

Competition, density response and self-thinning observed in rice

H.I. Oka¹ and Chi-Shan Lu

Department of Agronomy, National Chung Hsing University Taichung, Taiwan 402, Republic of China

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Abstract. To observe neighbor effects on plants at different planting densities, rice varieties Taichung 65 (T65) and Taichung Native 1 (TN1) were planted at a sequence of seven interplant spacings, each one half of the preceding, from 32 cm to 0.5 cm. The regression equation for single-plant biomass (W) on the number of plants per m^2 (N), $\ln W = \ln K - b \ln N$, fitted the data from all experiments and gave a coefficient of determination exceeding 0.97. Panicle weight per plant showed the same pattern of density response. The values of b were close to 1.0 in pure stands, being somewhat lower for plant biomass than for panicle weight. When early-sown plants and those sown 10 days later were mixed, the late-sown plants were suppressed by early ones and their b values approached 1.5. They had a high mortality (self-thinning) rate at high densities. When T65 and TN1 were mixed, TN1 was more competitive than T65, which had a higher mortality than did TN1. As density increased, the distribution of single-plant biomass and panicle weight was skewed to the right, and the interplant variance increased. The variance was strongly correlated with mortality and regression coefficient on density. These values were also correlated with skewness and the Gini coefficient, which show the inequality between individual plants.

Keywords: Biomass; Competition; Density; Neighbor effect; Regression on density; Self-thinning; Skewed distribution.

Introduction

The biomass of a plant (W) is inversely correlated to the number of plants per unit area (N). This relation is represented as: $WN^b = K$, or $\log W = \log K - b \log N$, where K stands for carrying capacity; K and b (regression coefficient) are constants in the given condition and can be estimated from the data. This equation was established in the pioneering work by Kira et al. (1953) and is known to hold true in general for plants ranging from small annuals to trees (Harper, 1977, Chap. 6, p. 183).

When many seeds germinate in a small plot, bringing about a high density of seedlings, the competition between the plants creates a hierarchical sequence in which smaller plants die. Because the value of b often approaches 3/2 under such conditions, the biomass-density relation is known as the 3/2 power law (Yoda et al., 1963).

When plants are tested at high densities, however, cases are found in which the regression coefficient on density (b) remains much lower than 1.5. It should be remembered that when $b > 1.0$, the plant biomass per unit area (yield) decreases as density increases; when $b < 1.0$, the yield increases as density increases; when $b = 1.0$, the yield is independent of density.

Only a few workers (Yamagishi et al., 1978; Assemat and Oka, 1980) have studied the influence of density on rice. The b values they found were close to 1.0, and no

death of plants occurred at 2.5 cm spacing (1,600 plants m^{-2}). It is suspected that rice is an exception to the 3/2 power law.

To examine the pattern of density response and density-dependent mortality in rice, the present experiments were conducted with special reference to the influence of mixing different-aged plants of the same variety, and plants of different varieties. The design of these experiments involved, to our knowledge, new facets in plant ecology. Some fundamentals of density response and competition were determined, and are reported in this paper.

Materials and Methods

We used two varieties of rice (*Oryza sativa* L.) in our experiments (Taichung 65 [T65] and Taichung Native 1 [TN1]) at National Chung Hsing University in Taichung. The two varieties were seeded on 14 (T65) and 24 (TN1) July 1986, and the seedlings were transplanted on 25 July and 1 August, respectively, at interplant spacings of 32 \times 32 cm (9.8 m^{-2}), 16 \times 16 (39 m^{-2}), 8 \times 8 (156 m^{-2}), and 4 \times 4 (625 m^{-2}) into a paddy field, and 2 \times 2 (2,500 m^{-2}), 1 \times 1 (10,000 m^{-2}), and 0.5 \times 0.5 (40,000 m^{-2}) into plastic boxes (40 \times 50 cm, 30 cm deep, filled with field soil). They were planted in pure stand and 1:1 mixture. In mixture, the seedlings of different ages or different varieties were planted alternately in both directions (alternate orthogonal design).

A plot consisted of 6 rows of 6 plants. In addition, border rows were planted, one row for 32, 16, and 8 cm spacings, two rows for 4 and 2 cm spacing, and three rows for

¹Corresponding author: H.I. Oka, National Institute of Genetics, Mishima, Shizuoka-Ken 411, Japan.

