EFFECTS OF PLANTING DENSITY ON YIELD COMPONENTS OF RICE

by

W. L. CHANG*

Interest in growing rice at high population density has greatly increased in recent years, and considerable emphasis is being placed on breeding rice varieties that will assure a maximum and stable yield under close spacing and heavy fertilization. Although many investigations have already been devoted to the problem of spacing, little information is available on the mutual associations of yield components at different planting densities. Preliminary evidence shows that the relationships among yield components vary with planting density and growing season (Chang, 1965). Inasmuch as grain yield is a complex character and is largely under the influence of yield components, a knowledge of interrelationships among the components of yield may be useful in selecting superior yielding genotypes adapted to high planting densities.

Usually, the grain yield of individual rice plants is reduced when the plant population is increased. However, the total grain yield per unit area may increase because the decrease in yield per plant is offset by the increase in plant numbers. Rice varieties give differential responses to planting densities (Chang, 1964) and show a highly significant variety×spacing interaction for grain yield (Tanaka *et al.*, 1964). Generally, the increase of yield by dense planting is greater in the panicle-weight type varieties than in the panicle-number type ones (Matsuo, 1965). Rice breeders will make a substantial contribution to rice production if they could succeed in developing a rice variety with a plant type adapted to the growing conditions of high planting density. An understanding of the interaction between genotype and planting density may be of some help to rice breeders in their pursuit of this objective.

The present study attempts to furnish information on the nature of associations among components of yield of rice plants grown under different planting densities.

MATERIALS AND METHODS

Chianung 242 and Chianan 8, two of the leading commercial rice varieties in Taiwan, were chosen for the experiment. The former is a low-tillering and heavy-panicled variety while the latter tends to have more and lighter panicles than the former. These two varieties were subjected to two levels of planting density, namely,

* Agronomist, Chiayi Agricultural Experiment Station. The writer is grateful to Dr. T. T. Chang, Geneticist, The International Rice Research Institute, Los Banos, Laguna, the Philippines, for his kind review of the manuscript.

64 and 128 hills per tsubo (3.3 m^2) The distances between rows were 24 cm for both spacings while the distances between hills within a row were 21.5 and 10.8 cm for 64 and 128 hills, respectively. Three seedlings were transplanted for each hill. The fertilizers applied on the experimental plots were 80, 40, and 40 kg per hectare for N, P_2O_5, and K_2O, respectively. The plots were 4×2.5 m in size which were equal to 10 m^2 or 1/1,000 hectare. The experiment was laid out in a randomized complete block design with three replications.

Fifteen hills from each plot were randomly selected and data on number of days from transplanting to heading, plant height, panicle length, panicle weight, grain yield per hill, number of panicles per hill, number of grains per panicle, and weight of 100 grains were taken from each individual plant hill. A variance analysis on each recorded variable and covariance analysis for each pair of variables were made based on the data of individual plant hill. Simple correlation coefficients for all possible comparisons were calculated from these variance and covariance components.

Path coefficients, as applied by Dewey and Lu (1959), were used to partition the simple correlation coefficients into direct and indirect effects of (1) number of panicles per hill, (2) number of grains per panicle, (3) 100-grain weight on (4) grain yield per hill The nature of the causal system is shown diagramatically in Fig. 1.

