1996. Growth of rice cultivars by direct seeding and transplanting under upland and lowland conditions. Field Crops Res. 48 : 115-123.

Oinhishi, M., Horie, T., Homma, K., Kondo, S., Takano, H., Inamura, T., Thonghai, C. and Supapoj, N. 1999. Modeling and evaluation of productivity of rainfed rice in Northeast Thailand. In T. Horie, S. Geng, T. Amano, T. Inamura and T. Shiraiwa eds., Proc. Int. Symp. World Food Security and Crop Production Technologies for Tomorrow. Kyoto. 173-176.

Pandy, S. 1998. Nutrient management technologies for rainfed rice in tomorrow’s Asia : economic and institutional considerations. In : J. K. Ladha, L. Wade, A. Dobermann, W. Reichardt, G.J.D. Kirk and C. Piggin eds., Rainfed Lowland Rice : Advances in Nutrient Management Research. IRRI,
Polthanee, A. 1996. Rice-based cropping systems in Northeast Thailand. In : S. Fukai, M. Cooper and J. Salisbury eds., Breeding Strategies for Rainfed Lowland Rice in Drought-prone Environments. ACIAR Proceedings 77, Canberra. 13-22.

Somrith, B. 1996. Cultivar improvement for rainfed lowland rice in Thailand. In : S. Fukai, M. Cooper and J. Salisbury eds., Breeding Strategies for Rainfed Lowland Rice in Drought-prone Environments. ACIAR Proceedings 77, Canberra. 36-42.

Supapoj, N. 1996. Rice line IR43070-UBN-501-2-1-1-1 (Neaw Ubon 2). Ubon Rice Research Center, Ubon. 1-17*.

Vorasoot, N., Jintrawet, A., Limpinuntana, V., Charoenwatana, T. and Virmani, S.M. 1985. Rainfall analysis for the Northeast Thailand. Khon Kaen Univ., Khon Kaen. 1-207.

Wada, G. and Cruz, P. C. S. 1989. Varietal difference in nitrogen response of rice plants with special reference to growth duration. Jpn. J. Crop. Sci. 58 : 732-739.

Wade, L. J., Fukai, S., Samson, B. K., Ali, A. and Mazid, M. A. 1999. Rainfed lowland rice : physical environment and cultivar requirements. Field Crops Res. 64 : 3-12.

Wade, L. J., Kamoshita, A., Yamauchi, A. and Azhiri-Sigari, T. 2000. Genotypic variation in response of rainfed lowland rice to drought and rewatering. 1. Growth and water use. Plant Prod. Sci. 3 : 173-179.

Whitbread, A., Blair, G., Naklang, K., Lefroy, R., Wonprasaid, S., Konboon, Y. and Suriya-arunroj, D. 1999. The management of rice straw, fertilizers and leaf litters in rice cropping systems in Northeast Thailand. 2. Rice yields and nutrient balances. Plant and Soil 209 : 29-36.

* In Thai.