1 cm and 0.5 cm spacing. In the mixture of different plants, each kind was represented by half the plants. All treatments were performed twice.

At high densities, the late-sown plants mixed with early-sown ones were very small. Some of them died, or had no panicle if they remained alive. Apparently, dying and not heading are both the result of suppression by neighbors, and not heading means no offspring. Synthetic evaluation of both would give a proper measure of the immoderate condition. From this viewpoint, mortality was estimated as: $m = 1 - \sqrt{s \cdot h}$ where s is survivorship and h is heading rate.

Pure and mixed planting experiments were conducted again in 1987, in the paddy field only, with 6 spacings from 32 cm to 1 cm. The early and late seedlings took place on July 15 and July 22.

At seed maturity, the number of surviving plants per plot, tiller number per plant, panicle number per plant, and plant height were recorded. The above-ground parts of plants were harvested by cutting at the surface of the ground, and then dried in a 80°C oven for three days to measure single-plant dry weight and panicle weight per plant. The natural logarithms of the mean measurements of single-plant dry weight and panicle weight (W) were taken for further computation. Density (d) was represented by the natural logarithm of plant number (N) per m^2 .

The regression equation, $\ln W = \ln K - b \ln N$, in which N represents the number of plants surviving to maturity, was computed for each treatment plot. Carrying capacity (K) was obtained from the data. In addition, seed fertility and weight of single grains were recorded in the 1987 experiment.

Results

Pure and Mixed Plantings at Varying Densities

The logarithms of the dry-weight data for single plants (single-plant biomass) and panicles per plant (panicle weight) showed linear regressions on density (Figure 1). The data fitted the regression equation, $\ln W = \ln K - b \ln N$, quite well. The coefficient of determination of regression (r^2) was 0.976 or more for single-plant biomass and 0.963 or more for panicle weight in all pure stands

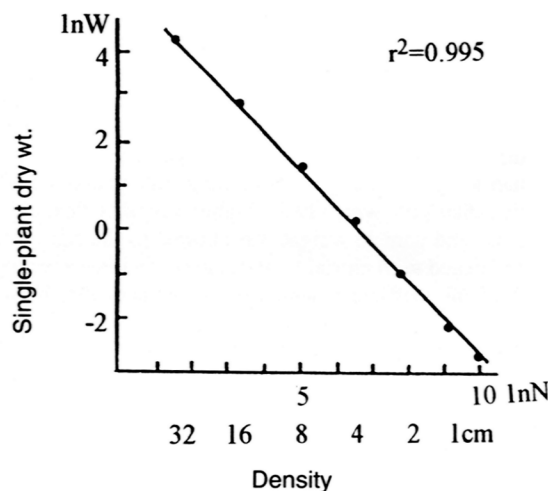


Figure 1. An example of regression of single-plant dry weight on number of plants per unit area, both in logarithms. T65, late-sown plants, 1986 experiment.

Table 1. Dry weight expected from regression on planting density, in natural logarithms.

Plot	Single-plant biomass			Panicle weight			Harvest index	
	Mean ^a	<i>b</i>	<i>r</i> ²	Mean ^a	<i>b</i>	<i>r</i> ²	Mean (%)	<i>b</i>
1986								
T65 E	0.39	0.965	0.998	-1.04	1.107	0.994	-1.43 (23.8)	0.142
T65 L	0.38	0.946	0.995	-1.49	1.293	0.963	-1.87 (15.4)	0.347
T65 E/L	1.09	0.854	0.997	-0.44	1.130	0.980	-1.53 (21.7)	0.276
T65 L/E	-3.18	1.665	0.991	No heading at spacings 4 cm and less				
TN1 E	0.26	0.975	0.991	-1.45	1.250	0.991	-1.71 (18.1)	0.275
TN1 L	0.14	0.936	0.996	-0.93	1.049	0.997	-1.07 (34.3)	0.113
TN1 E/L	1.00	0.860	0.991	-0.03	0.997	0.991	-1.94 (35.5)	0.137
TN1 L/E	-2.32	1.322	0.976	-4.53	1.662	0.964	-2.21 (10.9)	0.340
1987								
T65 E	1.51	0.672	0.957	0.28	0.970	0.976	-1.23 (29.3)	0.298
T65 E/L	1.73	0.637	0.958	0.60	0.871	0.963	-1.13 (32.2)	0.243
T65 L/E	0.65	0.738	0.967	-0.32	0.936	0.985	-0.97 (37.9)	0.198
TN1 E	1.58	0.741	0.980	0.81	0.833	0.991	-0.77 (46.2)	0.092

Regression equation: $y = (\text{mean biomass}) - b (\text{density})$.

y : biomass expected; b : regression coefficient; r^2 : coefficient of determination; E/L: shows the measurement of early-sown plants (E) mixed with late-sown ones (L), and so on.

