Effect of Plot Size on Accuracy of Yield Estimation of Rainfed Lowland Rice Genotypes with Different Plant Heights and Grown under Different Soil Fertility Conditions

Suwat Jearakongman1, Somdej Immark2, Apichart Noenplub3, Shu Fukai3 and Mark Cooper3

1Khon Kaen Rice Experiment Station, Khon Kaen, Thailand; 2Phitsanulok Rice Research Center, Phitsanulok, Thailand; 3School of Land and Food Sciences, The University of Queensland, Brisbane 4072, Australia

Abstract: Breeding programs for rainfed lowland rice normally use large plot sizes for accurate estimation of yield. Resource requirements are reduced and more genotypes can be tested if a small plot size can be used. A total of 4 experiments was conducted at high and low soil fertility locations in Thailand to determine the influence of plot size and arrangement of tall and short genotypes in small plots on the estimation of yield of genotypes differing in height. Ten to sixteen genotypes were grown in different orders of tall and short genotypes within 2-row plots and also in random arrangements in 4-row, 6-row and 16-row plots. Results showed that taller genotypes tended to suppress the performance of the neighboring shorter genotypes. Consequently the yield results from 2-row plots, in which genotypes were randomly allocated, were unreliable at the high soil fertility location with more vigorous growth, although they were sufficient at the low soil fertility location. Thus plot sizes of 4 and 6-rows appear necessary for accurate estimation of yield across environments. However, when all short genotypes were grouped together and formed a block, and all tall genotypes grouped to form another block, yield results from 2-row plots showed a rather small effect of the competition between the neighbouring genotypes. The yield estimation was improved further by adjusting yield according to the height of each genotype by using covariance analysis. With these modifications, 2-row plots were found to be sufficient for accurate estimation of yield.

Key words: Competition, Plant height, Plot size, Rice genotypes, Selection trial, Yield estimation.

Results of a series of multi-environment breeding trials showed that there is a large genotype by environment interaction component of variation for yield in rainfed lowland rice in Thailand (Cooper and Somrith, 1997). Relative to the current Thai breeding strategy, an increase in the number of inter-station and on-farm trials, together with testing a larger number of breeding lines, has been recommended as a necessary modification to increase the chance of selecting high yielding genotypes widely adapted to the target region of the rainfed lowland rice breeding program in Thailand (Fukai and Cooper, 1999). With space and other resource constraints an increase in the total number of plots in a breeding program may be possible if the plot size is reduced. The choice of plot size depends on many factors such as the nature of the genotypes to be used, the availability of experimental area and resources, and statistical precision required for testing hypothesis and estimations (Chaves and Miranda-Filho, 1992). Unnecessarily large plots would waste time and resources (Gomez, 1972 a). The optimal plot size may be described as that which reduces the variation due to uncontrolled variables and, therefore, increases the accuracy to the optimum (Puntener, 1981). Plot size can be defined by row number. Currently 4-row and 6-row plots are used and 1 border row from each side is not harvested for intra- and inter-station yield trials whereas a 16-row plot treatment with harvesting of 8 centre rows is used for on-farm yield trials for rainfed lowland rice in North and Northeast Thailand.

In a breeding trial to be used for selection on yield variation different genotypes are placed side by side in the field. As a consequence border plants have an environment different from the plot's center and the plants within a plot will be exposed to different competitive environments (Gomez and Gomez, 1984). Competition between adjacent plots in a breeding trial is magnified by large morphological differences of test genotypes. The complexity of relationships between morphological characteristics of genotypes and competitive ability of these genotypes in adjacent plots have been recognized by many researchers, for example, Gomez (1972b) and Thomas et al. (1994). The confounded effects of intergenotypic competition in small and large plots have been examined in wheat (Fischer, 1978), rice (Gomez, 1972b) and maize (Chaves and Miranda-Filho, 1992); the experiment with 1-m² plots was less efficient in discriminating for yield among progenies than those with 5-m². Most of those results of grain yield variation in small plots are generally related to genotype differences in plant height. For example in wheat, Fischer (1978) found that differences in height and to a lesser extent leaf angle substantially confounded yield in unbordered small plots; taller genotypes showed

Received 19 July 2002. Accepted 12 September 2002. Corresponding author: S. Fukai (s.fukai@uq.edu.au fax +61-7 33651168).

