

PLANTING DENSITY EFFECT ON NATURAL THINNING OF RICE LEAF^{1,2}

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Abstract

This study aims to find out the influence of the environment-growth interaction on plant leaf amount (comprising number of leaves, leaf area, and leaf weight), to set up a mathematical model for numerically measuring the interaction and to infer the relationship between net assimilation rate (NAR) and ripening rate in order to understand the low-yield problem of the second rice crop in Taiwan.

1. Leaf amount (α) was inversely equated with planting density (ρ) by analysis using linear regression, $1/\alpha = \alpha\rho + \beta$. When the environmental potential (α_i) and the genetical potential (β_i) for the leaf amount were plotted against time (t), they varied exponentially. The environmental potential (α) showed a large difference between the two crops. Higher estimates of the environmental potential were obtained at the earlier growth stage (before tillering) of the first crop, whereas the potential was estimated high at the later growth stage (after heading) of the second crop. However, little difference in genetical potential was found between the two crops.

2. The per unit area productivity rate of the leaf amount was higher for the first crop where it reached 100% at the later growth stage. The highest rate for the second crop occurred on the 80th day after transplanting (about one week after heading). However, the rate attained only 80% and then declined, it may account for one of the reasons giving low ripening rate in the second crop.

3. Leaf and stem weight were the major constituents of rice above-ground dry weight. If planting density remains fixed, changes in either leaf weight or stem weight (α) with time of growth in relation to the density (ρ) can be expressed as, $\ln \alpha(\rho) = \ln H + h \ln w(\rho)$, where H and h represent the parameters for time of growth, and w is the total above-ground weight. In this equation, h is also considered as allometric coefficient.

Data analysis showed that stem weight had higher h value than leaf weight. Rice growth under different growth environments contributed more from the stem weight. On the other hand, h value for leaf weight was high for the first crop, regardless of planting density. The leaf growth was rather poor in the second crop.

If the time of growth was fixed and the planting density was varied, the leaf or stem weight per unit area (Y_x) and the planting density (ρ) were expressed as, $\ln Y_x = \ln H + \ln \rho - h \ln (\alpha\rho + \beta)$. By this equation, the result showed a higher

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absolute value of h for stem weight than that for the leaf. The absolute h for leaf weight was higher in the second crop than that in the first crop during the early growth. However, the value declined after heading in the second crop, indicating that during the later growth stage, leaves developed poorly.

4. According to the rule of growth suggested by Watson (1958), NAR is linearly related with leaf area index (F), $NAR = a - bF$. However, this study indicated that the linear relationship did not exist before heading, if the planting density was too large or too small in the first crop. The relationship could not be found in the whole second crop season. Therefore, the study was not feasible to determine any appropriate planting density through the linear equation mentioned-above.

5. NAR was not correlated with ripening rate, indicating that low ripening rate had little connection with NAR in the second crop. Moreover, increasing planting density of rice did not decrease the ripening rate.

Key words: *Oryza sativa*; rice leaf; mathematical model; planting density; leaf area index; net assimilation rate; environmental potential; genetical potential.

Introduction

The development and differentiation of a plant is controlled by its ontogenetic drift and by the surrounding environment. This phenomenon exists not only among different plants but also among characters within an individual.

In the previous paper (Wu *et al.*, 1977), we studied the environment-growth interaction in terms of the plant dry weight and yield components of rice. We suggested an adequate planting density for different crop. In this study, we designed to investigate the influence of the environment-growth interaction on leaf amount (comprising number of leaves, leaf area and leaf weight), stem weight and canopy of rice. A mathematical model was designed to measure the interaction among plant characters and to infer the relationship between net assimilation rate (NAR) and ripening rate. The mechanism of rice productivity under different environmental conditions shall be understood.

Materials and Methods

Experimental Design and Sampling

Rice plants of *Oryza sativa* L. var. Taichung 65 was used for this investigation. The six planting densities used were 8.33 (26 cm × 46 cm), 16.67 (26 cm × 23 cm), 32.26 (26 cm × 12 cm), 33.33 (13 cm × 23 cm), 47.62 (9 cm × 23 cm) and 62.50 (13 cm × 12 cm) plants/m². A single plant per hill was planted and a random sample of 10 plants from each density plot was harvested every week. Characters of stem number, leaf number, leaf area, dry weight of leaf and stem part were separately measured. After maturity, the yield and its components were also investigated.

Mathematical and Statistical Approach

1. Density effect and productivity rate of unit area

The parameters of environmental potential (α) and genetical potential (β) as well as the productivity rate of a unit area (\hat{a} , m^2) of each growth stage for measuring plant characters were estimated by the modified method of Wu *et al.* (1977).

2. Allometric coefficient

Assume:

$$x(\rho) = Hw(\rho)^h \quad (1)$$

where $x(\rho)$ and $w(\rho)$ are the partial dry weight and the whole-plant dry weight of a plant at a given stage in a planting density of ρ , respectively. h is an allometric coefficient of a character, and H is the relational parameter between $x(\rho)$ and $w(\rho)$, where h and H are the parameters of growth time. Then:

$$\ln x(\rho) = \ln H + h \ln w(\rho) \quad (2)$$

hence, we may estimate the parameter of H and h at each growth stage under various densities.