Harvest index estimation: (Mean) $-1.43 = -1.04 - 0.39$; (b) $0.142 = 1.107 - 0.965$.

Seeding data: (1986) Early - July 14, Late - July 24; (1987) Early - July 15, Late - July 22.

^aLogarithms of single-plant biomass (or panicle weight) expected at 4 cm spacing ($625/m^2$) from regression equation; 1987 values are means for natural logarithms of different densities.

and mixtures (Table 1). Error variances in the data were 3% or less.

The standard error of a regression coefficient is given as: $s_b = \frac{\sigma_y}{\sigma_x} \sqrt{\frac{1-r^2}{n-2}}$ (cf. Steel and Torrie, 1980, p. 279). This computation showed that the 5% and 1% levels of significance of a difference in regression coefficient were about 0.10 and 0.15 for single-plant biomass, respectively, and about 0.15 and 0.22 for panicle weight.

Plants were grown in field and box at 4 cm spacing. Generally, the boxed plants had greater biomass than those in field. The average difference in natural logarithms was about 0.60, excluding late-sown plants mixed with early sown ones. The field and box data at 4 cm spacing for different treatments were strongly correlated ($r = 0.967$), suggesting that they can be regarded as essentially the same after an adjustment. In each treatment, the box data were adjusted to be comparable with the field data, by using the field-box balance at 4 cm spacing.

When we estimated mean single-plant biomass and mean panicle weight, the values for the 4-cm-spaced (625 m²) 1986 plants were considered representative, in view of the high coefficient of determination of regressions. For instance, the regression equation for T65 early-sown pure stand was obtained from the data as: $y = 6.60 - 0.965x$, and $x = 6.437$ for 625 m². The expected biomass, $y = 0.39$, was then derived as shown in the first line of Table 1. With 1987 data, however, means for different densities were computed after logarithmic transformation. The results of these computations are presented in Table 1.

In pure stands, the plant biomass and panicle weight of early- and late-sown plants did not differ by much, but in mixtures there was a strong interaction. Early-sown plants

exhibited an increased biomass and suppressed the late-sown ones, causing a marked difference in dry weight. The regression coefficient (b) decreased in early-sown plants and increased greatly in late-sown plants. As shown in Table 1, the regression coefficient for late-sown plants approached 1.5 when mixed with early-sown ones. The two varieties tested showed almost the same behavior in this respect.

Mean values of harvest index (the ratio of panicle weight to plant biomass) ranged from 15% to 34% in different treatments. Its logarithm was taken as the plant-panicle balance. Early-sown T65 plants had a greater harvest index than did late-sown ones, but this tendency was reversed in TN1 (Table 1). The statistical significance of differences in harvest index was not computed. The high coefficient of determination of regressions for plant biomass and panicle weight suggests that the harvest-index data are reliable to some extent. Assuming the error variance for plant biomass and panicle weight to be 1%, the least-significant difference in harvest index (5%; $df = 6$) would be 0.34 or 34%. It is difficult to deduce a conclusion about differences in harvest index from the data in Table 1.

Single-plant dry weight had b values lower than 1.0, while panicle weight had b values higher than 1.0—thus harvest index decreased with increasing density.

Estimation of Neighbor Effect

The influence of neighbors on a plant is indicated by the difference between pure and mixed stands. To estimate the neighbor effect, Assemat and Oka (1980) used the logarithms of the differences in mean dry weight and regression coefficient on density. This has enabled simulta-

Table 2. Neighbor effects between early-sown (E) and late-sown (L) plants, on single-plant biomass at 4 cm spacing computed from regression equation, and changes in regression coefficient due to neighbor effect. 1986 experiment.

