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Instructions for use

# STUDIES ON THE COMPETITIVE ABILITY OF
# RICE PLANT IN POPULATION*

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The word "competition" may be referred to what was stated by DONALD (1963). That is, "Competition occurs when each of two or more organisms seeks the measure it wants of any particular factor or thing and when the immediate supply of the factor or thing is below the combined demand of the organisms".

Organisms may compete for space, temperature, humidity in air, water in soil, oxygen, carbon-dioxide, nutrients, and light. There will be very few cases where plants compete for temperature and humidity. In dealing with competition in irrigated lowland rice community, water may be excluded from the factors. The facts that spacing and nitorgen have a drastic effect on many characters of rice plant suggest that the competitions for light and nutrients are highly possible. Lodging of rice crop in some cases might have something to do with competition for space. The measurement of carbon-dioxide of the air in corn community (LEMON, 1960) suggests the possibility of carbon-dioxide deficiency as the limiting factor in photosynthesis of corn field. But in the rice field carbon-dixide in the air may not be a significant factor since in rice leaves the response curve of photosynthesis to carbon-dioxide (MURATA, 1961) is not as sharp as in corn leaves (HESKETH and MOSS, 1963). This will be true also with the oxygen in the air. Since aeration to rice roots grown in culture solution does not show any big effect on the respiratory rate of the root (ARIKADO, 1958), oxygen in soil may not be a big factor in competition. Thus, it may be assumed that in rice community competition for light, nutrient, and space is likely to occur.

Although there are many combinations of competition, they would be divided into two categories, namely (1) competition among plants which differ in their genetic compositions, and (2) that among plants with the same genetic compositions. Examples for the former are the competitions between crop and

weed or legume and grass in pasture land, and the skew distribution of plant weight under high planting density in soybean population (KOYAMA and KIRA, 1956) will be the example for the latter. Of great importance to plant breeders would be the competition among varieties or lines or among the progenies derived from the inter-varietal hybridization in the bulk population.

There are significant differences in response to population density among the varieties of corn (LANG et al., 1956), soybean (HINSON and HANSON, 1962; LEHMAN and LAMBERT, 1960), and of rice (TANAKA et al., 1964). This suggests that the competitive ability of individual plants in the genetically mixed population may be different depending upon the genotypes. The experiment by HARLAN and MARTINI (1938) confirmed this viewpoint and their result shows that a competitive ability of a genotype differs according to the environment under which the genotype is subjected to competition.

The experimental evidences of SUNESON and WEIBE (1942) showed that the yield of barley variety in pure stand was not the same with its competitive ability in the genotypically mixed population. SUNESON (1949), therefore, through his experiences with the bulk population of barley varieties stated, "The bulk population method of breeding will not necessarily perpetuate either the highest yielding or the most disease resistant progenies, but that the otherwise intangible character of competitive ability may measure other very important plant characters".

SAKAI (1955) also suggested the independence of competitive ability from yielding ability and considered the competitive ability as a plant character governed by Mendelian genes. The important meaning of competitive ability to the process of plant evolution was emphasized. He also demonstrated that the effect of competition depended on the spacing between adjacent plants and was stronger at closer spacing.

YAMADA (1954 b) showed the trend that the varietal difference in phenotype is relatively increased by intensifying the effect of competition. He assumed that the variability in the plant population is increased by the interaction between genetic difference in the population and competition. He and his co-worker (1954 a) further emphasized that in order to clarify the effect of competition on the phenotypic difference in the plant population, the morphological differences of young plants, which work as internal factors on the competition effect, are to be made clear first. Then the relationship between these factors and other factors which later become limiting and the relationship among the intensities and directions of these factors are to be clarified.

KOYAMA and KIRA (1956) found in the soybean population where the individual plants were assumed to be genetically the same with each other

that the population initially of nearly uniform plant weight moved progressively toward a skew distribution of plant weight and that this trend was more obvious at closer spacing. This may suggest that the individual difference in the population which is originally caused by the micro-environmental difference would become bigger with the increase of competition intensity, though the skewness of plant weight distribution can occur, at least theoritically, independently of competition.

It can be assumed that individual plants in a community under a certain condition are largely influenced by planting density and that the difference among the individual plants, whether its origin is genetical or environmental, becomes bigger as the intensity of competition increases.

The genotype with big ability to utilize the additional space more efficiently may have bigger competitive ability in a genetically mixed population. Simultaneously, the effect of competition may be great on the plant characters which are highly influenced by planting density. HINSON and HANSON (1962) showed that the genotypes with late flowering dates, increased height, more nodes per plant and more branches per plant at wide spacings are able to utilize more efficiently the additional space provided by increased spacings in soybean population. YAMADA and HORIUCHI (1953, 1954 a, 1954 b) found that plant height of soybean or barley at early stage of growth, length of vegetative growth period in soybean, and erect growth habit of barley are positively related to the competitive ability in mixed population. SAKAI (1955), however, found no relationship between competitive ability and vigorous growth habit of $F_1$ hybrids in barley.

These problems also seem worthwhile to study in rice plant. Growth habit of rice plants and its meaning in varietal difference under various conditions were discussed in the previous reports (TANAKA et al., 1964; TANAKA and KAWANO, 1965, 1966; TANAKA, KAWANO, and YAMAGUCHI, 1966). The effect of inter-varietal competition on characters of rice plant at different growth stages and the inter-relationship among these characters will be discussed in this paper.

## Materials and Methods

*Experiment 1*

Two varieties, Peta and Taichung Native-1, were used. Pure and mixed populations were made at 0 and 150 kg N per hectare each of 50 kg $P_2O_5$ and $K_2O$. In the mixed population, two varieties were planted alternatively in both directions. The spacing was $30 \times 30$ cm in all populations, one plant per hill

of 20 days old seedlings.

Fifty plants were sampled from each plot at harvest. Grain yield, plant weight, yield components and plant height were observed on those samplings. Meanwhile, growth habit of two varieties were studied in the pure populations of this experiment by using the same methods as in the previous report (TANAKA and KAWANO, 1966).

Date of sowing was November 30, 1963, dates of flowering were February 25, 1964 for Taichung Native-1 and March 11 for Peta, and dates of harvest were March 30 for Taichung Native-1 and April 10 for Peta.

*Experiment 2*

Three varieties of approximately the same growth duration, Taichung Native-1 (A), B 5580 (B), and Tainan-3 (C), were used. Three pure populations of A, B, and C, and three mixed populations of A–B, A- C, and B–C were made in the same manner as in Experiment 1 at two spacings, $20 \times 20$ and $40 \times 40$ cm. Two nitrogen levels, 0 and 60 kg N per hectare, were also made. One plant per hill of 20 days old seedlings was transplanted to the field which received a uniform application of 40 kg per hectare each of $P_2O_5$ and $K_2O$. Nitrogen level was the main plot and variety and spacing were randomized in each nitrogen level.