Abbreviations: DAT, Days after transplanting; PSL, Phitsanulok; S, Short; T, Tall.
a yield advantage of from 0.8 to 2.5% of mean yield per cm height advantage, the actual value depending on the exact arrangement of genotypes. In rice, Gomez (1972 b) suggested that estimating yield by excluding two border rows on each side of the plot is adequate to cope with this inter-plot competition. Gomez and Gomez (1984) suggested that yield trials could be done in small plots if genotypes that are fairly homogeneous in competitive ability are grouped together in a block, and the blocks with genotypes of different height groups are randomly arranged. Thus, the objective of the work reported here is to determine the influence of plot size and genotype arrangement on the relative yields of rice genotypes differing in height and to assess whether small plots could be used to accommodate a large number of genotypes in multi-environmental breeding trials. If successful these screening methods will provide a great benefit in reducing the cost and time involved in traditional screening on the basis of grain yield determined in large plots.

Materials and Methods

1. Experimental locations

Two lowland rice experiments were conducted during the wet season of 1997 and 1998 at Ta Pra near Khon Kaen in the Northeast and Phitsanulok Rice Research Center (PSL) in the North of Thailand. Properties of the soils (0-15 cm) at both locations are shown in Table 1. The soil at PSL was fertile while the soil at Ta Pra was sandy with low fertility. In all experiments there were bunds to prevent runoff and to maintain standing water. The experiments at PSL were irrigated as required to ensure a high level of standing water throughout crop growth. The Ta Pra experiments were conducted without irrigation, except for one application to enable transplanting in 1997 because there was no standing water at the appropriate transplanting time.

2. Treatments

(1) 1997 experiments

A split-plot design with 3 replications was used at both locations. The plot-size treatments were as follows; 2-row (0.5 m × 5.0 m) and 4-row (1.0 m × 5.0 m) treatments had two plots in each replication, while 6-row (1.5 m × 5.0 m) and 16-row (4.0 m × 5.0 m) treatments had only one, and these 6 plots were randomized within each replication. Ten rice genotypes differing in height were grown randomly within each plot. Five genotypes, RD23, IR37514-PMI-5-B-1-2, IR66327-KKN-25-P1-3R-0, IR66327-KKN-77-P2-3R-0, and IR66368-CPA-85-P2-3R-0 had semi-dwarf stature. The other five genotypes, IR66369-CPA-72-P1-3R-0, KDML105, RD6, NSG19, and Chiang Saen (at Ta Pra) or Hahng Yi 71 (at PSL) were selected to represent a tall stature. At PSL, there was some rat damage to Chiang Saen in the seed bed prior to transplanting, and therefore Hahng Yi 71 was used. IR66327-KKN-25-P1-3R-0, IR66327-KKN-77-P2-3R-0, IR57514-PMI-5-B-1-2, IR66368-CPA-85-P2-3R-0 and IR66369-CPA-72-P1-3R-0 were promising advanced breeding lines selected from 1996 observation yield trials, and the other five, RD 23, KDML105, RD 6, NSG 19 and Chiang Saen (at Ta Pra) or Hahng Yi 71 (at PSL) were commonly grown cultivars in Thailand.

(2) 1998 experiments

A split-plot design with 4 replications was used at both locations. Six main-plot treatments were the plot size (row numbers) with different orders of tall (T) and short (S) genotype arrangement; 2-row (0.5m × 5.0m) complete blocking (TTTSSS...), 2-row partial blocking (TTSTTS...), 2-row alternate (TSTSTS...), 2-row random, 4-row (1.0 m × 5.0 m) random, and 6-row (1.5 m × 5.0 m) random. The 2-row, 4-row and 6-row random was the same as in the 1997 experiments and genotypes were randomly allocated within each main-plot. Four different orders of tall and short genotype arrangement in the 2-row plot treatments were carried out to determine the influence of adjacent genotypes on competition and yield of genotypes differing in height. The accuracy of estimating yield in small plots may be increased by blocking genotypes with similar heights together in either complete blocking (all genotypes together) or partial blocking (2 genotypes together). The 2-row alternate was included to examine the extreme in competition between tall and short genotypes.