Partner	Mean		b	
	E	L	E	L
T65				
E	0.39	-3.18	0.965	1.665
L	1.09	0.38	0.854	0.946
TN1				
E	0.26	-2.32	0.975	1.322
L	1.00	0.14	0.860	0.936

(T65)
Resistance of E to L:

$$h_{EL} = 1.09 - 0.39 = 0.70$$

Aggressiveness of E to L:

$$-h_{LE} = 3.18 - (-0.38) = 3.56$$

Resistance of L to E:

$$h_{LE} = -3.18 - 0.38 = -3.56$$

Change in regression slope of E due to neighbor effect of L:

$$q_{EL} = -0.854 - (-0.965) = 0.111$$

Change in regression slope of L due to neighbor effect of E:

$$q_{LE} = -1.665 - (-0.946) = -0.719$$

$$h_{ij} = \bar{X}_{ij} - \bar{X}_{ii}; q_{ij} = b_{ij} - b_{ii} \text{ (Assemat and Oka, 1980).}$$

(TN1)

$$h_{EL} = 1.00 - 0.26 = 0.74$$

$$-h_{LE} = 2.32 - (-0.14) = 2.46$$

$$h_{LE} = -2.32 - 0.14 = -2.46$$

$$q_{EL} = -0.860 - (-0.975) = 0.115$$

$$q_{LE} = -1.322 - (-0.936) = -0.386$$

neous estimation of density response and competition on the same basis, that is: letting $x = \ln X$, the influence of plant j on i at a given density is represented by $h_{ij} = x_{ij} - x_{ii}$, and the change in regression coefficient on density is represented by $q_{ij} = b_{ij} - b_{ii}$, where subscript ij is the value of i mix-planted with j , ii is the value of i in pure stand, h is the neighbor effect on plant biomass or panicle weight, and q is the neighbor effect on regression coefficient. It is expected that at a given density (d), $h_{ij(d)} = \bar{h}_{ij} - q_{ij}d$ ($d = \ln N - \ln N$).

The values for pure stand and early-late mixture were extracted (Table 2) from the data for mean single-plant biomass and regression coefficient given in Table 1. According to Assemat and Oka (1980), the resistance of plant i to the aggression of j is shown by $h_{ij} = \bar{x}_{ij} - \bar{x}_{ii}$, and the

aggressiveness of i to j is shown by the negative value of response of j to i as: $-h_{ji} = -\bar{x}_{ji} + \bar{x}_{jj}$.

The aggressiveness of early-sown plants to late-sown ones was quite high when mixed, and the resistance of late-sown plants to early-sown ones was negative (Table 2, footnote). The change in regression coefficient of early-sown plants, caused by mixed planting was positive, and that of late-sown plants was negative.

To show the influence of the neighbor effect on the regression equation, regression lines for different treatments were computed. The regression slope for early-sown plants mixed with late-sown ones was somewhat flatter than that for pure stand and that for late-sown plants mixed with early-sown ones was much steeper (Figure 2). This pattern was also observed with T65 and TN1.