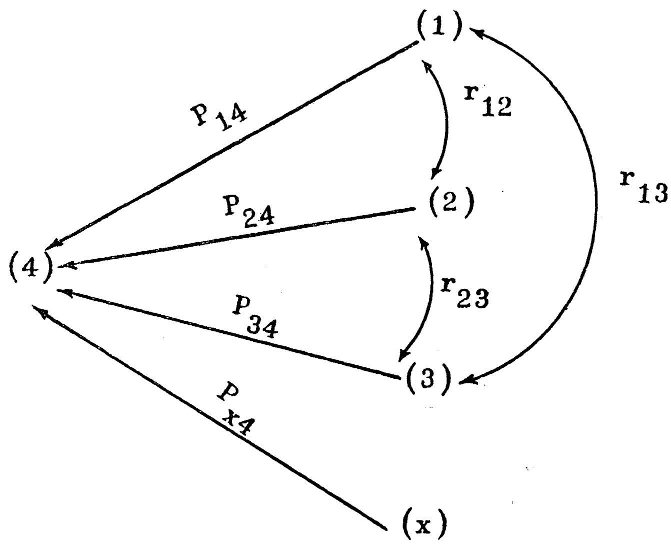

Fig. 1. Diagramatic representation of Path-coefficient analysis of the interrelationships of number of panicles per hill (1), number of grains per panicle (2), and 100-grain weight (3), with grain yield per hill (4). X represents the residual portion.

In the path diagram, the double-arrow lines indicate mutual association as measured by correlation coefficients. The single-arrow lines represent direct influence as measured by path coefficients. The residual variable (X) includes direct effects of all other factors affecting grain yield per hill in this study and is considered independent of the other 3 variables. The path coefficients in this study were obtained by simultaneous solution through the method of least squares.

This experiment was conducted in the first crop of 1964 at Chiayi Agricultural Experiment Station.

EXPERIMEMTAL RESULTS

Effect of Planting Density on Agronomic Traits of Rice Plant

The effects of the spacing treatments upon the observed agronomic traits of the two varieties were quite remarkable (Table 1). Average yield of Chianan 8 was higher than that of Chianung 242 when both varieties were sparsely planted (64 hills per 3.3 m^2). As population density doubled (128 hills per 3.3 m^2), the grain yield per hill of Chianan 8 was reduced more rapidly (52%) than Chianung 242 (46%). Thus, at the high planting density, Chianung 242 yielded higher than Chianan 8. The average grain yield per hill of Chianung 242 was, therefore, sligh.ly higher than that of Chianan 8 when data were pooled over two spacings.

Table 1. Average values of agronomic traits of two rice varieties grown at two spacings in the first crop of 1964

Variety	Spacing (hills/tsubo)	No. of days to heading	Plant height (cm)	Panicle length (cm)	Panicle weight (g)	Panicles per hill	Grains per panicle	100-grain weight (g)	Grain yield per hill (g)	Grain yied per ha. (kg)
Chianan 8	64	93	102	18.3	2.65	15	98	2.80	33.91	6,565
	128	91	99	16.2	1.92	9	67	2.84	16.44	6,366
Chianung 242	64	95	115	22.1	3.31	11	110	3.04	32.94	6,377
	128	94	110	20.0	2.58	7	85	3.06	17.66	6,838
Mean of 2 varieties	64	94	108	20.2	2.98	13	104	2.92	33.43	6,472
	128	92	105	18.1	2.25	8	76	2.95	17.08	6,613
Chianan 8	Mean of 2 spacing	93	100	17.2	2.30	12	83	2.82	25.18	6,466
Chianung 242	Mean of 2 spacing	94	112	21.1	2.95	9	97	3.05	25.30	6,608
Mean of 2 varieties	Mean of 2 spacing	93	106	19.1	2.62	11	90	2.94	25.24	6,537

Among the yield components, the number of panicles per hill and the number of grains per panicle of both varieties exhibited almost the same trends as grain yield per hill. There were a slight increase (1%) in 100-grain weight in the 128-hill plots for both varieties. When data were pooled over varieties, the grain yield per hill and its three components still reflected a similar response to spacings as they did in the individual treatments. Under high planting density, rice plants headed earlier, grew shorter, and bore smaller and lighter panicles. Varietal responses to spacings were similar for these four traits in both individual and pooled data.