Sampling of 10 plants free from border effect was made at 40 days and 61 days after transplanting and of 20 plants at harvest. Sampled plants were uprooted, roots were discarded and washed, and leaf blades were separated from plants, dried in an air-forced oven at 70°C for two days and weighed. The leaf area of eight leaf blades taken at random from each sample was measured by a blueprint method. Sample leaves were dried in the oven and the dry weight per unit area was calculated. Total leaf area was computed from the total leaf blade weight and the dry weight per unit area. Tiller number, leaf number, plant height, leaf length, leaf width, leaf thickness and yield components were observed. Occasional measurement of light distribution in the communities was made with a Toshiba light meter.

## Results

*Experiment 1*

Plant characters in mixed populations differed from those in pure populations (Table 1). The differences were big in grain yield, plant weight, ratio of grain weight to total weight, and panicle number. Plant height and 1000-grain weight were not much affected by competition. Grain yield, plant weight,

TABLE 1. Characters of Peta and Taichung Native-1 at 0 and
150 kg/ha N in pure and mixed populations.

| N level (kg/ha) | Variety | Population | Grain yield (g/plt) | Plant weight (g/plt) | Grain wt/ total wt (%) | Plant height (cm) | Panicle number per plant | Spikelet number per panicle | Filled grain (%) | 1000-grain weight (g) |
|---|---|---|---|---|---|---|---|---|---|---|
| 0 | Peta | Pure (a) | 37.0 | 93.2 | 39.4 | 135.5 | 11.0 | 179 | 74.8 | 27.2 |
| | | Mixture (b) | 44.6 | 105.8 | 41.3 | 129.7 | 13.0 | 195 | 70.7 | 25.8 |
| | | (b-a)/a | + 0.21 | + 0.16 | + 0.05 | − 0.04 | + 0.19 | + 0.09 | − 0.09 | − 0.05 |
| | Taichung Native-1 | Pure (a) | 30.3 | 63.4 | 50.0 | 86.5 | 14.8 | 114 | 85.1 | 22.0 |
| | | Mixture (b) | 25.8 | 54.0 | 48.5 | 87.7 | 10.9 | 124 | 77.9 | 20.2 |
| | | (b-a)/a | − 0.15 | − 0.15 | − 0.03 | − 0.01 | − 0.26 | + 0.09 | − 0.09 | − 0.08 |
| 60 | Peta | Pure (a) | 23.4 | 108.0 | 27.5 | 170.6 | 11.6 | 195 | 62.0 | 25.6 |
| | | Mixture (b) | 69.3 | 179.3 | 38.9 | 163.4 | 19.4 | 221 | 79.1 | 28.0 |
| | | (b-a)/a | + 1.75 | + 0.66 | + 0.41 | − 0.04 | + 0.69 | + 0.13 | + 0.28 | + 0.09 |
| | Taichung Native-1 | Pure (a) | 54.6 | 113.8 | 48.2 | 100.4 | 24.1 | 143 | 80.2 | 24.2 |
| | | Mixture (b) | 29.5 | 102.4 | 28.9 | 100.4 | 19.1 | 118 | 43.0 | 21.2 |
| | | (b-a)/(a) | − 0.46 | − 0.10 | − 0.40 | 0.00 | − 0.21 | − 0.18 | − 0.46 | − 0.12 |
| Standard deviation of error (d. f. = 8) | | | 5.80 | 10.82 | 1.81 | 2.11 | 1.35 | 15.1 | 4.68 | 1.58 |

ratio of grain weight to total weight, panicle number, and spikelet number per panicle of Peta were higher in mixed populations than in pure populations, while those of Taichung Native-1 were lower. The differences caused by competition were bigger under high nitrogen level.

Yield per unit area in mixed populations was higher than the mean yield of two varieties in pure populations though this trend was not very significant (Table 2). In pure populations, Peta yielded higher in the 0 N plot than in

TABLE 2.   Yield of the pure and mixed populations and the deviation of yield in the mixture from the mean yield of two varieties in the pure population.

| N level | Population | Yield (ton/ha) | Deviation (ton/ha) |
|---------|-----------|----------------|---------------------|
| 0 | Peta | 4.11 | |
| | Mixture | 3.89 | + 0.15 |
| | Taichung Native-1 | 3.37 | |
| 150 | Peta | 2.79 | |
| | Mixture | 5.49 | + 1.06 |
| | Taichung Native-1 | 6.06 | |

the 150 N plot, while Taichung Native-1 did higher in the 150 N plot than in the 0 N plot. Peta yielded better than Taichung Native-1 in the 0 N plot, while in the 150 N plot, Taichung Native-1 yielded better than Peta. In mixed populations, Peta yielded better in the 150 N plot than in the 0 N plot and
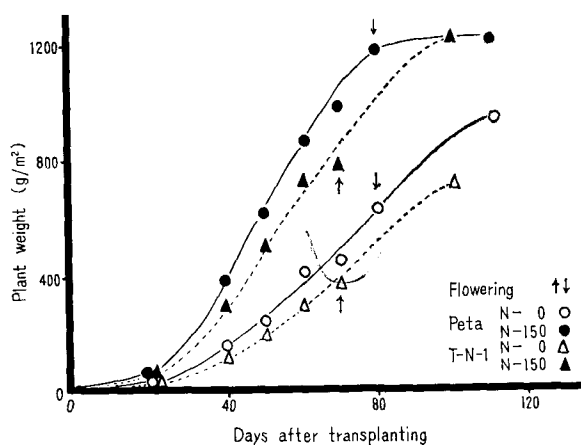


Fig. 1.   Plant weight at each growth stage.

exceeded the yield of Taichung Native-1 in both N levels (Table 1).