Sub-plot treatments were 16 contrasting genotypes. Eight genotypes, IR66327-KKN-12-P1-3R-0, IR66327-KKN-54-P1-3R-0, IR66327-KKN-54-P1-3R-0, IR66327-KKN-54-P1-3R-0, IR66327-KKN-23-P1-3R-0, IR66321-UBN-43-P1-3R-0, IR66321-UBN-37-P1-3R-0, IR66368-CPA-85-P2-3R-0, and IR57514-PMI-5-B-1-2 had semi-dwarf stature with average height of around 120 cm. The other
Table 2. Change in plant height (cm) of various rice genotypes in short and tall groups at Ta Pra and PSL in 1997 wet season.

|        | Ta Pra | PSL |        |       |       |        |       |
|--------|--------|-----|--------|-------|-------|--------|-------|
|        | 30DAT* | 60DAT | Maturity | 30DAT | 60DAT | Maturity |       |
| RD23   | 48de   | 98c  | 104£   | 63c   | 116cd | 122fg  |       |
| IR66327-KKN-77-P2-3R-0 | 49d     | 96cd | 129d   | 59d   | 126c  | 135e   |       |
| IR66327-KKN-25-P1-3R-0 | 43f     | 89d  | 118e   | 50e   | 102d  | 124f   |       |
| IR66368-CPA-85-P2-3R-O | 47ef    | 92cd | 123de  | 61cd  | 120c  | 121g   |       |
| IR57514-PMI-5-B-1-2 | 49de    | 97cd | 121e   | 64c   | 112cd | 124f   |       |
| Mean(short genotypes) | 47      | 94   | 119    | 59    | 115   | 125    |       |
| IR66369-CPA-72-P1-3R-O | 55bc    | 119b | 160b   | 73b   | 165ab | 173b   |       |
| KDML105 | 54bc   | 113b | 164b   | 70b   | 155b  | 164c   |       |
| RD6    | 52cd   | 115b | 173a   | 70b   | 174a  | 177a   |       |
| NSG19  | 58ab   | 128a | 147c   | 80a   | 156ab | 156d   |       |
| Chiang Saen(Ta Pra) | 60a     | 118b | 176a   |       |       |        |       |
| Hahng Yi71(PSL) |         | 79a  | 163ab  | 163c  |       |        |       |
| Mean(tall genotypes) | 56      | 119  | 164    | 74    | 163   | 167    |       |
| Average | 51      | 106  | 141    | 66    | 139   | 146    |       |
| F-value | 13.7**  | 25.7** | 138** | 6.25** | 22.1** | 667** |       |
| CV(%)  | 14.8    | 13.0 | 8.1    | 9.0   | 20.7  | 3.1    |       |

*DAT, Days after transplanting.
a. Means followed by the same letter in the same column are not significantly different at P=0.05.

eight genotypes, RD6, KDML105, IR66369-CPA-76-P2-3R-0, IR66368-CPA-55-P2-3R-0, IR66368-CPA-41-P1-3R-0, IR66369-CPA-86-P1-3R-0, IR66369-CPA-48-P2-3R-0, and IR66369-CPA-72-P1-3R-0 were selected to represent a tall stature with average height of around 150 cm. These genotypes, except for the popular cultivars RD6 and KDML105, were advanced promising lines in the rainfed lowland rice breeding program in Thailand. The tall cultivar KDML105 and short line IR57514-PMI-5-B-I-2 were used also for border plots and planted beside the tall or short genotypes at the first and last plots in the 2-row complete blocking treatment to reduce the error due to competition between the neighbouring tall and short genotypes. The tall and short groups flowered at almost the same time (average of 117 days after sowing) and produced almost the same grain yield (average 2.6 t ha⁻¹) in 1997.