Simple Correlations Among Components of Grain Yield

Relationships among grain yield per hill and its three yield components are

Table 2. Simple correlation coefficients among yield compoments of rice for individual and grouped data obtained in the first crop of 1964

Variety	Spacing (hills/tsubo)	N	Correlation coefficients***					
			r_{12}	r_{13}	r_{14}	r_{23}	r_{24}	r_{34}
Chianan 8	64	45	0.0787	−0.1744	0.7733**	−0.1044	0.3007*	−0.2534
	128	45	−0.2165	−0.1803	0.6467**	0.2176	0.3770**	0.2004
Chianung 242	64	45	−0.1042	0.1529	0.5078**	−0.0365	0.3586*	0.2070
	128	45	−0.1930	−0.3232*	0.8643**	0.1141	0.1940	−0.3040
Mean of 2 varieties	64	90	−0.0283	−0.1149	0.6812**	−0.0489	0.2912**	−0.1068
	128	90	−0.3127**	−0.2527*	0.7137**	0.0824	0.2817**	−0.0202
Chianan 8	Mean of 2 spacings	90	0.0487	−0.1317	0.7596**	0.2091*	0.3629**	0.0312
Chianung 242	Mean of 2 spacings	90	−0.2230*	−0.2046*	0.7220**	−0.0030	0.1687	−0.2366*
Mean of 2 varieties	Mean of 2 spacings	180	−0.0918	−0.1313	0.7324**	0.2347*	0.2601**	−0.0048

* Significant at the 5% level.
** Significant at the 1% level.
*** X_1=panicles/hill, X_2=grains/panicle, X_3=100-grain weight, X_4=grain yield/hill.

shown by simple correlation coefficients in Table 2. Number of panicles per hill was positively correlated with grain yield per hill. The correlation coefficients were significant at the 1% level in both spacings and also in pooled data of the two varieties. The association between panicle number and grain yield was closer in the sparse planting of Chianan 8, whereas, the situation was reversed in Chianung 242. Number of panicles per hill was more closely associated with grain yield per hill in Chianan 8 and in dense planting when the data were pooled over two spacings and varieties. Generally, number of panicles per hill was negatively associated with both number of grains per panicle and 100-grain weight, especially in the dense planting of Chianung 242, where the correlations reached a significant level.

Number of grains per panicle was positively correlated with grain yield per hill in all combinations of the data. The correlation coefficients were significant except those of dense planting with Chianung 242 and its pooled data of two spacings. However, the magnitude of these correlation coefficients was much smaller than that between panicle number and grain yield. The number of grains per panicle showed a slightly closer association with grain yield when plants of Chianan 8 were closely spaced, but the reverse was true with Chianung 242. The correlation coefficient of Chianan 8 was more than twice that of Chianung 242 when data of varieties were pooled over spacings, while sparse planting gave only slightly higher correlation coefficient than that of dense planting when data were pooled over varieties. On the whole, sparse planting gave negative correlations between grain number and 100-grain weight, while dense planting the positive ones. However, the correlations were mostly of small magnitude to be of any significance.

Chianan 8 gave negative correlation between 100-grain weight and grain yield in sparse planting and a positive one when population density was doubled. In Chianung 242 the associations were completely reversed. Four of the five grouped data except that of Chianan 8 showed negative correlations which were not significant except that of the pooled data of Chianung 242.

Path Coefficient Analysis

Path coefficients included in Table 3 show that grain yield per hill is in part the sum of number of panicles per hill, number of grains per penicle, 100-grain weight and a composite variable that includes all other factors affecting grain yield per hill in this study. Table 3 illustrates that the number of panicle per hill was the most important component and the number of grains per panicle the second most important character affecting grain yield per hill. The 100-grain weight apparently had little to do with grain yield per hill. The direct effects of the unknown variable P_{x4} were quite high and they accounted for about 12 to 55% of the variation in grain yield per hill.