Growth habits of Peta and Taichung Native-1 in pure populations are shown in Figs. 1–4. Peta grew taller, had larger leaf area, and intercepted more light than did Taichung Native-1 in both nitrogen levels.
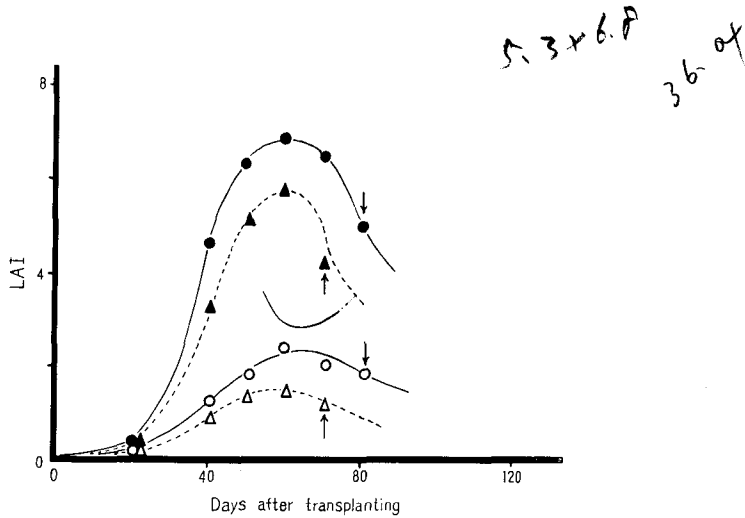


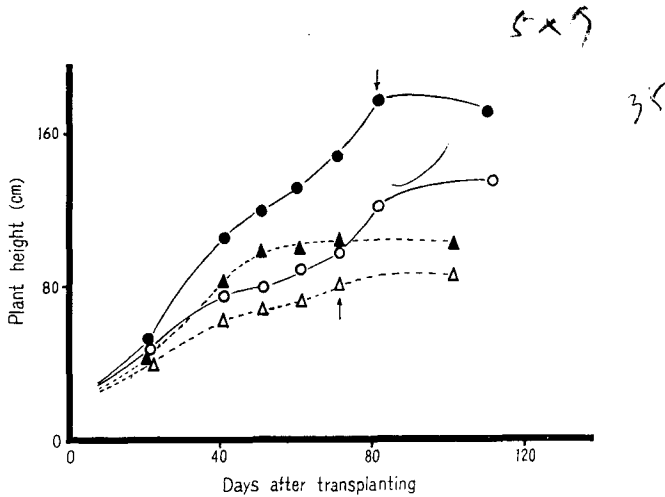**Fig. 2.** LAI at each growth stage. (Symbols are the same as in Fig. 1).



**Fig. 3.** Plant height at each growth stage. (Symbols are the same as in Fig. 1).
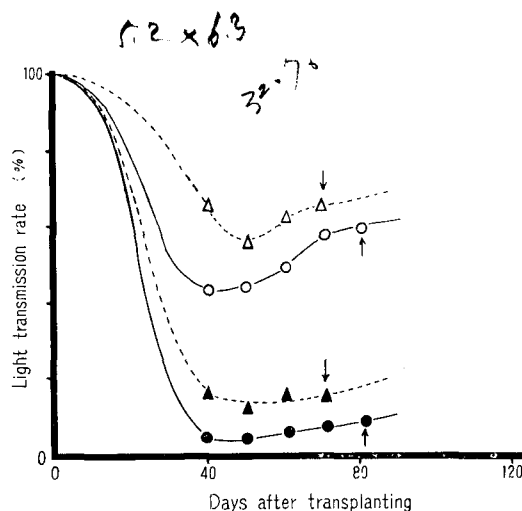
**Fig. 4.** Light Transmission Rate at each growth stage.
(Symbols are the same as in Fig. 1.).

*Experiment 2*

In pure populations, Taichung Native-1 gave the highest yield at all spacings and nitrogen levels. B 5580 was second and Tainan-3 the last at all plots other than at the 0 N of 40 × 40 spacing where Tainan-3 was second to Taichung Native-1 (Table 3).

There was no particular trend in the relationship between the yields of pure populations and those of mixed populations. But the yields from more than half of the mixed populations were higher than the mean yield of two component varieties in each pure population.

Plant characters at each variety in pure populations at harvest are shown in Table 4, and the characters in mixed populations are compared with those in pure populations (Table 5).

The yield of Taichung Native-1 was the lowest in pure populations and was the highest in the mixture with B 5580 at all spacings and nitrogen levels. The grain yield of B 5580 was always the highest in pure populations. Competition with other varieties always reduced the yield of this variety. Tainan-3 yielded highest when it was combined with B 5580. It is very apparent that the inter-varietal competition affected the grain yield. Taichung Native-1 had the highest competitive ability, Tainan-3 the next, and B 5580 the weakest. This trend was also true with plant characters like plant weight, amount of nitrogen in the plant, or number of panicles.

Variance analysis in two dimensions (variety × competition) was made in

TABLE 3.  Grain yield of the pure and mixed populations and the deviation of the yield of the mixed population from the mean yield of two component varieties in the pure population.

| Spacing (cm) | N level (kg/ha) | Population | Yield (kg/10 m²) | Deviation (kg/10 m²) |
|---|---|---|---|---|
| 20 × 20 | 0 | A | 3.45 | |
| | | B | 3.08 | |
| | | C | 2.98 | |
| | | A–B | 3.16 | − 0.10 |
| | | A–C | 3.40 | + 0.18 |
| | | B–C | 3.35 | + 0.32 |
| | 60 | A | 4.47 | |
| | | B | 4.25 | |
| | | C | 2.85 | |
| | | A–B | 4.32 | + 0.04 |
| | | A–C | 4.56 | + 0.90 |
| | | B–C | 3.71 | + 0.16 |
| 40 × 40 | 0 | A | 2.51 | |
| | | B | 2.20 | |
| | | C | 2.24 | |
| | | A–B | 2.56 | + 0.21 |
| | | A–C | 2.88 | + 0.50 |
| | | B–C | 2.24 | + 0.02 |
| | 60 | A | 3.01 | |
| | | B | 2.25 | |
| | | C | 2.00 | |
| | | A–B | 2.53 | − 0.10 |
| | | A–C | 2.60 | + 0.10 |
| | | B–C | 1.73 | − 0.47 |

A: Taichung Native-1
B: B 5580
C: Tainan-3

TABLE 4.   Characters at harvest of each variety at each
spacing and nitrogen level.