3. Cultural conditions

The experiment at Ta Pra was transplanted on 1 August 1997 and on 27 August 1998, and at PSL on 18 August 1997 and on 16 August 1998. The seedlings were 30 days old at transplanting and about three seedlings were transplanted to each hill, spaced at 25 × 25 cm apart. Basal fertilizer was applied around the time of transplanting at a rate of 18.75–37.5–37.5 kg N-P₂O₅-K₃O ha⁻¹. Top dressing of N was applied at 18.75 kg ha⁻¹ around panicle initiation in September. Weeds were controlled manually, and thrips and other insects were controlled by applying insecticides. Fungicide was also applied at Ta Pra.

4. Measurements

Standing water level above the soil surface was determined about once a week. Flowering dates were recorded when 75% of the plants had flowered. Plant heights were measured three times at 30, 60 days after transplanting (DAT) and at maturity in all experiments. In 1997, tiller number was also determined on these days. In all experiments grain yields were estimated by harvesting all plants in the 2-row plots (without border row or border hills on harvesting rows), while the 2 central rows were harvested in 4-row plots and 4 central rows in 6-row plots leaving 1 border row on each side. On harvesting rows, 1 border hill at each end in 4-row and 6-row plots and 2 border hills in 6-row plots were not harvested. In 1998, in 6-row plots yields were estimated also from 2 central rows. The harvested area was 2 m × 4 m (8 rows × 16 hills) in 16-row plots used in 1997. The harvesting areas for 4-, 6-, and 16-row plots were those used in the local breeding program.
Table 3. Change in tiller number of rice genotypes in short and tall groups at Ta Pra and PSL in 1997 wet season.

|       | TaPra 30DAT* | TaPra 60DAT | TaPra Maturity | PSL 30DAT | PSL 60DAT | PSL Maturity |
|-------|--------------|-------------|----------------|-----------|-----------|-------------|
| RD 23 | 12a          | 11b         | 11ab           | 17bc      | 18b       | 15b         |
| IR66327-KKN-77-P2-3R-O | 11a        | 12ab        | 11ab           | 19ab      | 17bc      | 14bc        |
| IR66327-KKN-25-P1-3R-O | 12a        | 14a         | 12a            | 17bc      | 22a       | 19a         |
| IR66368-CPA-85-P2-3R-O | 11a        | 11b         | 10a            | 16c       | 17bc      | 13bc        |
| IR57314-PMI-5-B-1-2    | 10a         | 12ab        | 12a            | 20c       | 20ab      | 14bc        |
| Mean (short genotypes) | 11          | 12          | 11             | 18        | 19        | 15          |
| IR66369-CPA-72-P1-3R-O | 9a          | 11b         | 10b            | 17bc      | 16c       | 14bc        |
| KDML105                | 10a         | 11b         | 10b            | 15c       | 13d       | 14bc        |
| RD6                     | 9a          | 12ab        | 10b            | 18abc     | 16c       | 10c         |
| NSG19                   | 9a          | 11b         | 11ab           | 17bc      | 14cd      | 12bc        |
| Chiang Saen (Ta Pra)    | 7a          | 10c         | 6c             |           |           |             |
| Hahng Yi71 (PSL)        |             |             |                |           |           |             |
| Mean (tall genotypes)   | 9           | 11          | 9              | 16        | 14        | 12          |
| Average                 | 10          | 11          | 10             | 17        | 16        | 14          |
| F-value                 | 2.1**       | 16.2**      | 8.4**          | 5.5**     | 10.7**    | 10.8**      |
| CV(%)                   | 32.5        | 19.8        | 26.1           | 23.4      | 22.6      | 24.4        |

*DAT, Days after transplanting.