If y_x and y represent the dry weight of a character and of the whole-plant in a unit area, respectively, we may obtain:

$$y_x \equiv x\rho \quad (3)$$

and

$$y = w\rho \quad (4)$$

According to the assumption of Bleasdale and Nelder (1960), Hozumi (1973), Bleasdale (1966), Mead (1970) and Wu *et al.* (1977), we may obtain the linear relationship between $1/w$ and ρ , thus:

$$1/w = \alpha\rho + \beta \quad (5)$$

then

$$w = 1/(\alpha\rho + \beta) \quad (6)$$

thus

$$w^h = 1/(\alpha\rho + \beta)^h \quad (7)$$

From equation (1), $x = Hw^h$,

$$\therefore y_x = x\rho = Hw^h \cdot \rho = H\rho/(\alpha\rho + \beta)^h \quad (8)$$

which can be linearized to:

$$\ln y_x = \ln (H\rho/(\alpha\rho + \beta)^h) = \ln H + \ln \rho - h \ln (\alpha\rho + \beta) \quad (9)$$

where estimated value of α and β can be obtained from equation (5). So that, it may obtain the estimated values of H and h of each density at various growth stages.

If $h = 1$, it may obtain the same relationship of y_x to ρ and y to ρ . If $h < 1$, when ρ increased, y_x increased. If $h > 1$, we may estimate the optimum density at t th growth stage, as:

$$\rho_{\text{opt}}(t) = \beta(t)/(\alpha(t)(h-1)) \quad (10)$$

If $\beta > 0$ and $h > 1$, then $y_{x\text{max}}$ will be obtained from equations (8) and (10), thus:

$$y_{x\text{max}} = (\beta/\alpha)(H/\beta^h)(1/(h-1)) \quad (11)$$

and if $\beta \rightarrow 0$, y_x will be obtained from equation (8), as:

$$y_x = H\rho/(\alpha\rho)^h = H\rho^{1-h}/\alpha^h \quad (12)$$

hence the relation between $\ln y_x$ and $\ln \rho$ becomes linear for any h .

3. The density effect on leaf dry weight and leaf number

Let u and w_L are the mean values of leaf area and leaf weight, and F and y_L are leaf area index (LAI) and leaf weight per unit area, respectively. Then:

$$\left. \begin{array}{l} F = u\rho \\ y_L = w_L\rho \end{array} \right\} \quad (13)$$

If the relation between leaf area and density become linear, thus:

$$1/u = \alpha_u \rho + \beta_u \quad (14)$$

hence,

$$1/(u\rho) = \alpha_u + \beta_u/\rho \quad (15)$$

therefore,

$$1/F = \alpha_u + \beta_u/\rho \quad (16)$$

The value of α_u and β_u of equation (14) can be obtained by the method of regression analysis, and we can also obtain F value from equation (16).

As above-mentioned, we can also obtain:

$$1/w_L = \alpha_L \rho + \beta_L \quad (17)$$

$$1/(\rho w_L) = \alpha_L + \beta_L/\rho \quad (18)$$

$$1/y_L = \alpha_L + \beta_L/\rho \quad (19)$$

The relationship of α_L and β_L also can be estimated by the regression analysis of $1/w_L$ and ρ , and the estimate of y_L can also be obtained. Comparison of the change of estimated value of F or y_L under various environments, we can understand the influence of environmental factors on F or y_L .

4. Estimated value of net assimilate rate (NAR)

According to Watson's growth law, the relation of NAR and leaf area index

(F) of an individual plant showed negative correlation, thus:

$$\text{NAR} = a - bF \quad (20)$$

Since

$$\text{NAR} = (1/u)(dw/dt) \quad (21)$$

hence

$$\text{NAR} = (1/u\rho)(\rho dw/dt) = (1/F)(dy/dt) = (1/F) \cdot \text{CGR} \quad (22)$$

$$\therefore \text{CGR} = \text{NAR} \cdot F = aF - bF^2 \quad (23)$$

Thus, the relation of CGR and F showed quadratic form, and we can obtain NAR from equation (23). The increase of dry weight after heading is mostly contributed by the accumulation of carbohydrate to panicle. Therefore, the regression coefficient of NAR and ripening rate may indicate the relationship between the amount of carbohydrate and ripening rate.

Results and Discussion

Density Effect and Unit Area Productivity Rate

1. Single leaf weight

According to equations (17) to (19), we may estimate the density effect on leaf weight. The estimates of environmental (α) and genetical (β) potentials are shown in Fig. 1. The α value showed the maximum value at two weeks, but

