High-Yielding Performance of a New Rice Variety, IR53650 in Mildly Improved Acid Sulfate Soil Conditions

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Acid sulfate soil is one of the problem soils in the tropical Asia and Africa, which is formed by oxidation of upcoming iron sulfate and pyrite from the bottom of ancient seas or lagoons (Suthipradit et al., 1995; Farina et al., 2000). In most cases, pH of acid sulfate soil becomes as low as nearly 3.0, and it causes low productivity in many kinds of the crops (Attanandana et al., 1999). In Narathiwat, Province in the most southern part of Thailand near the border to Malaysia, acid sulfate soil is a major cause of low yield of rice, and hence improvement of acid sulfate soil is an urgent issue (Kang et al., 2001). Application of lime is the most practical and useful means to improve the crop yield in acid soil conditions, but the increasing cost of lime is gradually making it difficult to cultivate rice in this region. A solution to this problem would be to cultivate acid soil-tolerant varieties using a small amount of lime (Clark et al., 1997).

A few years ago, we identified the variety IR53650 as an acid soil-tolerant variety in a screening test which was made with the seedlings on a nursery bed (Kang and Ishii, 2003). IR53650 was developed by D. Senadhira of The International Rice Research Institute (IRRI), initially as a submergence-tolerant variety. In this sense, the identification of IR53650 as an acid soil-tolerant variety might be incidental. The purpose of this study was to confirm the yielding performance of IR53650 cultivated in paddy fields with acid sulfate soil mildly improved by applying a small amount of lime in Narathiwat.

Materials and Methods

Two experiments were conducted in Pikun Thong Royal Development Centre in Narathiwat Province of southern Thailand. The first experiment (Exp. 1) was made with the plants grown in the pots under greenhouse conditions from January to April 1997, and the second one (Exp. 2) was with the plants grown in the field from May to September 1999.

1. Yield trials in a greenhouse (Experiment 1)

A preliminary experiment with potted plants grown in a greenhouse was done prior to the field trial in order to test the acid soil tolerance of IR53650 in terms of the yield under the precise monitoring of the soil acidity. Based on the results of our previous study (Kang and Ishii, 2003), KDML105, and FR13A, served as a tolerant, and an intolerant reference variety, respectively, in the present study. IR53650 was developed from a crossing of IR9764-45-2-2 as the female parent and BKNFR76106-16-0-1 derived from FR13A as the male parent.

The typical acid sulfate soil of Munoh series defined by Sithibush et al. (1996) was collected in Tak-bai region of Narathiwat Province, and 9 kg of the dried soil was packed in a 1/2,000 a Wagner pot. The pots were then flooded. The seeds were sown in the nursery on 12 December 1996 and seedlings were transplanted to the pot on 20 January 1997. Three grams of compound chemical fertilizer (N-P-K, 16-20-0) were applied as surface layer application to each pot as the basal dressing, and another 3 grams each were applied at the maximum tillering stage, and at the panicle initiation stage. A seedling of each variety was transplanted to the same pot, so that three plants of different varieties were grown in each pot.

Two weeks before transplanting, lime was applied to the pots at two levels. Four pots were prepared for each liming level. The level of lime application was determined according to the method of Sithibush et al. (1996) for improvement of the acid sulfate soil. Full lime requirement (1 LR) corresponded to the amount of lime (CaCO₃) that makes the soil pH 7.0, and 0.5 LR is half amount of 1 LR. In this experiment, 140, and 70 g of lime was applied to the surface layer of the soil in a pot, which corresponded to 1 LR, and 0.5 LR liming levels, respectively. The temperature in the greenhouse was 29 ± 2°C in the daytime and 22 ± 1°C.
at night. The experiment was done in a completely randomized block design with three varieties and two levels of liming. Four pots for each liming level were used to determine the dry matter weight and the grain yield.