Results

1. 1997 Experiments

(1) Growing conditions and flowering time

Rainfall distribution at Ta Pra was such that there was no standing water in August and irrigation had to be applied for transplanting. Although Ta Pra had low rainfall in the growing season, standing water was retained until near maturity. The mean duration from sowing to flowering was 105 and 111 days for short and tall genotype groups, respectively, at Ta Pra, and 103 and 94 days at PSL. Because of early flowering, NSG19 and RD23 were damaged by rats and birds, especially at Ta Pra. In PSL, Hahng Yi 71 lodged severely as other genotypes in neighboring plots were still short when this genotype elongated. The results of these genotypes were excluded from further analysis. Lodging in PSL was also noted in other genotypes, particularly in 2-row plots.

(2) Competition effect on rice growth

The plant heights during early stages of growth increased at a slower rate at the less fertile Ta Pra than at PSL (Table 2). At 30 days after transplanting (DAT), tall genotypes were significantly taller than short genotypes, the mean plant height difference being around 15 cm at PSL, whereas it was only 9 cm at Ta Pra. The difference increased to 48 cm at PSL and around 25 cm at Ta Pra at 60 DAT. At maturity, the mean plant height was similar between the locations for both short and tall height groups.

The tiller number at 30 DAT was greater at PSL than Ta Pra (Table 3), although the difference became smaller with time. Short genotypes generally had more tillers than tall genotypes at both locations.

(3) Grain yield

The 16-row plots, which were wide enough to permit the removal of 4 border rows on each side at harvesting, may be considered to provide the most accurate yield estimation for a genotype. At PSL, short genotypes produced higher yield than tall genotypes in this large plot (Figure 1) while the difference was smaller when the plot size was reduced to 6-rows and 4-rows. By contrast, tall genotypes in 2-row plots showed a yield advantage. Thus, the effect of plot size on yield estimation was large at PSL and genotypic ranking in 2-row plots was different from that in 16-row plots. At Ta Pra there was no significant interaction between plot size and genotype for yield, although Chiang Saen tended to have a low yield in the 16-row plot where the crop lodged severely.

The yield of short genotypes in the 2-row plot was
affected by the height of the genotypes in the adjacent plots (Figure 2), particularly at PSL where the crops had more vigorous growth. The yield of a short genotype decreased when the mean height of the adjacent genotype increased, while this effect was not apparent at Ta Pra.

2. 1998 Experiments

(1) Growing conditions and flowering time

Rainfall at Ta Pra was high early in the rainy season (July) but stopped in early October. There was no standing water from around flowering time in late October to crop maturity. This may have affected crop phenology and yield of particularly late maturing genotypes. Although some tall genotypes lodged at near maturity, there were no severe yield-reducing effects at both locations.

The mean numbers of days to flowering were 102 and 99 days for short and tall groups, respectively at Ta Pra, and 101 and 95 days at PSL.

(2) Plant height

At 30 DAT, genotypes had a similar height of around 60-70 cm at both locations but thereafter height increased at a slower rate at Ta Pra than at PSL (Table 4). At maturity, the plant height at PSL was taller than that at Ta Pra by around 30 cm for the tall group and 25 cm for the short group. A large height difference among genotypes was observed at 60 DAT when the rice crops were close to the maximum tillering stage. At this time, the height difference between the tall and short groups was around 25 cm at Ta Pra, and more than 30 cm at PSL. Height measured at 60 DAT was strongly related to that at maturity among the 18 genotypes used in the experiments ($r=0.93^{**}$ at Ta Pra and $r=0.86^{**}$ at PSL).

(3) Grain yield

Mean grain yields of tall and short genotypes varied among the different plot sizes. Estimated mean grain yield from the 2-row plots, which included border hills for yield estimation, were generally higher than that from larger plot sizes, particularly at PSL (Table 5). The grain yield also varied among the 2-row plots that differed in blocking pattern of tall and short genotypes, with significant interaction between height group and genotype arrangement. Mean grain yield of the short genotypes was higher than that of the taller genotypes in the 2-row plots with complete blocking of all 8 genotypes of similar heights (.....TSSS.....). The mean yield of the short group in the alternate (.....TSTSTS.....), partial blocking (.....TTSSTT.....) and random arrangements was reduced due to severe competition from neighboring tall genotypes. The results from 4-row and 6-row plots showed higher mean yield of the short genotypes, as was also found in the 2-row complete blocking. The effects of plot size and genotype arrangement were greater at PSL than Ta Pra.