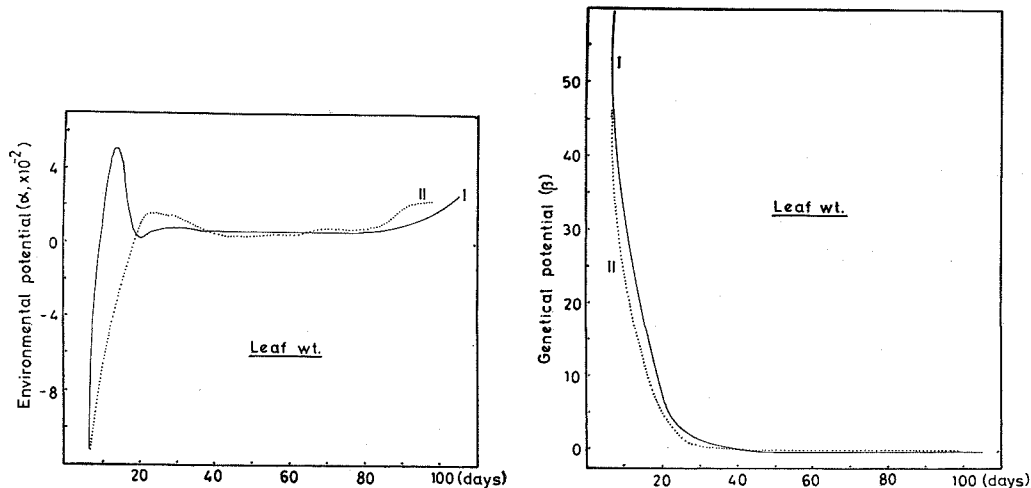


Fig. 1. The relationship between environmental potential (α) and genetical potential (β) of leaf weight and developmental time (I=first crop; II=second crop).

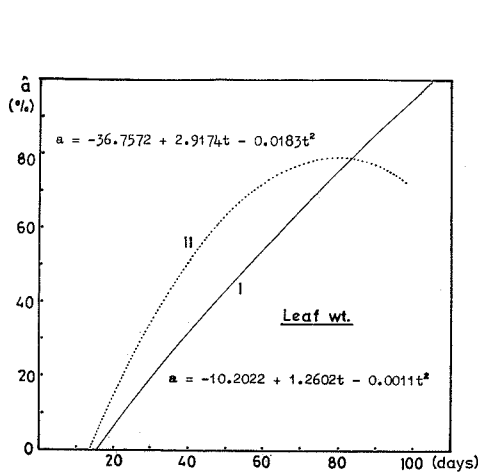


Fig. 2. The relationship between productivity rate (\hat{a}) of leaf weight and developmental time (I=first crop; II=second crop).

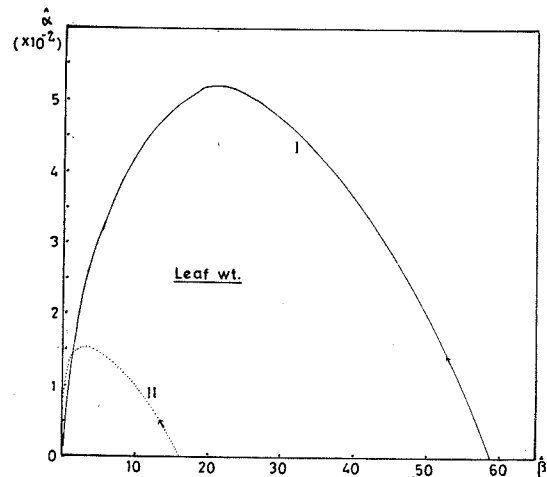


Fig. 3. The relationship between $\hat{\alpha}$ and $\hat{\beta}$ value (Arrow shows the developmental time of rice plant).

decreasing and becoming stable after three weeks till 80 days after the day of transplanting. Then the α value became large at the maturing stage in the first crop. In the second crop, the maximum value of α appeared at three weeks, then it decreases and kept stable until 80 days after transplanting. Therefore, we got the same density effect on leaf weight of the two crops from tillering to ripening stages. At the initial growth stage of both crops, the plant density effect on leaf weight showed a nonlinear relationship. At later growth stage, especially during ripening, the density effect on leaf weight of the first crop was significantly different from the second crop. At the later growth stage of the first crop, the temperature was high and the solar radiation was intensive, the environmental conditions were good enough for leaf growth. Hence, the plant density effect on leaf weight did not become significant. On the other hand, at the same growth stage of the second crop, the leaf growth was inhibited by low temperature and less solar radiation. Hence, the planting density significantly affect the leaf weight. It may indicate that the density effect on leaf weight exist under unfavorable environments.

The estimated value of genetical potential ($\hat{\beta}$) showed same tendency in the two crops (Fig. 1). At the early growth stage, the β value was large and decreased with growth proceeded until 30 days after transplanting. The value kept approximately constant afterwards until maturity.

The productivity rate per unit area (\hat{a}) for leaf weight is shown in Fig. 2. In the first crop, the \hat{a} value increased with the plant growth, and reached 100% at maturity. But, in the second crop, the \hat{a} value presented quadratic form having

maximum value of 79.5% at 79.7 days after transplanting. But, the $\hat{\alpha}$ value reduced to 73.4% at maturity. Hence, we may conclude that the leaf weight is limited under unfavorable environment of the second crop season. We did not obtain the maximum productivity rate of leaf weight in this season. The temperature during this period varied from 20°C to 17°C. The leaf weight could not increase under such low temperature. Murata (1979) indicated that the optimum temperature for photosynthesis of rice leaves ranged from 25° to 35°C, and the photosynthetic rate was limited by CO₂-fixation rate at low temperature. Therefore, leaf weight did not increase. In the later stage of first crop, the temperature ranged from 35°C to 25°C, and leaf weight may increase under such temperature. Hence, the productivity rate of leaf weight may reach 100%.

From the view point of the relationship between environmental and genetical potentials (Fig. 3), we obtained the different relation between $\hat{\alpha}$ and $\hat{\beta}$ for the two crops. The clear relationship at the initial growth stage of the first crop and at the later stage of the second crop may be obtained. These results were similar to total dry weight (Wu *et al.*, 1977).