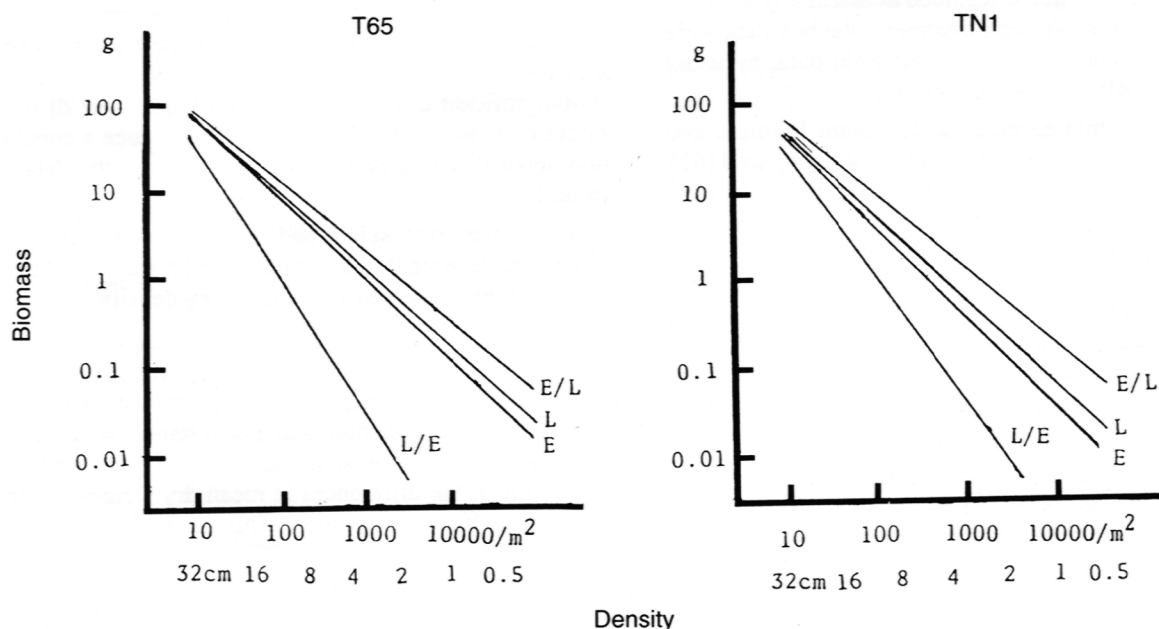


Figure 2. Regression lines of biomass on density for T65 and TN1 in pure and mixed stands. E, sown July 12; L, sown 24 July 1986.

Table 3. Mutual effects of T65 and TN1 in mixture, on single-plant biomass, panicle weight and harvest index.

Plot	Single-plant biomass			Panicle weight			Harvest index	
	Mean	b	r^2	Mean	b	r^2	Mean (%)	b
1986								
T65/TN1 E	0.17	0.952	0.978	-0.73	0.903	0.986	-0.90 (40.5)	-0.049
TN1/T65 E	1.07	0.750	0.975	-0.61	1.054	0.970	-1.68 (18.6)	0.304
T65/TN1 L	-0.40	1.104	0.976	-1.63	1.159	0.991	-1.24 (29.1)	0.055
TN1/T65 L	0.21	1.067	0.986	-0.40	1.033	0.980	-0.61 (54.2)	-0.034
1987								
T65/TN1 E	1.37	0.700	0.973	-0.11	0.892	0.982	-1.48 (22.6)	0.190
TN1/T65 E	1.54	0.777	0.977	0.67	0.976	0.973	-0.87 (41.8)	0.199

Notation and symbols - the same as in Table 1. The data in this table can be compared with those in Table 1.

Resistance of T65 to TN1: $0.17 - 0.39 = -0.22$ for early-sown plants; $-0.40 - 0.38 = -0.78$ for late-sown plants.

Resistance of TN1 to T65: $1.07 - 0.26 = 0.81$ for early-sown plants; $0.21 - 0.14 = 0.07$ for late-sown plants.

Change in regression slope of T65 due to neighbor effect of TN1: $\text{T65/TN1} = -0.952 - (-0.965) = 0.013$ (early-sown); $-1.109 - (-0.946) = -0.158$ (late-sown).

Change in regression slope of TN1 due to neighbor effect of T65: $\text{TN1/T65} = -0.750 - (-0.975) = 0.225$ (early-sown); $-1.067 - (-0.936) = -0.131$ (late-sown).

Mixture of T65 and TN1

When the two varieties were planted in 1:1 mixture, T65 was suppressed by TN1 and the biomass of TN1 increased (Table 3; pure-stand data in Table 1). The resistance of T65 to TN1 was negative and that of TN1 to T65 was positive (Table 3, footnote). This indicates that TN1 is a strong competitor against T65, and agrees with the general trend that Indicas are more competitive than Japonicas (Oka, 1960). The same trend was seen with panicle weight, but the influence of varietal mixture on early-sown plants was irregular.

The influence on regression coefficient of mixing varieties was less than that of mixing early- and late-sown plants. It was found that, in comparison with the data for pure stand in Table 1, mixing varieties brought about an increase in regression slope for early-sown plants and a decrease in regression slope for late-sown plants (*q* values, Table 3, footnote).

The coefficient of determination of the regressions on density was not affected by the mixing of the two varieties—it remained higher than 0.97 for plant biomass and panicle weight. In the mixed planting of the two varieties, the harvest index of each variety was somewhat increased, although the increases were statistically insignificant.