| Variety | Grain yield (g/hill) | Plant weight (g/hill) | Grain wt/ total wt (%) | Panicle number per hill | Spikelet no. per panicle | Filled grain (%) | 1000-grain weight (g) | Amount of N (g/hill) | N (%) | Culm length (cm) |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | 20×20 cm, 0 kg/ha N | | | | | | |
| Taichung N-1 | 13.8 | 26.9 | 51.3 | 8.8 | 90 | 78.8 | 22.3 | 0.24 | 0.89 | 66.5 |
| B 5580 | 12.3 | 30.3 | 40.6 | 8.7 | 119 | 61.6 | 21.5 | 0.27 | 0.89 | 78.2 |
| Tainan-3 | 11.9 | 31.6 | 37.7 | 6.8 | 128 | 71.8 | 20.3 | 0.28 | 0.89 | 103.7 |
| | | | | 20×20 cm, 60 kg/ha N | | | | | | |
| Taichung N-1 | 17.9 | 38.4 | 46.6 | 11.6 | 93 | 75.9 | 22.8 | 0.38 | 0.99 | 85.0 |
| B 5580 | 17.0 | 37.3 | 45.6 | 9.0 | 160 | 79.9 | 16.3 | 0.38 | 1.02 | 82.7 |
| Tainan-3 | 11.4 | 39.1 | 29.2 | 8.6 | 130 | 54.7 | 21.3 | 0.34 | 0.87 | 113.0 |
| | | | | 40×40 cm, 0 kg/ha N | | | | | | |
| Taichung N-1 | 40.2 | 83.3 | 48.3 | 25.9 | 102 | 69.2 | 22.1 | 0.80 | 0.96 | 68.2 |
| B 5580 | 35.3 | 76.9 | 45.9 | 14.7 | 182 | 84.2 | 17.4 | 1.03 | 1.34 | 76.2 |
| Tainan-3 | 35.8 | 94.8 | 37.8 | 16.9 | 166 | 75.8 | 19.8 | 1.06 | 1.12 | 92.5 |
| | | | | 40×40 cm, 60 kg/ha N | | | | | | |
| Taichung N-1 | 48.2 | 106.4 | 45.3 | 33.4 | 106 | 70.0 | 22.1 | 1.28 | 1.20 | 76.0 |
| B 5580 | 36.1 | 83.3 | 43.3 | 14.1 | 199 | 88.0 | 16.2 | 1.18 | 1.47 | 73.5 |
| Tainan-3 | 31.8 | 101.6 | 31.3 | 15.8 | 202 | 53.6 | 18.7 | 1.28 | 1.26 | 98.7 |

TABLE 5. Deviation of characters in the mixed population from that in the pure population as expressed by the percentage of the value in the pure population.

| Variety | Population | Grain yield | Plant weight | Grain wt/ total wt | Panicle number | Spikelet number/ panicle | Filled grain % | 1000-grain weight (g) | Amount of N | N % | Culm length |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | 20×20 cm, 0 kg/ha N | | | | | | |
| Taichung N-1 (A) | Mixture with B | + 22.3 | + 23.8 | − 1.0 | + 16.0 | − 1.1 | + 4.5 | + 27.2 | + 28.1 | + 4.5 | + 1.8 |
| | Mixture with C | + 9.3 | + 3.4 | + 5.6 | + 7.9 | + 16.6 | − 9.8 | − 12.5 | − 4.1 | − 6.7 | 0.0 |
| B 5580 (B) | Mixture with A | − 40.6 | − 49.8 | + 18.0 | − 49.4 | + 10.9 | + 38.0 | − 29.8 | − 55.5 | − 11.3 | − 6.4 |
| | Mixture with C | − 17.0 | − 30.0 | + 18.3 | − 34.5 | + 14.2 | + 41.5 | − 29.2 | − 21.7 | − 4.4 | − 7.0 |
| Tainan-3 (C) | Mixture with A | + 4.1 | − 25.0 | + 27.6 | − 26.5 | − 23.4 | + 25.1 | + 25.1 | − 37.0 | − 19.0 | − 21.8 |
| | Mixture with B | + 32.8 | + 11.3 | + 19.1 | 0.0 | + 1.6 | + 18.5 | + 13.2 | − 3.5 | − 13.4 | − 9.2 |
| | | | | | 20×20 cm, 60 kg/ha N | | | | | | |
| Taichung N-1 (A) | Mixture with B | + 43.5 | + 47.0 | − 2.3 | + 42.2 | + 12.9 | − 18.4 | + 1.2 | + 52.6 | + 4.1 | − 7.4 |
| | Mixture with C | + 25.8 | + 34.9 | − 6.9 | + 50.0 | + 5.3 | − 12.9 | − 0.4 | + 42.0 | + 5.0 | − 5.2 |
| B 5580 (B) | Mixture with A | − 56.5 | − 53.9 | − 6.4 | − 44.4 | − 20.6 | + 0.9 | − 13.5 | − 57.9 | − 8.8 | − 1.1 |
| | Mixture with C | − 57.6 | − 47.4 | − 19.7 | − 28.8 | − 17.5 | − 11.7 | − 3.0 | − 47.4 | 0.0 | − 0.6 |
| Tainan-3 (C) | Mixture with A | + 8.7 | − 23.5 | + 42.1 | − 29.1 | − 0.7 | + 45.2 | − 1.8 | − 29.4 | − 8.0 | − 6.4 |
| | Mixture with B | + 86.0 | + 46.9 | + 26.3 | + 21.0 | + 20.7 | + 16.5 | − 1.4 | + 50.0 | + 2.2 | − 9.9 |

Table 5 (Cont'd.)

| Variety | Population | Grain yield | Plant weight | Grain wt/ total wt | Panicle number | Spikelet number/ panicle | Filled grain % | 1000-grain weight (g) | Amount of N | N % | Culm length |
|---------|-----------|-------------|--------------|--------------------|-----------------|---------------------------|----------------|------------------------|-------------|------|-------------|
| | | | | | 40×40 cm, 0 kg/ha N | | | | | | |
| Taichung N–1 (A) | Mixture with B | + 38.0 | + 32.9 | + 4.5 | + 28.9 | + 6.8 | + 2.6 | − 3.2 | + 42.5 | + 7.3 | − 4.4 |
| | Mixture with C | + 36.5 | + 40.2 | − 2.7 | + 41.3 | − 1.0 | 0.0 | − 2.7 | + 111.2 | + 50.0 | + 3.6 |
| B 5580 (B) | Mixture with A | − 27.0 | − 33.8 | + 10.8 | − 31.8 | + 3.9 | − 5.2 | − 2.8 | − 45.6 | − 17.9 | + 2.5 |
| | Mixture with C | − 29.4 | − 26.0 | − 4.6 | − 20.4 | − 3.8 | + 1.5 | + 2.8 | − 22.3 | + 5.2 | + 1.7 |
| Tainan-3 (C) | Mixture with A | + 3.8 | − 3.0 | + 6.8 | − 10.7 | + 11.3 | + 6.9 | − 10.6 | − 12.2 | − 9.8 | + 9.6 |
| | Mixture with B | + 30.3 | + 16.8 | + 11.6 | + 14.8 | + 3.0 | + 7.9 | + 4.5 | − 0.8 | − 15.2 | − 1.6 |
| | | | | | 40×40 cm, 60 kg/ha N | | | | | | |
| Taichung N–1 (A) | Mixture with B | + 13.8 | + 29.0 | − 11.8 | + 24.4 | − 8.5 | − 11.4 | − 0.7 | + 61.0 | + 25.0 | − 13.5 |
| | Mixture with C | + 19.6 | + 38.2 | − 13.2 | + 19.7 | + 4.6 | − 2.7 | − 0.7 | + 70.2 | + 23.3 | − 0.4 |
| B 5580 (B) | Mixture with A | − 28.8 | − 28.8 | 0.0 | − 22.6 | + 2.0 | − 12.7 | − 1.7 | − 26.3 | − 0.6 | + 12.5 |
| | Mixture with C | − 35.2 | − 26.3 | − 12.0 | − 12.1 | − 2.0 | − 13.0 | + 3.8 | − 17.0 | + 8.8 | + 3.5 |
| Tainan-3 (C) | Mixture with A | − 21.0 | − 9.1 | − 13.0 | − 8.9 | − 17.3 | + 39.6 | + 1.1 | − 27.3 | − 19.8 | − 4.3 |
| | Mixture with B | + 1.1 | + 24.2 | − 6.6 | + 15.8 | − 13.3 | + 27.2 | − 2.1 | + 24.1 | 0.0 | − 9.0 |