The grains were manually threshed and air-dried for two days to determine the grain yield, and the remaining parts were dried in an oven for three days at 80°C, to determine the dry matter weight. The yield and yield components were determined according to the protocol of Sato and Saigusa (1995). The pH of soil solution was measured every two weeks from the transplanting to the harvest time with a portable pH meter (LACOM pH tester, Iuchi Co., Ltd., Japan).

2. Yield trials in the paddy field (Experiment 2)

After the preliminary yield trial with the potted plants, the yield trial in the field was conducted in Pikun Thong Royal Development Centre in Narathiwat from 21 May to 26 September 1999. The temperature in the field during the experimental period was nearly 30 ± 2°C in the daytime and 23 ± 1°C at night, and the average amount of rainfall was 100 to 180 mm/month. Two varieties, Suphanburi 90 (S-buri 90) and Chainat 1, both developed in Thailand for good yielding under acid sulfate soil conditions, were used as the reference variety to IR53650. The fertilizer was applied in the form of compound fertilizer (N-P-K, 16-20-0) at the rate of 188 kg ha⁻¹ as the basal dressing, 12.5 kg ha⁻¹ at the maximum tillering stage in seven weeks after transplanting, and the same amount at the panicle initiation stage. Twenty eight-day-old seedlings were transplanted at a density of 25 × 25 cm to the paddy field. The soil pH was improved from 3.0 to 5.0 by application of 14 t CaCO₃ ha⁻¹, which corresponded to 0.5 LR level defined by Sitthibush et al. (1996).

The size of a plot was 4 × 3 m for each variety in a completely randomized block design. Twelve hills of each variety from a plot were harvested, and served for the determination of the yield and yield components.

A portable CO₂ exchange rate measuring analyzer (LCA-4, ADC Co., Ltd., England) was used to determine the net CO₂ exchange rate per unit leaf area (CER). The CER was measured in the field on the fully expanded upper leaves from twelve plants of each variety at six weeks after transplanting under the conditions of 350 ppm CO₂ and the natural light intensity of about 2,000 µmol m⁻² s⁻¹.

3. Statistics

In Exp. 1, a one-way analysis of variance (ANOVA) was made for each lime application level. The number of plants for each variety was four. When a significant difference was identified by ANOVA, Duncan's Multiple Range Test (DMRT) was applied. The same procedures of statistical analysis were applied for Exp. 2 too.

Results and Discussion

In Exp. 1, we measured the pH of the soil solution continuously throughout the whole period of the experiment. The pH of soil solution in the 0.5 LR
Pot increased gradually, reaching nearly 6.5 at the harvesting time, whereas that in the 1.0 LR pot was as high as 7.0 already at the time of transplanting, and did not change throughout the whole period of the experiment (Fig. 1). It was considered, therefore, that the pH 7 in 1.0 LR pot observed at transplanting, had probably been achieved immediately after lime was applied two weeks before transplanting. All the plants in 0 LR pots died within one day after transplanting, indicating that rice plants can not survive in the acid sulfate soil conditions of Narathiwat without lime application.

The average grain yield per individual plant was significantly higher in IR53650 than in two other varieties in 1 LR and 0.5 LR conditions (Fig. 2). This suggests that IR53650 has a high-yielding potential which was demonstrated under favorable soil conditions such as 1 LR, and also that it has acid soil tolerance for the grain yield in the mildly improved acid soil conditions such as 0.5 LR. The grain yield was significantly (P < 0.05) correlated with the aboveground dry matter yield (Fig. 3), suggesting that the grain yield of rice under the acid soil conditions, even though it is mild, is limited by the source capacity for the grain yield formation.

To confirm the superior high-yielding performance of IR53650 observed with the potted plant, the yield trial was made in the field where the soil pH was mildly improved by lime application at the 0.5 LR level, with two improved Thai varieties as a reference (Exp. 2). The average grain yield was significantly (P < 0.05 for 1 LR and P < 0.05 for 0.5 LR) correlated with the aboveground dry matter yield (Fig. 4), suggesting that the grain yield of rice under the acid soil conditions, even though it is mild, is limited by the source capacity for the grain yield formation.