2. Stem weight

As shown in Fig. 4, environmental potential became linear and had a constant tendency from five and three weeks after transplanting to harvest for the first and second crops, respectively. The competition of dry weight among stems of second crop seemed to happen earlier than the first. But in the last two weeks of first crop, we can not find the density effect on the stem weight. For the genetical potential (β), the difference can be found between the two crops

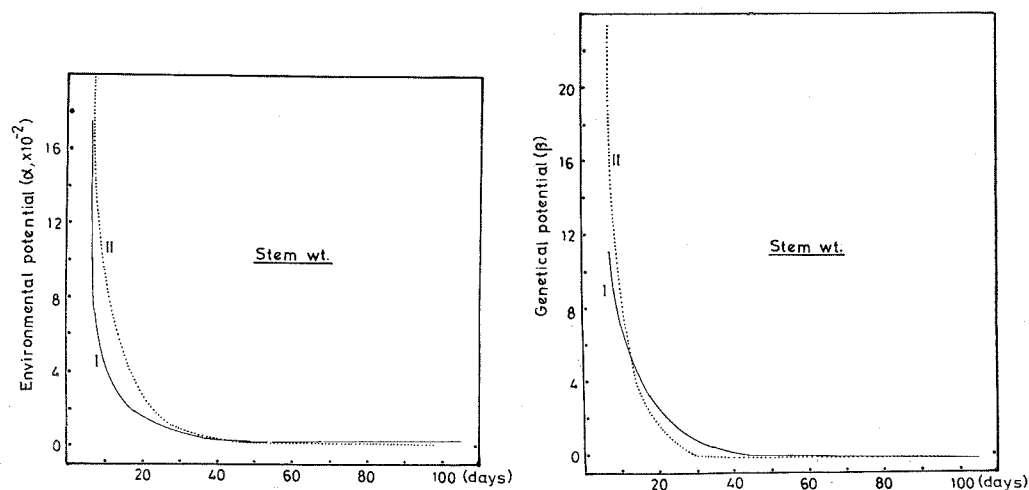


Fig. 4. The relationship between environmental potential (α) and genetical potential (β) of stem weight and developmental time (I=first crop; II=second crop).

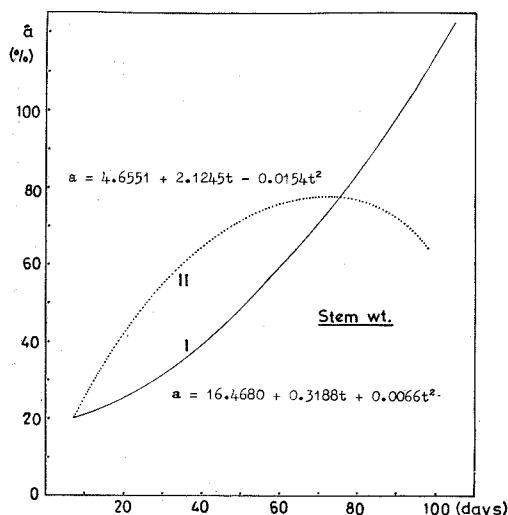


Fig. 5. The relationship between productivity rate (\hat{a}) of stem weight and developmental time (I=first crop; II=second crop).

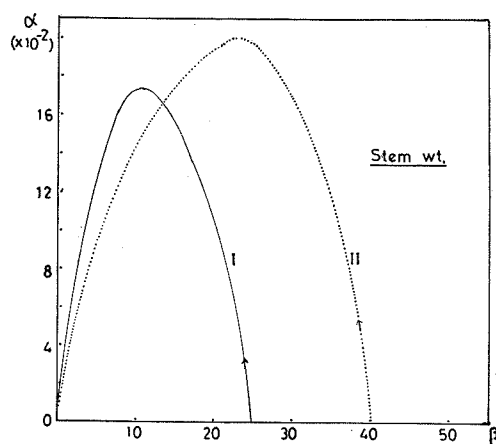


Fig. 6. The relationship between α and β value (Arrows show the developmental time of rice plant).

(Fig. 4). After 40 days of transplanting, the β value was constant and stable. Therefore, we may conclude that the genetical potential of stem weight did not fluctuate under different cropping seasons.

The productivity rate per unit area of stem weight in first crop may reach 100%. But, in second crop, it only reached 78% at 69 days after transplanting then decreased (Fig. 5). These results are similar to those of dry weight of a single plant or leaf weight.

From the relation of environmental and genetical potentials of the two crops (Fig. 6), we obtained more clear relation in the second crop than in the first.

Density Effect on the Natural Thinning of Leaf Amount

1. Leaf area

From equation (14), we may estimate the density effect on leaf area. Fig. 7 shows that the environmental potential for the two crops differed slightly. The linear relation between density and leaf area did not exist in the initial three to four weeks after transplanting for the first and second crops. But, from 30 to 80 days after transplanting of the first crop, we found a constant effect on leaf area. In the second crop, we obtained fluctuating result during the same stage, especially in the later growth stage. The leaf area growth of the two crop rice responded differently to the environmental stress. This phenomenon also exists in dry weight of single plant, leaf weight, and stem weight. At the later growth stage

of first crop, the temperature is high and solar energy is intensive. The leaves would grow well. And, an intensive competition for leaf area occurred. The environmental potential became large. But in the same stage of the second crop, the trend of environmental conditions were contrary to the first one. In general, the competition for leaf area was small. The reason is not so clear at present time. The fluctuation of the genetical potential during the rice growth is showed in Fig. 7. We found the same tendency of β values in the two crops.