TABLE 6. F values for the effect of inter-varietal competition and varietal order (large to small) of competitive ability in nitrogen amount in the plant, plant weight, and leaf area at different growth stages.

| Spacing | N level | 40 days after transplanting | | | 61 days after transplanting | | | 61 days-harvest | At harvest | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Amount of N | Plant weight | Leaf area | Amount of N | Plant weight | Leaf area | Dry matter increase | Amount of N | Plant weight | Grain yield |
| 20 × 20 | 0 | A-C-B | A-C-B | A-C-B | A-C-B | A-C-B | A-C-B | C-A-B | A-C-B | A-C-B | A-C-B |
| | | 5.17 | 3.56 | 5.62 | 7.33 | 10.55 | 2.52 | 1.80 | 6.27 | 13.48 | 22.32 |
| | 60 | A-C-B | A-C-B | A-C-B | A-B-C | A-C-B | A-C-B | C-A-B | A-C-B | A-C-B | A-C-B |
| | | 0.73 | 0.02 | 1.08 | 23.14 | 9.43 | 16.23 | 6.23 | 21.75 | 18.99 | 17.13 |
| 40 × 40 | 0 | A-C-B | A-C-B | A-C-B | A-B-C | A-C-B | A-B-C | A-C-B | A-B-C | A-C-B | A-C-B |
| | | 4.29 | 4.85 | 1.51 | 1.42 | 1.14 | 0.57 | 11.67 | 0.75 | 5.28 | 4.73 |
| | 60 | C-B-A | B-C-A | C-B-A | A-C-B | A-C-B | A-B-C | A-C-B | A-C-B | A-C-B | A-C-B |
| | | 0.02 | 0.59 | 0.10 | 44.63 | 2.11 | 4.28 | 1.17 | 0.46 | 4.96 | 2.40 |

A : Taichung Native-1
B : B 5580
C : Tainan-3

$$(d, f = 4, 2)$$

TABLE 7. F values for the effect of inter-varietal competition and varietal order (large to small) of competitive ability in plant characters at 61 days afer transplanting.

| Spacing | N level | N% of plant | N% of leaves | Thickness of leaves | Length of leaves | Leaf size * | Plant height | Tiller number | Number of leaves |
|---|---|---|---|---|---|---|---|---|---|
| 20 × 20 | 0 | A–C–B | A–C–B | B–C–A | B–C–A | A–C–B | A–C–B | A–C–B | A–C–B |
| | | 1.31 | 1.92 | 0.19 | 0.40 | 0.75 | 1.17 | 15.95 | 2.86 |
| | 60 | A–B–C | A–B–C | A–C–B | A–C–B | A–C–B | A–C–B | A–B–C | A–B–C |
| | | 3.45 | 1.77 | 0.40 | 7.63 | 5.52 | 1.48 | 14.89 | 11.53 |
| 40 × 40 | 0 | A–B–C | A–B–C | A–C–B | B–A–C | C–B–A | C–A–B | A–B–C | A–C–B |
| | | 4.03 | 2.01 | 27.33 | 0.08 | 3.40 | 0.06 | 2.84 | 2.37 |
| | 60 | A–B–C | A–C–B | C–A–B | C–B–A | A–B–C | B–C–A | A–C–B | A–B–C |
| | | 1.47 | 2.37 | 0.38 | 1.26 | 0.71 | 2.18 | 8.40 | 1.49 |

\* Average area of individual leaves.
A : Taichung Native-1
B : B 5580
C : Tainan-3

TABLE 8.   F values for the effect of inter-varietal competition
and varietal order (larger to smaller) of competitive
ability in characters at harvest.

| Spacing | N level | Culm length | Grain wt/ total wt | Panicle number | Spikelet no. per panicle | Filled grain % | 1000- grain wt | N % |
|---------|---------|-------------|-------------------|----------------|-------------------------|----------------|----------------|-----|
| 20×20 | 0 | A-B-C<br>1.09 | B-C-A<br>0.45 | A-C-B<br>5.53 | A-B-C<br>1.43 | B-C-A<br>1.09 | C-A-B<br>3.56 | A-C-B<br>0.81 |
| | 60 | B-A-C<br>0.93 | A-B-C<br>6.30 | A-C-B<br>10.98 | A-C-B<br>11.60 | C-B-A<br>9.57 | C-A-B<br>0.93 | A-C-B<br>20.63 |
| 40×40 | 0 | B-C-A<br>1.91 | C-B-A<br>2.10 | A-C-B<br>4.28 | C-B-A<br>2.88 | A-C-B<br>0.27 | A-C-B<br>0.23 | A-B-C<br>4.94 |
| | 60 | B-A-C<br>6.00 | C-B-A<br>0.42 | A-C-B<br>7.30 | B-A-C<br>1.00 | C-A-B<br>2.78 | B-C-A<br>3.33 | A-B-C<br>7.17 |

A :  Taichung Native-1
B :  B 5580
C :  Tainan-3

each of 4 treatments (2 spacings × 2 nitrogen levels) by arranging the com-
peting varieties in one direction and the varieties to be competed in another.
In pure populations, plants are assumed to be competing against plants of the
same genotype (Tables 6, 7, and 8).  In these cases, the effect of intervarietal
competition was estimated as the difference in varietal measurement among
three populations, namely pure population and mixtures with other two va-
rieties.  By assuming the interaction between competing variety and variety
to be competed as the error, the F value for the effect of variety to be com-
peted (the effect of inter-varietal competition) was calculated.  A variety with
suppressing effect to the competing variety in the mixed population can be
considered as a variety with strong competitive ability.