Mortality and Self-Thinning

Non-heading was taken into account when estimating mortality. The mortality at 4-cm and lower spacings observed in T65 and TN1 is presented in Table 4, which shows that mortality becomes high when plants are suppressed by neighbors, particularly in late-sown plants mixed with early-sown ones. Apparently, mortality is density-dependent. This may be taken to represent the self-thinning discussed by Yoda et al. (1963).

Variations Among Single Plants

Dense planting increased the variance among plants. The logarithms of single-plant mean variance computed in each treatment for all densities (σ_a^2 in Table 4) and dense plantings at 4 cm and smaller spacings (σ_b^2 in Table 4) were strongly correlated among 10 plots ($r = 0.989$). Either variance could be used to examine the relation between single-plant variability and other characters.

The correlations between single-plant variance, mortality, and other values are given in Table 5. The variance was correlated with mortality ($r = 0.956$) and regression coefficient on density ($r = 0.959$). Mortality and regression coefficient were also correlated ($r = 0.977$). All these values increased with density (Figure 3).

Table 4. Mortality at high densities and interplant variance of log-transformed single-plant biomass.

Plot	Mortality 1986					1987	Variance	
	Field 4cm	Box 2cm	Box 1cm	Box ½cm	Mean	Mean	σ_a^2	σ_b^2
T65 E	0.056	0.111	0.236	0.574	0.244	0.248	0.152	0.194
T65 L	0.071	0.042	0.475	0.588	0.294	0	0.176	0.215
T65 E/L	0	0.056	0.150	0.072	0.070	0.151	0.114	0.159
T65 L/E	0.922	0.863	0.947	0.913	0.911	0.332	0.401	0.537
TN1 E	0.194	0.007	0.134	0.351	0.172	0.092	0.144	0.174
TN1 L	0.194	0.028	0.186	0.561	0.242	0	0.202	0.283
TN1 E/L	0	0	0.028	0.111	0.035	0	0.152	0.195
TN1 L/E	0.559	0.275	0.833	0.953	0.655	0	0.343	0.454
T65/TN1 E	0.028	0.280	0.711	0.686	0.426	0.283	0.186	0.254
TN1/T65 E	0	0	0	0	0	0.166	0.177	0.280
Mean	0.202	0.166	0.370	0.481	0.305	0	0	0

Mortality: $m = 1 - \sqrt{s \bullet h}$, s = survival rate and h = heading rate.

σ_a^2 = Mean variance for all densities; σ_b^2 = Mean variance for 4 cm and lower spacings.

E: Early-sown plants; L: Late-sown plants.

Table 5. Correlations between values showing density response, obtained in 10 plots: T65E, T65L, T65E/L, T65L/E, TN1E, TN1L, TN1E/L, TN1L/E, T65/TN1 (E), and TN1/T65 (E).

Value	b^a	m	σ^2	Gini coef.
Mortality ($1 - \sqrt{s \bullet h}$; mean given in Table 4), m	0.964			
Variance of log plant wt. (mean for all densities), σ^2	0.959	0.956		
Gini coef. for plant biomass (mean for all densities)	0.793	0.948	0.886	
Skewness (g_1 , mean for 2, 1 and 0.5 cm spacings)	0.965	0.922	0.946	0.846

^aRegression coef. of plant biomass on density.

All correlations significant at 1% level.

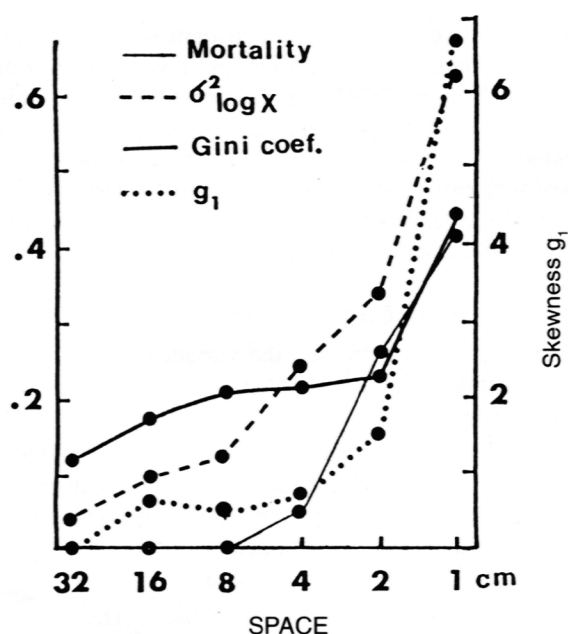


Figure 3. Mortality, variance of log-transformed dry weights of individual plants, Gini coefficient, and g_1 showing skewness at 6 density levels (shown by distance between plants). T65 in 1987, second crop experiment.