The productivity rate of leaf area is shown in Fig. 8. The rate increased linearly 15 days after transplanting in the first crop and reached 100% at maturity. In second crop, the rate appeared in quadratic form. The maximum rate reached 76.8% at 73 days after transplanting, then decreased to 60% at maturity. This phenomenon is the same as other plant characters described above-mentioned.

The relation between estimated value of environmental and genetical potentials is shown in Fig. 9. The plant density effect on leaf area was large in the initial period of first crop and in the later period of the second. The phenomenon differed from the above-mentioned plant characters. The low solar energy and low temperature caused the occurrence of plant density effect on leaf area at later stage of second crop.

2. Leaf number

The environmental potential was linear at 35 and 28 days after transplanting in the first and second crops, respectively, but became non-linear at the later stage of first crop (Fig. 10). The tendencies of genetical potential are similar in both crops (Fig. 10).

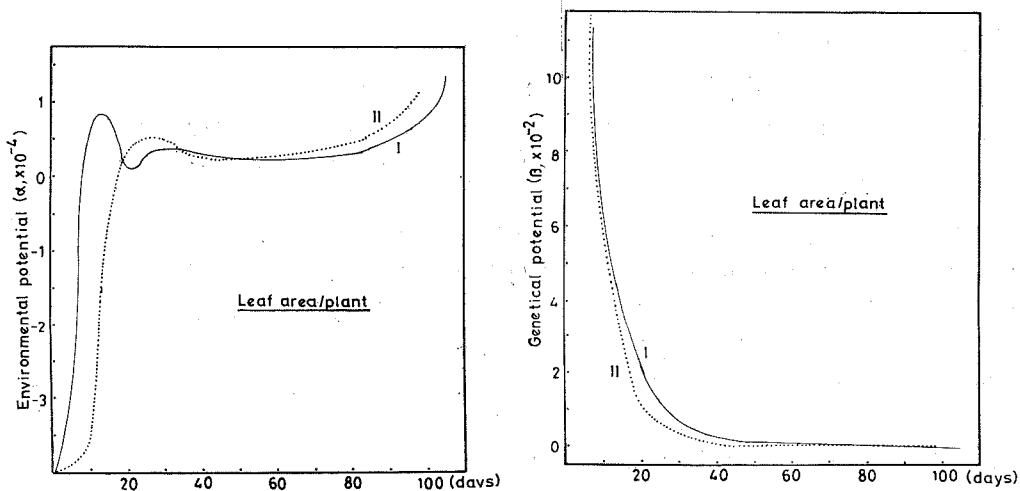


Fig. 7. The relationship between environmental potential (α) and genetical potential (β) of leaf area and developmental time (I=first crop; II=second crop).

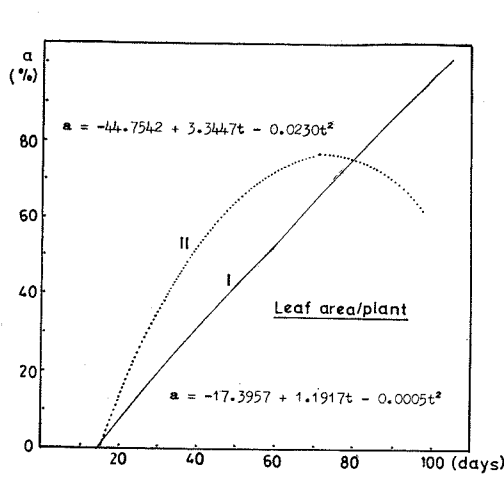


Fig. 8. The relationship between productivity rate (a) of leaf area and developmental time (I=first crop; II=second crop).

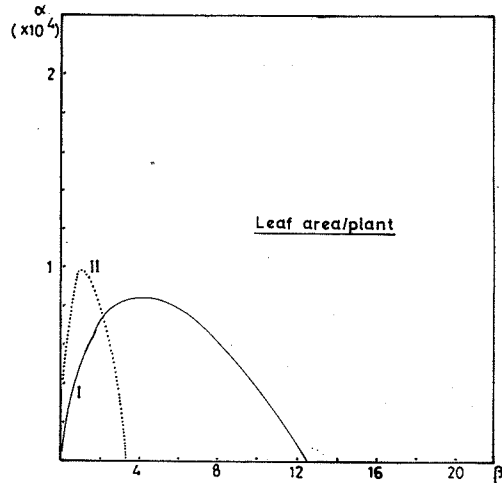


Fig. 9. The relationship between α and β value.