Competition seemed to exist in grain yield and plant weight at harvest
at all spacings and nitrogen levels (Table 6).  The extent to which plants
were affected by inter-varietal competition seemed to be much bigger at 20 × 20
cm spacing than at 40 × 40 cm.  Taichung Native-1 was the strongest in com-
petitive ability of these plant characters; Tainan-3 followed next, and B 5580
was the weakest at all spacings and nitrogen levels.

At 40 days after transplanting, the existence of intervarietal competition
was highly probable for the amount of nitrogen in the plants, plant weight,
and leaf area at 0 N of 20 × 20 cm spacing (Table 6).  Taichung Native-1 was

the strongest in competition. At 61 days after transplanting, which was approximately the flowering time of the three varieties, the existence of inter-varietal competition was highly probable for these characters at both nitrogen levels of $20 \times 20$ cm spacing. The inter-varietal competition might have existed also at $40 \times 40$ cm spacing since Taichung Native-1 also appeared first in this case in the varietal order of competitive ability.

During the period from 61 days after transplanting to harvest, Tainan-3 seemed to have the highest competitive ability in dry matter production at $20 \times 20$ cm spacing. The varietal order of dry matter production might have been reversed sometime around 60 days after transplanting at $20 \times 20$ cm spacing.

The effect of inter-varietal competition on net assimilation rate (GREGORY, 1917) at different growth periods is shown in Table 9. After flowering, Tainan-3 had high competitive ability at $20 \times 20$ cm spacing though it was not very significant.

TABLE 9. F values for the effect of inter-varietal competition and the varietal order (larger to smaller) of competitive ability in net assimilation rate.

| Spacing | N level | 0-40 days | 40-61 days | 61 days-harvest | 61 days to harvest |
|---|---|---|---|---|---|
| | | NAR (per leaf area) | | | NAR (per N)* |
| $20 \times 20$ | 0 | A–C–B | B–C–A | C–B–A | C–B–A |
| | | 1.78 | 0.91 | 1.00 | 1.78 |
| | 60 | C–A–B | A–C–B | C–A–B | C–A–B |
| | | 0.44 | 1.04 | 3.69 | 4.35 |
| $40 \times 40$ | 0 | A–C–B | C–A–B | C–A–B | C–A–B |
| | | 0.12 | 1.81 | 1.15 | 0.75 |
| | 60 | A–C–B | A–C–B | C–A–B | C–A–B |
| | | 3.41 | 0.88 | 0.53 | 0.46 |

* Net assimilation rate based on nitrogen in the leaves.
A: Taichung Native-1
B: B 5580
C: Tainan-3

Tiller number (Table 7) and panicle number (Table 8) seemed to have been highly affected by inter-varietal competition, while thickness of leaf, N% of leaves, plant heigth, culm length, and 1000-grain weight (Tables 7 and 8)

were scarcely affected.  Characters like N% of plant, leaf length, leaf size, ratio of grain weight to total weight, spikelet number per panicle, and % of filled grains seemed to have been affected only at 60 N of $20 \times 20$ cm spacing. Flowering date was not affected.

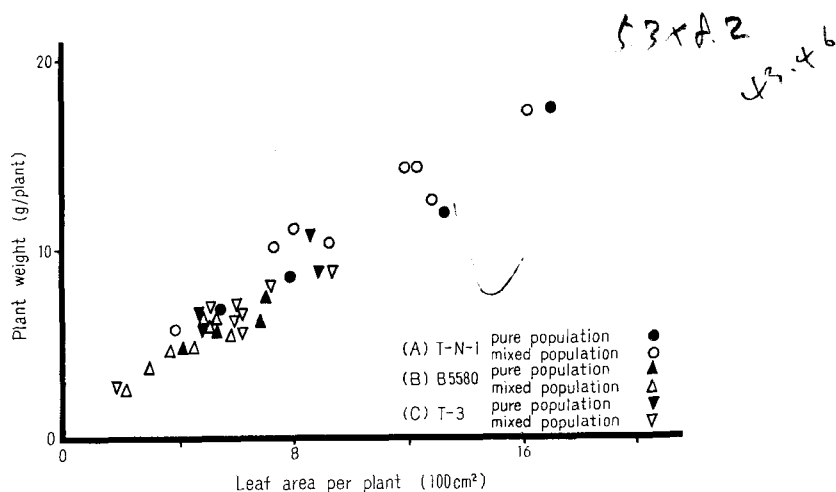Relationships among amount of nitrogen in the plants, leaf area, plant



Fig. 5.  Relation between leaf area and pant weight at 40 days after transplanting (data from all spacings and nitrogen levels).
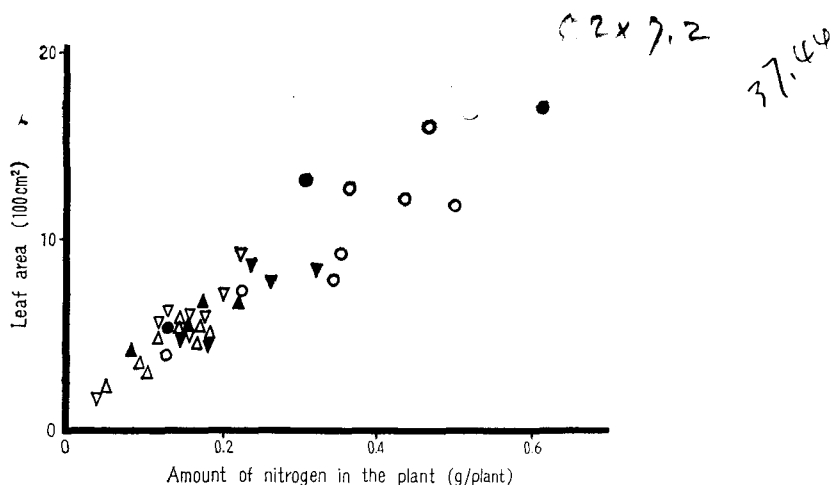


Fig. 6.  Relation between the amount of nitrogen in the plant and the leaf area. (Symbols are the same as in Fig. 5).

weight, and tiller number at 40 days after transplanting are presented in Figs.
5, 6, 7, and 8.   There were close relations among these plant characters re-
gardless of varieties or kinds of populations.   There was no particular trend
relating to the difference between pure and mixed populations.