To evaluate the degree of inequality of individual plants, two more parameters were computed:

Skewness $g_1 = m_3 / (m_2 \sqrt{m_2})$, where $m_2 = \sum_i (X_i - \bar{X})^2 / n$

; $m_3 = \sum_i (X_i - \bar{X})^3 / n$.

(Snedecor and Cochran, 1980, p. 78; n = number of plants sampled)

Gini coefficient = $\sum_i \sum_j |X_i - X_j| / 2n^2 \bar{X}$, which measures the tendency of small plants to predominate over large ones (cf. Weiner, 1985, 1986).

These parameter values increased with increasing density (Figure 3) and were strongly correlated with mortality, regression coefficient, and single-plant variance (Table 5).

Search for Optimal Density

The regression coefficient on density fluctuates around 1.0. This indicates that the biomass yield per unit area is a constant not affected much by planting density. The harvest index, however, tends to decrease with increasing density.

Grain yield depends not only on biomass production, but also on other factors, such as seed fertility and grain test weight. These characters generally show convex curves on density. Single-grain weight exhibited a curvilinear response to density, reaching maximum at 16 cm spacing (Figure 4). Seed fertility and plant height tended

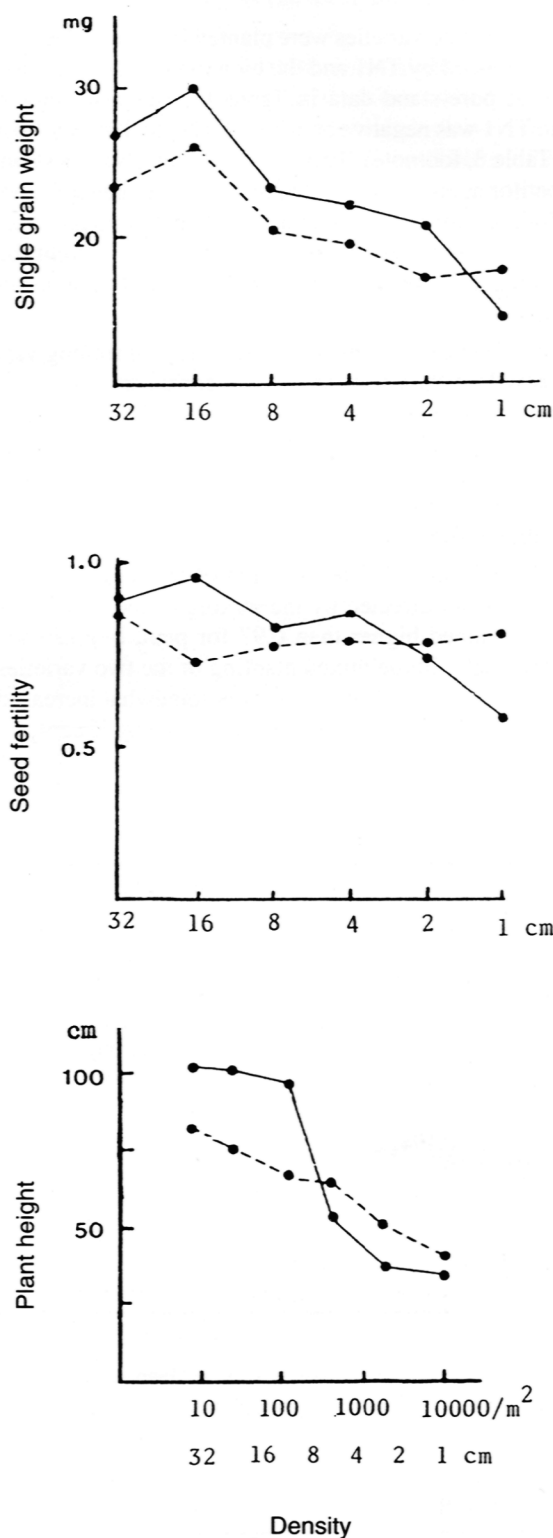


Figure 4. Single grain weight, seed fertility, and plant height changes with density. T65, Solid line; TN1, broken line. 1987 experiment.

to be lower with increasing density, but the changing patterns were non-linear (Figure 4). These non-linear reactions, when combined, bring about a convex curve of grain production on density. There is an optimal planting density where grain yield is maximum—probably between 16 cm and 32 cm spacing (Iso, 1944).