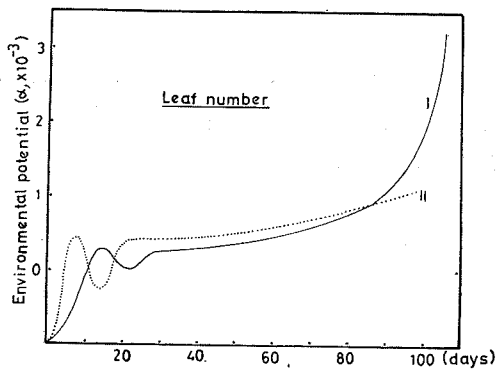
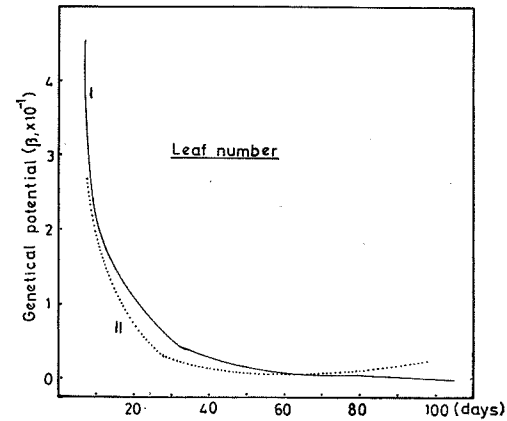


Fig. 10. The relationship between environmental potential (α) and genetical potential (β) of leaf number and developmental time (I=first crop; II=second crop).



The productivity rate of leaf number is shown in Fig. 11. The rate increased linearly in the first crop and reached 100% at maturity. But in the second crop, it showed quadratic form, reached maximum rate of 67% at 72 days after transplanting, and decreased to 50% at maturity. The natural thinning of rice leaves reduced photosynthetic capacity in the later period.

Allometric Growth of Leaf and Stem Weight

1. Allometric growth of leaf and stem weight at various planting densities

The estimated values of H and h of leaf and stem weight with various

planting densities in a complete growth period are shown in Fig. 12. The H and h values showed quadratic with respect to plant densities. However, the H values were smaller than h values. The biological meaning for $h > 1$ is that the increase of whole plant weight would increase the partial weight (leaf or stem) and the changing rate would be larger than 1. When $0 < h < 1$, the changing rate is smaller than 1. The h value of stem weight in various densities were larger than 1. The h value of leaf weight were smaller than 1. Therefore, the partitioning of dry weight between stems and leaves of an individual plant showed negative relation.

From the tendency of h values of stem and leaf weight in the various densities in the first crop, we obtained the maximum value of relative growth rate (RGR) of leaf weight at the density of 33.13 plants/m², and minimum value of RGR of

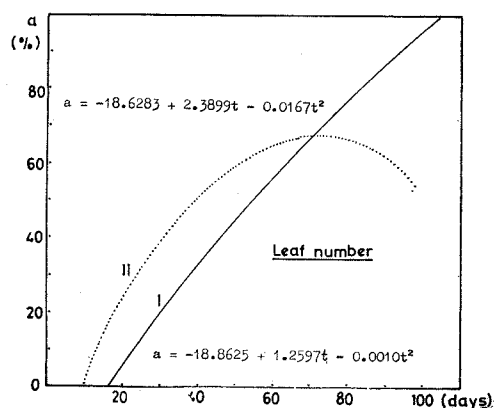


Fig. 11. The relationship between productivity rate (a) of leaf number and developmental time (I=first crop; II=second crop).

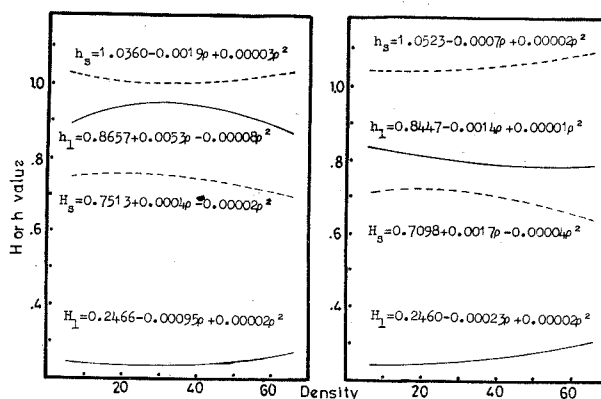


Fig. 12. The relationship between the estimated value of H or h of leaf weight (l) as well as stem weight (s) and density. (Left: I crop; right: II crop)

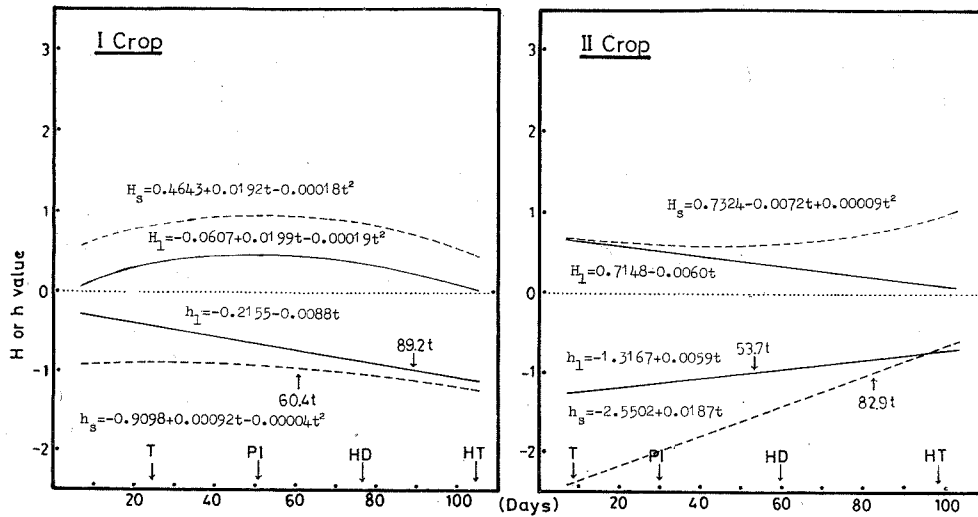


Fig. 13. The relationship between the estimated value of H or h of leaf weight (l) as well as stem weight (s) and developmental time (T = tilling; PI = panicle initiation; HD = heading time; HT = harvest time).