Table 1. Net CO₂ exchange rate (CER) of three rice varieties.

| Variety   | CER (μmol CO₂ m⁻² s⁻¹) | DMRT |
|-----------|-------------------------|------|
| Chainat   | 18.40                   | c    |
| S-buri    | 22.57                   | b    |
| IR53650   | 24.38                   | a    |
| Mean      | 21.78                   |      |

DMRT, Duncan’s Multiple Range Test. Same letters in DMRT mean no significant difference at probability level 0.05. As for the conditions for the determination of CER, see the text.
Table 2. Yield components of three rice varieties.

| Variety | No. of panicles (m²) | No. of grain (panicle) | 1000-grain wt.(g) | Filled grains(%) | Harvest index |
|---------|----------------------|------------------------|-------------------|-----------------|---------------|
| Chainat 1 | 129<sup>b</sup> | 138<sup>b</sup> | 25.3<sup>ns</sup> | 84.6<sup>b</sup> | 0.52<sup>ns</sup> |
| S-buri 90 | 125<sup>b</sup> | 172<sup>a</sup> | 25.3<sup>ns</sup> | 89.6<sup>b</sup> | 0.54<sup>ns</sup> |
| IR53650 | 176<sup>a</sup> | 186<sup>a</sup> | 25.6<sup>ns</sup> | 85.6<sup>a</sup> | 0.51<sup>ns</sup> |
| Mean | 143 | 165 | 25.4 | 86.6 | 0.52 |

ns: not significant. Same letters indicate that no significant difference at probability level 0.05 was observed by DMRT. The determination of yield component was made on twelve hills for each variety.

IR53650 followed by S-buri 90 (3.0 t ha⁻¹), and Chainat 1 (2.4 t ha⁻¹). The grain yield was significantly (P < 0.01) correlated with total above ground dry matter weight (Fig. 5). This suggests that the high dry matter production leads to a high grain yield in rice under mildly improved acid sulfate soil conditions. Belesky and Fedders (1995) reported that high-yielding genotypes in acid soil conditions showed greater root/shoot ratio when they were supplied with lime than low-yielding genotypes which did not respond to application of lime in any morphological traits. Khan et al. (1994) found by a pot experiment that the acidity and salinity stress in rice under acid sulfate soil conditions were alleviated and/or improved by the application of lime at the rate of 5.0-7.5 g kg⁻¹ soil. Attanandana et al. (1999) reported that application of lime and trace elements such as Cu, B and Zn raised the grain yield of rice with a marked decrease of sterility. From these results, application of lime every three years is considered to be the most powerful means to improve the grain yield in acid sulfate soil conditions. The present paper demonstrated that rice yield in acid sulfate soil could be improved by cultivating acid-tolerant varieties such as IR53650, and by applying lime at a low level such as 0.5 LR. This will be valuable information for the farmers to obtain a good yielding performance saving the cost for lime application.

CO₂ exchange rate (CER), a factor of source capacity, was significantly higher in IR53650 than in the two Thai rice varieties (Table 1). This suggests that high CER contributed to high dry matter production in IR53650, and this large source capacity was the major cause of high yielding of the variety (Table 1 and Fig. 4). In addition, a large number of panicles per unit land area and also a large number of grains per panicle were the major components for high yielding in IR53650 (Table 2), suggesting that the yield components associated with the sink capacity, also contributed to the high-yielding property of IR53650 along with a large source capacity predicted by high dry matter production (Fig. 5). Ying et al. (1998) reported that the yield potential of rice in the tropics could be determined mainly by the capacity of dry matter production and the size of sink organs. High-yielding performance of IR53650 under the lime application of 0.5 LR could be attributed to both high dry matter production and large sink capacity (Fig. 5 and Table 2).

Since the present paper clearly showed that the variety IR53650 was a highly promising variety in the acid sulfate soil conditions, we are planning to make yield trials in the farmers’ field with their own management to confirm the merit of this variety in the region of acid sulfate soil in Thailand.

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