The difference between yield of 6-row plots where four centre rows were harvested and that of the other five row treatments was plotted against the plant height of each genotype (Figure 3). The 2-row random, alternate and partial blocking had the largest response to plant height indicating the existence of strong competition between tall and short genotypes, particularly at PSL where...
Table 4. Change in plant height (cm) of rice genotypes in short and tall groups at Ta Pra and PSL in 1998 wet season.

| Genotype          | TaPra 30DAT* | TaPra 60DAT | TaPra Maturity | PSL 30DAT | PSL 60DAT | PSL Maturity |
|-------------------|--------------|-------------|----------------|-----------|-----------|--------------|
| IR66327-KKN-12-P1-3R-0 | 64gh         | 87e         | 100f           | 59g       | 101f      | 134i         |
| IR66327-KKN-54-P1-3R-0 | 70d          | 96d         | 110e           | 56h       | 99f       | 122j         |
| IR66327-KKN-54-P2-3R-0 | 67ef         | 93d         | 103f           | 61f       | 106e      | 133i         |
| IR66327-KKN-23-P1-3R-0 | 59g          | 94d         | 101f           | 59g       | 107e      | 136j         |
| IR66321-UBN-43-P1-3R-0 | 70de         | 85ef        | 105f           | 64e       | 107e      | 136j         |
| IR66322-UBN-37-P1-3R-0 | 74ab         | 96d         | 118d           | 55h       | 92g       | 100i         |
| IR66368-CPA-85-P2-3R-0 | 63b          | 86ef        | 88h            | 53i       | 87h       | 109k         |
| IR57514-PMI-5-B-1-2 | 65fgh        | 83f         | 91g            | 65de      | 107e      | 123j         |
| Mean (short genotypes) | 66           | 93          | 102             | 59        | 101       | 127          |
| IR66369-CPA-76-P2-3R-0 | 77a          | 121a        | 130ab          | 71a       | 136a      | 151e         |
| IR66368-CPA-55-P2-3R-0 | 71d          | 120a        | 125c           | 65cd      | 130cd     | 156c         |
| IR66368-CPA-41-P1-3R-0 | 71d          | 120ab       | 126bc          | 68b       | 134ab     | 145g         |
| IR66369-CPA-66-P1-3R-0 | 75ab         | 117ab       | 128abc         | 68b       | 129d      | 152d         |
| IR66369-CPA-48-P2-3R-0 | 74bc         | 117ab       | 125c           | 69b       | 132bc     | 145g         |
| IR66331-SRN-92-P1-3R-0 | 69de         | 116b        | 131a           | 66c       | 135a      | 169a         |
| RD 6 | 71d | 119ab | 119d | 69b | 135a | 163b |
| KDML105 | 66fg | 111c | 112e | 68b | 129d | 148f |
| Mean (tall genotypes) | 72           | 118         | 125             | 68        | 132       | 154          |
| Average | 69 | 104 | 113 | 63 | 116 | 140 |
| CV (%) | 6.6 | 6.5 | 7.1 | 3.6 | 3.5 | 2.2 |

*DAT, Days after transplanting.
a, Means followed by the same letter in the same column are not significantly different at P = 0.05.