Table 3. Path coefficients of factors affecting grain yield per hill for various groupings of data obtained in the first crop of 1964

Variety	Spacing (hills/3.2 m^2)	Path coefficients*			
		P_{14}	P_{24}	P_{34}	P_{x4}
Chianan 8	64	0.7375	0.2322	−0.1005	0.5783
	128	0.7971	0.4983	0.2357	0.4994
Chianung 242	64	0.5298	0.4189	0.1413	0.7426
	128	0.9212	0.3774	−0.0494	0.3400
Mean of 2 varieties	64	0.6885	0.3101	−0.0125	0.6629
	128	0.9312	0.5590	0.1691	0.4258
Chianan 8	Mean of 2 spacings	0.7530	0.3127	0.0650	0.5590
Chianung 242	Mean of 2 spacings	0.7831	0.3431	−0.0754	0.5991
Mean of 2 varieties	Mean of 2 spacings	0.7648	0.3259	0.0191	0.5960

* a_1=panicles/hill, a_2=grains/panicle, a_3=100-grain weight, a_4=grain yield/hill, x=residual factor.

The relative contribution of the three variables to yield varied with variety and spacing. The number of panicles per hill was 3.2 and 1.2 times as influential on grain yield per hill as number of grains per panicle in the sparse plantings for Chianan 8 and Chianung 242, respectively. The comparative importance of the former component to the latter one on grain yield per hill, however, dropped to only 1.6 times in Chianan 8 but climbed to 2.4 times in Chianung 242 when plants were closely spaced. When data of planting densities were pooled over varieties, the number of panicles per hill was 2.2 and 1.7 times more influential than the number of grains per panicle on grain yield per hill in sparse and dense plantings, respectively. The direct effects of the residual factor were generally higher in sparse planting than in dense one.

The direct effects of four variables were almost the same in equations computed for each variety by including both spacings as well as in that when all data were included for the analysis. The number of panicles per hill proved to be about 2.4 times as influential on grain yield as number of grains per panicle in these three comparisons.

DISCUSSION

It was noticed that Chianung 242 and Chianan 8 responded differently to changes in spacing, with Chianung 242 showing a positive response and Chianan 8 a negative one to increased population density. When computed on a per unit area basis, the grain yield of Chianung 242 increased 7% with increased population density, which was attributable to a large increase (27%) in number of panicles per unit area and an associated small decrease (23%) in the number of grains per panicle. In contrast, yield of Chianan 8 decreased 3% with increased population density. Although number of panicles per unit area increased 20%, a more drastic decline (32%) in number of grains per panicle offset it. Grain weight was only slightly affected by spacings in both varieties, hence very little change in yield accompanied increased population density. These results have some significance on the techniques of rice culture and breeding. In growing rice, an optimum spacing should be planned for a given variety at a given crop season based upon its response to changes in spacing, since each variety seems to have an optimum spacing for maximum yield production (Tanaka *et al.*, 1964). Equidistant planting has also shown promise of increasing efficiency of grain production at high population density (Chang and Yang, 1965). In varietal trials, several levels of spacing should be provided so that relative yield potentials of genotypes tested could be correctly evaluated.

Chianung 242 is generally regarded as a typical panicle-weight-type variety. It appeared therefore, that panicle-weight-type variety was more adaptable to the growing conditions of high population density. The result of this experiment was in close agreement with the finding of Takahashi (1944). He reported that the increment of yield by dense planting was greater in the panicle-weight-type varieties than in the panicle-number-type varieties. Matsuo (1965) cited an experimental result of the Hokaido Agricultural Experiment Station showing that the panicle-weight-type variety, Ishikarishiroge, increased more in yield under dense planting than did the panicle-number-type, Eiko. Tanaka (1965) also suggested that a higher yield will probably be obtained with a weak-tillering variety closely spaced.