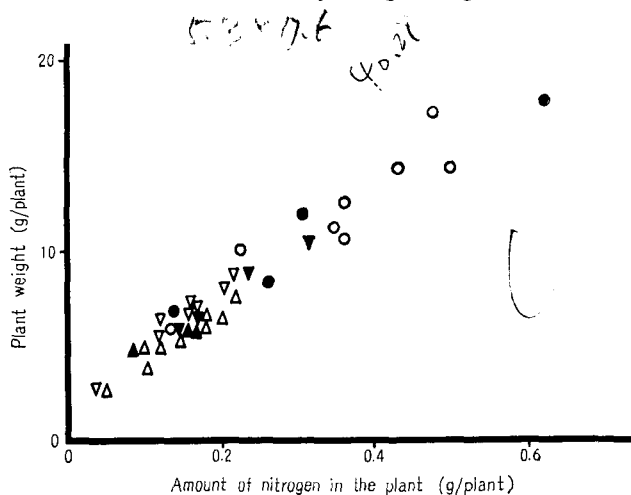Varietal characteristics at the early stage of growth in pure populations



Fig. 7.  Relation between the amount of nitrogen in
         the plant and the plant weight.  (Symbols
         are the same as in Fig. 5).
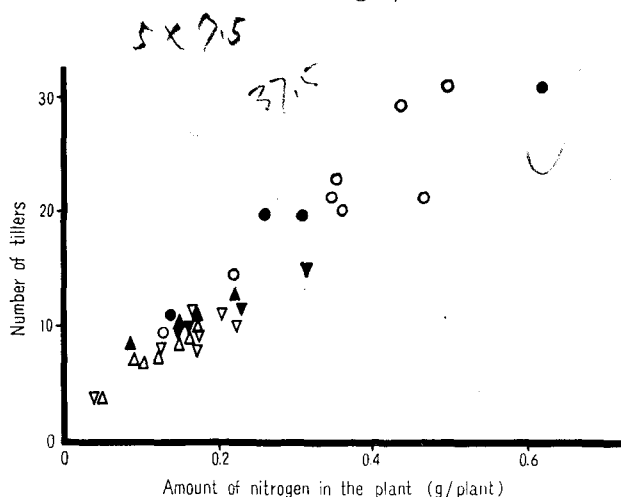


Fig. 8.  Relation between the amount of nitrogen in the
         plant and the number of tillers.  (Symbols are
         the same as in Fig. 5).

TABLE 10. Amount of nitrogen absorbed, LAI, and plant weight of three varieties in the pure population at 40 days after transplanting.

| Spacing | N level | Variety | N absorbed per m² | LAI | Plant weight per m² (g) |
|---------|---------|---------|-------------------|-----|------------------------|
| 20 × 20 | 0 | Taichung N-1 | 3.35 | 1.32 | 166 |
| | | B 5580 | 1.95 | 1.02 | 121 |
| | | Tainan-3 | 3.57 | 1.22 | 149 |
| | 60 | Taichung N-1 | 7.58 | 3.31 | 299 |
| | | B 5580 | 4.30 | 1.67 | 150 |
| | | Tainan-3 | 5.68 | 2.23 | 221 |
| 40 × 40 | 0 | Taichung N-1 | 1.64 | 0.50 | 51.1 |
| | | B 5580 | 0.95 | 0.32 | 36.7 |
| | | Tainan-3 | 1.08 | 0.30 | 40.1 |
| | 60 | Taichung N-1 | 3.88 | 1.06 | 110 |
| | | B 5580 | 1.39 | 0.43 | 46.7 |
| | | Tainan-3 | 1.98 | 0.53 | 65.8 |

TABLE 11. Plant height and leaf characters in the pure population at 61 days after transplanting

| Spacing | N level | Variety | Plant height (cm) | Leaf length* (cm) | Leaf angle** | K*** |
|---------|---------|---------|-------------------|-------------------|--------------|------|
| 20 × 20 | 0 | Taichung N-1 | 76.0 | 39.0 | 79 | 0.49 |
| | | B 5580 | 93.0 | 45.5 | 74 | 0.53 |
| | | Tainan-3 | 103.7 | 60.7 | 74 | 0.51 |
| | 60 | Taichung N-1 | 90.7 | 48.2 | 72 | 0.46 |
| | | B 5580 | 93.0 | 49.5 | 68 | 0.41 |
| | | Tainan-3 | 124.2 | 62.0 | 47 | 0.55 |
| 40 × 40 | 0 | Taichung N-1 | 87.7 | 48.0 | 74 | 0.25 |
| | | B 5580 | 95.2 | 45.5 | 66 | 0.39 |
| | | Tainan-3 | 106.7 | 61.5 | 61 | 0.43 |
| | 60 | Taichung N-1 | 102.7 | 57.7 | 70 | 0.19 |
| | | B 5580 | 94.2 | 45.5 | 66 | 0.38 |
| | | Tainan-3 | 114.5 | 60.2 | 51 | 0.31 |

　* 2nd leaf from the top.
　** Angle between the line from the base of leaf blade to the tip of the 2nd leaf and the culm.
*** Extinction coefficient (Monsi and Saeki, 1953).

are compared in Table 10. Plant height and leaf characters of three varieties in pure populations at 61 days after transplanting are given in Table 11. Tainan-3 showed the highest value in plant height and leaf length, and the lowest in leaf angle at all spacings and nitrogen levels. The extinction coefficient (K), proposed by MONSI and SAEKI (1953), tended to be big with Tainan-3.

## Discussion

In lowland rice community, competition would occur for nutrition and light. Rice plants would be competing for nutrients in the soil and for light above the ground. Competition occurs in a similar manner plants respond to planting density. Plant characters which are influenced by planting density tend to be influenced by inter-varietal competition.

The results from Experiment 1 show the drastic effect of inter-varietal competition. Since light utilization by plants is a key factor to yield and other plant characters when heavy nitrogen is applied (TANAKA and KAWANO, 1966), Peta would have held the "mastery of the air" in the mixed plots. The difference in plant height would have been decisive in the competition and the difference in leaf area or growth duration might have also been the factor. The result shows that the yielding ability does not necessarily tell much of the competitive ability.

The results from Experiment 2 suggest that competition among varieties with approximately the same growth durations has also big effects on many plant characters.

Combined yields of mixed populations did not differ significantly from the mean yields of the component varieties in each pure population. This leads to the assumption that in many cases it is at the sacrifice of another component genotype in the mixture that one genotype performs better in the mixed than in the pure populations.