Discussion

The log-transformed values of single-plant dry weight and panicles per plant showed linear regressions on log-transformed plant number per unit area, fitting the equation presented first by Kira et al. (1953), $\ln W = \ln K - b \ln N$. All regression equations obtained had a coefficient of determination exceeding 0.97. T65 and TN1 showed almost the same response to density stress; the Indica-Japonica difference does not seem to have a significant influence on the density response.

The regression coefficient (b) was below 1.0 for single-plant biomass in pure stands, and approached 1.5 in late-sown plants mixed with early-sown one. Under this strongly-suppressed condition, the plants followed the $3/2$ power law. When $b = 1.5$, halving the space between plants reduces the mean biomass 88%, and the late-sown plants suffer high mortality. The mortality was density-dependent, and can be regarded as the self-thinning discussed by Yoda et al. (1963).

When the distance between plants is large enough, the biomass variation would follow the normal distribution. As the space is narrowed, neighboring plants come into contact and compete for light and resources, to bring about superior and inferior individuals. It is then generally found that plants smaller than the average become more numerous than larger ones (Weiner, 1985). The distribution tends toward L-shaped and approaches log-normal (Koyama and Kira, 1956). We have observed that the variance of single-plant biomass transformed into logarithms increases with increasing density; even in logarithms, smaller plants become more numerous than larger ones as density increases.

Weiner (1986) pointed out that, based on experiments with *Iponoea tricolor* which distinguished shoot interference from root interference, competition for light by shoots is asymmetrical or one-directional and increases size variability among plants, although competition for nutrients by roots does not. Weiner's study suggests that the increase of size inequality with density can be at least partly the result of competition for light, which begins earlier at higher densities. Such competition would bring about a hierarchical sequence among the plants, and inferior plants would die.

Strong correlations were found between the variance of log-biomass, mortality, and regression coefficient on density. All these values were density dependent. The tendency of inferior plants to increase against superior ones with increasing density was also shown by parameters for individual inequality, skewness, and Gini coefficient.

These responses of a population to density stress will result in selection if there are genetic differences, but these are physiological processes which can take place in a genetically homogeneous population.

The mixed population of early and late-sown plants may be regarded as simulating a natural population in which seeds do not germinate simultaneously. The late-sown plants are suppressed by the early-sown ones, which intercept light and have a high regression coefficient on density and a high mortality. They are eliminated if the population grows under favorable conditions, but can serve as reserves for a calamity that kills vigorously growing plants. Physiological heterogeneity in a population can contribute to adaptation.

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水稻的競爭、密度反應與自然疏伐之研究

H.I. Oka 陸集珊

國立中興大學農藝學系

目前通訊：日本國家遺傳研究所

利用水稻台中 65 號及台中在來一號兩品種測試從 32 公分至 0.5 公分共七種株距之影響，以了解不同栽培密度植株間之近鄰效應。其單株生合成量 (W) 對每平方公尺之植株數 (N) 或密度之迴歸方程式均成對數關係 ($\ln W = \ln K - b \ln N$)，不同之試驗數據均符合此公式且決定係數高於 0.97。每株穗重對密度之反應亦如此。迴歸係數 b 值在單植中非常接近 1.0，唯植株生合成量之 b 值稍小於穗重之 b 值。當同一品種早十天播種與晚播株混種在一起時，晚播株明顯受早播株壓制其 b 值接近 1.5。且在高密度下其有高度之死亡率或自然疏伐率。而當台中 65 號與台中在來一號混植時，台中在來一號有較強之競爭力，且台中 65 號之死亡率亦高於台中在來一號。當密度增加時，單株生合成量及穗重易偏歪至右，且植株間之變方增加，此變方與死亡率及密度迴歸係數有很強之關聯性。這些值亦與歪度及顯示個別植株不等性之 Gini 係數有關。

關鍵詞：近鄰效應；生合成量；密度；密度迴歸；自然疏伐；競爭力；偏歪分布。