The relationships among the three components of yield and their relative contributions to grain yield per hill changed with spacing, although they consistently displayed considerable influence upon grain yield. Among the three yield components, number of panicles per hill appeared to be the most significant variable affecting grain yield, especially at high population density. It is worthy of note that the number panicles per hill generally had stronger negative associations with the other two yield components at closer spacing. This will be a great concern to rice breeders because simultaneous improvement of these three components is made difficult, if not entirely impossible, by the unfavorable correlations between number of panicles per hill and the other two components of yield. Since a unit of length chopped off the long edge of a rectangular parallelepiped will decrease the volume (yield) less than a unit removed from a short edge (Grafius, 1964), it seems more profitable to increase the number of grains per panicle in breeding programs designed to develop a new variety adapted to high population density. Inasmuch as number of grains per panicle was negatively correlated with the number of panicles per hill, selection for more grains is likely to exclude the possiblility of selecting a high tillering type which may be less adapted to closer spacing (Takahashi, 1944; Matsuo, 1965; Tanaka, 1965). Heritability estimate of grain number per panicle is generally high (Matsuo, 1955), therefore, selection for this character would be effective.

Rice plants compete severely for light and nutrients at closer spacing. Lowered light penetration from increased foliar shading produces more elongated internodes and thinner culms. These characters increase lodging tendency at high population density. Another difficulty which may result from dense planting is reduced spikelet fertility which arises presumably through increased shading of panicles during anthesis (Jennings and Sornchai, 1964). To avoid these pitfalls, some basic changes in architecture of the rice plant may be needed. Since most varieties adapted to dense planting are also adapted to heavy fertilization (Matsuo, 1965), a plant type of short, sturdy culms and erect, short, narrow, thick, dark-green leaves suggested by Jennings and Beachell (1965) for nitrogen responsiveness may well be the right one to seek for dense planting. By a more efficient combination of yield components, plant type and cultural methods, it is highly probable that rice culture at high population density can be greatly improved.

SUMMARY

Experimental results of two rice varieties, Chianung 242 and Chianan 8, planted at two spacing treatments in the first crop of 1964 at Chiayi Agricultural Experiment Station are reported.

Grain yield per hill decreased with increased population density, with Chianan 8 decreasing at a higher rate than Chianung 242. However, per unit area grain yield increased in Chianung 242, while that of Chianan 8 decreased at higher population density. A similar trend prevailed also in number of panicles per hill. Number of grains per panicle decreased whereas 100-grain weight increased at higher population density.

The relationships among the 3 variables changed with spacing. Number of panicles per hill was positively associated with grain yield per hill, the correlation coefficients being highly significant. The magnitude of the correlation coefficients was reduced in Chianan 8 but increased in Chianung 242 with increased population density. Number of panicles per hill showed higher negative correlations with

number of grains per panicle and 100-grain weight at high population density. Number of grains per panicle was also positively correlated with grain yield per hill. Weight of 100 grains was not significantly associated with grain yield per hill.

Examination of the direct influence of yield components on grain yield per hill indicated that the number of panicles per hill was the most important character affecting grain yield per hill, and the number of grains per panicle ranked next. Weight of 100 grains had little direct influence on grain yield per hill. Residual factor appeared to have affected about 12 to 55% of the variation in grain yield per hill.

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栽植密度對水稻產量構成因素之影響

張 萬 來

摘 要

嘉義農業試驗分所於民國53年第1期作舉辦栽植密度對水稻產量構成因素影響之試驗並得下列結果。

嘉農 242 號及嘉南 8 號水稻每株谷粒產量均隨栽植密度之增加而減少，尤以後者爲甚。惟嘉農 242 號水稻之單位面積谷粒產量却隨栽植密度之提高而增加， 而嘉南 8 號則減少。每株穗數亦具有類似每株谷產量之反應。每穗粒數因密植而減少，但百粒重則稍增。

每株谷粒產量及其構成因素彼此間之關係，隨栽植密度而改變，每株穗數與谷粒產量具有極顯著之正相關，嘉農 242 號之相關係數，因密植而增大，而嘉南 8 號則因密植而變小。每株穗數與每穗粒數及百粒重之間成負相關，其關係以密植處理者爲密切。每穗粒數與每株谷粒產量亦成正相關，但百粒重與每株谷粒產量之間却無顯著之相關關係。

每株穗數爲決定每株谷粒產量之最重要因素，每穗粒數次之。 百粒重對每株谷粒產量之直接影響甚微。剩餘因素尚能決定12至55%之產量變異。