Competition occurred first at 0 N of $20 \times 20$ cm spacing. This suggests that the inter-varietal competition started first for nitrogen in the soil rather than for light above the ground since leaf area index was bigger at 60 N plots than at 0 N plots. This can be seen also in the effect of competition on the amount of nitrogen in the plants, since it is more or less equal to the amount of nitrogen absorbed by plants until this stage. Nitrogen absorbed by the plants till this growth stage will be used in the production of leaf and the leaf thus produced will increase plant weight. In this manner, the effect of competition in the absorption of nitrogen will be reflected in leaf area, plant weight, and tiller number.

At 60 days after transplanting, the effect of competition in these characters was highly apparent at both nitrogen levels of $20 \times 20$ cm spacing and the effect of competition seemed to be bigger at 60 N plots.  This may be so because the competition for nitrogen was saturated earlier at 0 N plot as the amount of the remaining nitrogen in the soil became smaller.

Competition for nutrients other than nitrogen might have occurred but its influence on other plant characters would have been much smaller, if any, than in the case of nitrogen.

High competitive ability of Tainan-3 in dry matter production or NAR after flowering suggests the existence of competition for light.  This viewpoint is also supported by high competitive ability of this variety in the percentage of filled grain at 60 N of $20 \times 20$ cm spacing where competition for light was the biggest because shading after flowering has big bearing on the percentage of filled grain (MATSUSHIMA, 1957).

There is an equation on light transmission in plant community $(I/I_0)$ and leaf area index (LAI) shown as follows:

$$I/I_0 = e^{-K \cdot \text{LAI}}$$

(MONSI and SAEKI, 1953), where $I_0$ is the vertical light intensity at the surface of plant community, $I$ is that at the bottom, $e$ the base of natural logarythm, and $K$ the extinction coefficient.  The amount of light intercepted by plant community with $l$ LAI will be given as $(l - e^{K \cdot l}) \cdot I_0$.  This implies that the bigger the $K$, the more will be the amount of light intercepted by unit leaf area.  This leads to the assumption that a variety with big $K$ value has a high ability in competition for light.  Long and open leaf characters are related to big $K$ as varietal characteristics (TANAKA and KAWANO, 1965).  Tainan-3 was taller by about 20 cm than the other two varieties.  The differences in plant height and the big $K$ value of Tainan-3 would have been advantageous in competition for light.

There was a significant varietal difference in regression coefficients of leaf area with the amount of nitrogen in plants (Fig. 9).  This suggests the importance of relative leaf growth rate for unit amount of nitrogen or leaf area ratio to plant weight in competition for light.

When a hybrid population of rice plants is kept for generations without artificial selections, genotype which will dominate the population of the later generation will be apparently seen.  High activity to absorb nitrogen at the early growth stage, high expansion rate of leaf area for unit amount of nitrogen, tall growth habit, long growth duration, and big $K$ value (long and open leaf) are advantageous in competition within bulk population.  These are the
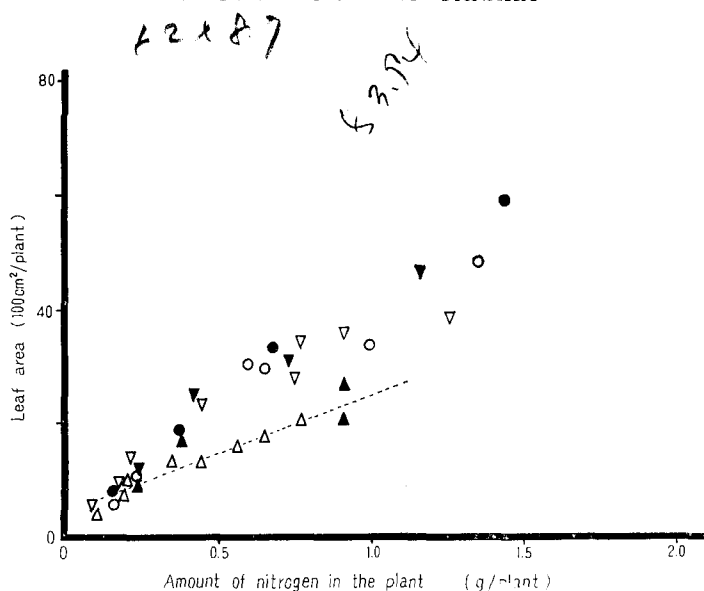
**Fig. 9.** Relation between the amount of nitrogen in the plant
and the leaf area at 61 days after transplanting.
(Symbols are same as in Fig. 5).

characteristics of varieties which respond negatively to nitrogen application
but yield fairly well when grown without nitrogen application (TANAKA and
KAWANO, 1965; TANAKA, KAWANO, and YAMAGUCHI, 1966). Typical rice
varieties in the tropics are of this type (JENNINGS, 1964; JENNINGS and BEA-
CHELL, 1964). It is reasonable to consider that this type of varieties has come
to existence as a result of competition in bulk population for many generations,
since in the tropics the history of artificial selection has been started not long
ago. It may then be concluded that bulk population method of rice breeding
will be advisable when breeders seek for the genotype suitable for the culti-
vation of no nitrogen application but not advisable when the genotype suitable
for the cultivation with heavy nitrogen application is to be bred.

## Summary

In rice community, competition occurs for nitrogen in the soil and for
light above the ground. The genotype with high ability to absorb nitrogen
is advantageous in inter-varietal competition not only for nitrogen but also for
light because the absorbed nitrogen is utilized in the expansion of leaf area.
Genotype with tall growth habit, long growth duration, big value of extinction
coefficient ($K$) (long and open leaf), and high leaf expansion rate for unit

amount of nitrogen is advantageous in inter-varietal competition for light.

Yielding ability under a certain environmental condition does not necessarily accord with the competitive ability of the genotype under the same environmental condition.

Competition starts first for nitrogen and then competition for light sets in as long as spacing among plants in population is not far less than $20 \times 20$ cm. Competition exists for nitrogen already at 40 days after transplanting in a population of high planting density without nitrogen application.

Grain yield, plant weight, leaf area, amount of nitrogen in the plant, and tiller number or panicle number are highly affected by competition. Growth duration, plant height, culm length, 1000-grain weight, and thickness of leaf seem not to be affected. N% of plant, ratio of grain weight to total weight, spikelet number per panicle, % filled grain, and length of leaf are affected when the effect of competition is big.

The bulk population method in rice breeding will bring about a genotype that is unsuitable for the cultivation under heavy nitrogen application but yields reasonably when grown without nitrogen application.

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