Table 5. Mean yield (kg ha⁻¹) of 2 groups of genotypes (Tall and Short) grown in different plot sizes at (a) PSL and (b) Ta Pra in 1998 wet season.

| Plot size (p) | Genotype (G) | Short (S) | Tall (T) | Mean | S-T  |
|---------------|--------------|-----------|----------|------|------|
| (a) PSL       |              |           |          |      |      |
| 2-row(TTTSTSSS) | 2754a        | 2609c     | 2682     | 145ns|
| 2-row(TTSTTSSS) | 2579ab       | 3143ab    | 2861     | -564**|
| 2-row(TSTSTTSS) | 2333b        | 3337a     | 2835     | -1004**|
| 2-row(random)  | 2503ab       | 3037b     | 2770     | -534**|
| 4-row(2rows harvested) | 2386b | 229d | 2340 | 91ns |
| 6-row(2rows harvested) | 2433b | 2036e | 2234 | 397**|
| 6-row(4rows harvested) | 2379b | 2108de | 2244 | 270**|
| G-Mean | 2481 | 2652 | 2566 |
| F-values 6.14** for plot size, 1.33 NS for genotype group, 32.10** for interaction |
| Comparison of 2-G mean at each P; LSD 5% = 220, LSD 1% = 302 |

| (b) Ta Pra     |              |           |          |      |      |
| 2-row(TTTSTSSS) | 2667ab       | 2114bc    | 2391     | 553**|
| 2-row(TTSTTSSS) | 2596abc      | 2476a     | 2521     | 90ns |
| 2-row(TSTSTTSS) | 2002d        | 2440ab    | 2221     | -439**|
| 2-row(random)  | 2348bc       | 2383abc   | 2366     | -35ns|
| 4-row(2rows harvested) | 2767a | 2483a | 2625 | 284**|
| 6-row(2rows harvested) | 2401bc | 2030c | 2215 | 370**|
| 6-row(4rows harvested) | 2285cd | 2051c | 2168 | 234ns|
| G-Mean | 2434 | 2283 | 2358 |

Comparison of 2-G means at each P; LSD 5% = 240, LSD 1% = 316.
** = significant at 1% level; * = significant at 5% level; ns = not significant.
a, Means followed by the same letter in the same column are not significantly different at P = 0.05.
height difference was large. By contrast, complete blocking of similar height genotypes (...TTTSSSS...) showed a rather small effect of the height.

When the yield in 2-row plots was adjusted with height as a covariate, this resulted in 2-row plots producing yields that were strongly related to those obtained in the 6-row plots (Figure 4). This effect of the adjustment was most effective ($R^2 = 0.72$ after adjustment) in the complete blocking arrangement of the 2-row plots.

**Discussion**

Estimated yields varied among different plot sizes. Yields of the shorter genotypes, despite their higher tillering ability in the present experiments, were generally underestimated in 2-rows when genotypes were randomly allocated, due to the effect of competition between neighbouring genotypes (Gomez, 1972b). When genotypes are grown in 2-row plots, a short genotype adjacent to taller genotypes would have intercepted less solar radiation than the same genotypes in a larger plot (Fischer 1978), and hence this would have resulted in less growth and underestimation of grain yield. The effects of plot size on competition and yield of contrasting genotypes were smaller at the location with low soil fertility and less vigorous growth (Ta Pra). Although the free water level above the ground was similar, particularly during early stages of growth, between the two locations in both experiments, the Ta Pra site as in most soils in the Northeast Thailand was low in organic matter, available phosphorus and cation exchange capacity (Jiraporncharoen, 1993) causing reduced
growth and hence reduced competition between neighbouring genotypes. Without irrigation water in most parts of the Northeast Thailand, the plot size effect may be rather small, except in the case of the extreme arrangement of 2-rows alternate (....TSTSTS....). On the other hand, plot size effects were strong at PSL in Northern Thailand where soil fertility is generally higher. Plants grew more vigorously and competition between neighbouring plots would be severe. Banziger et al. (1995) demonstrated a stronger competition effect between neighbouring genotypes when nitrogen was applied to maize, although in their experiments the application of N did not cause larger yield differences among genotypes at a smaller plot size of 1 row. It can be concluded from the present work at the PSL site that the use of 2-row plots does not appear appropriate in estimating yield as the yield varied greatly from that of larger plots. Therefore, a plot size of 4 to 6-rows is necessary for accurate estimation of yield in multi-location trials that are conducted under various growth environments. The results of the 1997 experiments, however, indicate that 16-row plots are not necessary. This suggests that preliminary on-farm yield testing can be conducted using 6-rows whereas 16-rows can be used more for demonstration plots immediately prior to the release of a new line as a cultivar. This practice is now adopted in a new genotype testing program for rainfed lowland rice in Thailand (Jongdee, 2001).