stem weight at 31.67 plants/m². Therefore, if we obtained the increased amount of leaf weight, the stem weight decreased relatively. But in the second crop, we obtained the minimum value of RGR of leaf weight at density 70 plants/m², and maximum value of RGR of stem weight at 17.75 plants/m². The difference of RGR of leaf weight between two crops was significant. The growth model of leaf weight for two crops was also different.

2. Allometric growth of leaf and stem weight at various growth stages

The theoretical tendency of H and h for leaf and stem weight at various growth stages is shown in Fig. 13. The tendency was found in quadratic form in the first crop except the h value of leaf weight showing a linear relationship. The h values were smaller than 0, indicating that the dry weight of whole plant increased with the leaf and stem weights. The allometric growth of these two plant characters were similar. Owing to the h value is smaller than 1, we could not get the optimum plant density for leaf and stem growths.

In the first crop, the h value of leaf weight changed linearly, and the allometric growth also increased during the growth. The stem weight became quadratic form, having minimum value at 11.5 days after transplanting. The tendency of the leaf and stem weight increase under various plant densities was similar as increasing of whole plant weight at 89.2 and 60.4 days after transplanting, respectively. At the initial growth stage, the allometrical growth of stem weight was larger than leaf weight, while at the later growth stage, the growth of both plant characters were similar.

In the second crop, the change of h value of leaf and stem weights showed in linear model. The allometric growth decreased with the advance of growth. Before heading, the allometric growth of stem weight was larger than the leaf weight. The tendency of leaf and stem weights, under various densities, increased similarly to whole plant weight at 53.7 and 82.9 days after transplanting, respectively. These results were contrary to those of the first crop. The allometric growth of leaf weight decreased after two weeks and one week before heading in the first and second crops, respectively. Therefore, the low yielding of second crop seemed to be affected by the photosynthesis of leaves.

From the distribution of leaf weight ratio ($h_l/(h_l + h_s)$) during whole growth period (Fig. 14), we obtained similar quadratic form in both crops. The ratio of leaf weight in the first crop was larger than that of the second crop at later growth stage. The maximum ratio occurred at 79.3 and 74.8 days after transplanting in first and second crops, respectively. In the first crop, it occurred at heading, the newly synthesized photosynthate may be sufficient to support spikelet growth. In the second crop, the maximum ratio occurred two weeks after heading. In this case, the carbohydrate should supply the growth of both leaves and spikelets and would cause low yield in the second crop.

Change of Net Assimilation Rate

The regression analysis for NAR and LAI are shown in Table 1. The results are similar to those obtained by Shieh (1979), *i.e.*, NAR and LAI presenting a linear relationship. The changes of regression coefficients of NAR with plant density during growth are shown in Fig. 15. We found that the planting density affected NAR at two important stages. One was at the tillering stage and the other at booting, especially in the first crop. However, at later growth stage of

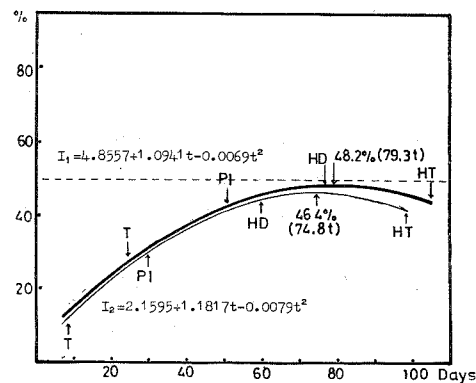


Fig. 14. Relative value of allometric coefficient of leaf weight in the growth time (T=tilling; PI=panicle initiation; HD=heading date; HT=harvest time).

Table 1. The linear regression of NAR and LAI at various planting densities
($NAR = a + b \text{ LAI}$, r = correlation coefficient)

| Crop | Density | A | B | C | D | E | F |
|------|---------|------------|------------|-----------|------------|------------|----------|
| I | a | 100.3338 | 116.6749 | 71.7974 | 43.2700 | 33.4185 | 45.9316 |
| | b | - 3.6139 | - 6.2263 | - 3.0633 | - 0.6911 | - 0.6067 | - 1.6784 |
| | r | - 0.9530** | - 0.7284** | - 0.6404* | - 0.2083 | - 0.5655* | - 0.4753 |
| II | a | 100.3715 | 59.7039 | 68.1430 | 68.4712 | 64.5563 | 24.9079 |
| | b | - 4.2424 | - 0.5490 | - 1.5917 | - 1.3465 | - 0.9010 | 0.4351 |
| | r | - 0.6627** | - 0.0969 | - 0.6075* | - 0.6534** | - 0.7346** | 0.3476 |

* and **: Significant at 5% and 1% level, respectively.