When genotypes were grouped in 2-row plots as a complete block according to the height, reducing the effect of genotypic competition (Gomez and Gomez, 1984), the accuracy of yield estimation was improved. It is however necessary to determine the heights of all genotypes in the season prior to the selection trials so that genotypes can be grouped together according to the height. The high correlation coefficient of height at maturity and at 60 DAT found in the present work suggests that the height determined at maturity can be used for grouping genotypes. When genotypes differ greatly in height in yield testing trials, it may be necessary to make more than two height groups so that each group may contain genotypes that differ for height by less than about 20 cm. However, even if the genotypes are grouped to 2-4 height groups from the previous season's results, there would still be some height variation within a group in the year of yield testing, and thus this variation would cause inaccuracy in yield estimation in 2-row plots. The accuracy of estimating yield would be improved further if grain yields are adjusted within a height group by using covariance analysis to correct for the effect of competition due to height difference between neighboring plots. Therefore, it would be advisable to measure height again at maturity, and this can be used for estimation of adjusted yield. The regression relating a genotype's height and the yield difference between 2-row plots and 6-row plots can be established for a trial, and the yield of all 2-row plots can then be adjusted according to the height of each genotype within a height group.

Acknowledgements

Financial support by the Australian Centre for International Agricultural Research is gratefully acknowledged.

References

Banziger, M., Lafitte, H.R. and Edmeades, 1995. Inter-genotypic competition during evaluation of maize progenies under limited and adequate N supply. Field Crops Res. 44: 25-31.

Chaves, L.J. and Miranda Filho, J.B.de. 1992. Plot size for progeny selection in maize (Zea mays L.). Theor. Appl. Genet. 84: 963-970.

Cooper, M. and Sonrith, B. 1997. Implications of genotype-by-environment interactions for yield adaptation of rainfed lowland rice: influence of flowering date on yield variation. In S. Fukai, M. Cooper, and J. Salisbury, eds., Proceedings of International Workshop held at Ubun Ratchathani, Thailand, 5-8 November 1996. ACIAR Proceeding No.77: 104-114.

Fischer, R.A. 1978. Are your results confounded by inter-genotypic competition? Proc. 5th Int. Wheat Genetics Symposium, New Delhi. 767-777.

Fukai, S. and Cooper, M. 1999. Plant breeding strategies for rainfed lowland rice in northeast Thailand. In T. Horie, S. Geng, T. Amano, T. Inamura, and T. Shiraiwa, eds., Proceedings of the International Symposium on World Food Security and Crop Production Technologies for Tomorrow, 8-9 October 1999, Kyoto, Japan. 153-156.

Gomez, K.A. 1972a. Techniques for field experiments with rice. International Rice Research Institute, PO Box 933, Manila, Philippines. 1-48.

Gomez, K.A. 1972b. Border effects in rice experimental plot. II. Varietal competition. Exp. Agric. 7: 87-92.

Gomez, K.A. and Gomez, A.A. 1984. Statistical procedures for agricultural research. 2nd ed. John Wiley & Sons, New York. 1-680.

Jirapornchareon, S. 1993. The use of chemical and organic fertilizers in crop production in Thailand. Food and Fertilizer Technology Center, ASPEC. Extention Bulletin No.370. 1-10.

Jongdee, B. 2001. New rice breeding methods for the rainfed lowlands of North and Northeast Thailand. In S.Fukai and J. Basharaka eds., Proceedings of an International Workshop held in Viaani, Laos. ACIAR Proceedings No. 101: 221-228.

Puntener, W. 1981. Manual for Field Trial in Plant Protection. 2nd ed. CIBA-GEIGY Limited. Basle, Switzerland. 1-205.

Thomas, J.B., Schaalje, G.B. and Grant, M.N. 1994. Height, competition and yield potential in winter wheat. Euphytica 74: 9-17.