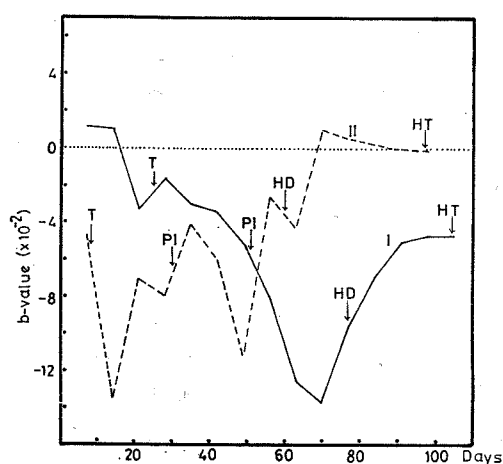


Fig. 15. The changes of regression coefficient of NAR and density during growth time (T: tillering; PI: panicle initiation; HD: heading; HT: harvest; I=first crop; II=second crop).

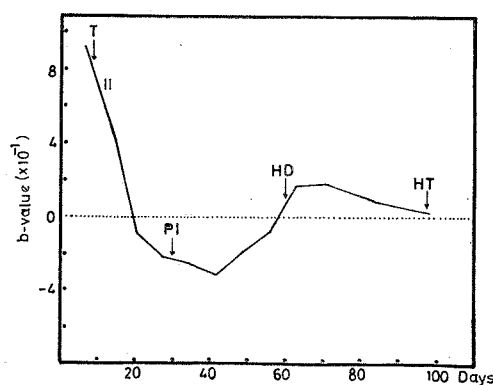


Fig. 16. The changes of regression coefficient of NAR and ripened rate of rice plant during the growth time (T: tillering; PI: panicle initiation; HD: heading; HT: harvest; I=first crop; II=second crop).

the second crop, the planting density did not affect NAR. Therefore, the test weight did not decrease in second crop. The changes of regression coefficients of NAR and ripening rate during whole growth period are shown in Fig. 16. The large NAR in the later stage of second crop would increase ripening rate. But, at panicle initiation, the large NAR resulted in slow ripening. The relationship between NAR and ripening rate fluctuated with plant growth. At the panicle initiation stage, carbohydrate may support spikelet formation. The large spikelet number at this stage would decrease the ripening rate. Therefore, a negative correlation between NAR and ripening rate was found. After heading, the carbohydrate may fully accumulate to spikelets; the growth phase did not change

at this stage. Hence, it showed a positive correlation, and the ripening rate may increase with the increase in NAR.

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密度對水稻葉片自然疏落的影響

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植物個體之生長與發育除與本身的遺傳有關外，尚與外界環境有密切關係。前文 (Wu, 1977) 曾探討植株間的相互關係對乾物重生長，產量及其構成因素的影響，並推測最適栽培密度。本文則繼續探討此種相互作用對葉量 (包括葉重、葉面積及葉片數) 之影響，建立葉量自然疏落的數學模型，並推測個體羣純同化率的大小與稔實率的關係，以進一步了解二期稻作稔實率的降低與稻葉的同化機能的關係。主要結果如下：

1. 葉量 (葉重、葉面積及葉片數) 的倒數 ($1/w$) 與栽培密度 (ρ) 間呈直線式 $1/w = \alpha\rho + \beta$ ，式中 α 為環境潛力， β 為遺傳潛力， α 值的變化在期作間差異甚大，分蘖前一期作的值較大，抽穗後則二期作較大，而遺傳潛力則在期作間無差異存在。
2. 葉量的土地利用以一期作較大，生長後期可達 100%，但二期作則在移植後 72-80 日左右可達最大利用率，但只有 67-80%，此後則日漸減少，此可能為稔實率無法提高的原因之一。
3. 葉重與莖重為構成稻株地上部乾物重的主要構成因素，如密度一定，則在生長時間變化下，部分重 (葉重或莖重) x 與密度 ρ 間的關係可用下式表示：

$$\ln x(\rho) = \ln H + h \ln w(\rho)$$

式中 H 及 h 為生長時間的介量， w 為稻株總乾物重， h 為部分重的相對生長係數。推測結果 h 值在密度間呈二次曲線關係，莖重的 h 值較葉重大，故不同期作下，莖重的生長較為有利。而一期作的葉重之 h 值較二期作時大，故二期作時葉之生長不良。如生長時間一定，則在密度變化下，單位面積的部分重 y_x 與密度 ρ 間的關係可用下式表示：

$$\ln y_x = \ln H + \ln \rho - h \ln (\alpha\rho + \beta)$$

依此式估計結果，莖重的 h 絕對值亦較葉重者大，莖重的 h 值在一期作時，於生長期間呈二次曲線關係，而二期作的莖重 h 值或兩期作葉重的 h 值在生長期間皆呈直線關係。二期作生長初期葉重之 h 值較一期作大，但二期作逐漸減少而一期則增大，此示二期作後期葉重生長不良，且一期作時葉重之 h 絕對值，在抽穗時最大，故可供應最大之同化物質，而二期作時則在抽穗後二星期，故抽穗時無法獲得最大的同化物質，稔實率降低。

4. 純同化率與葉面積指數間呈直線關係，而純同化率與密度間的關係在幼穗分化到抽穗時呈負相關，尤其是一期作時的影響較二期作時密切，故二期作密植，並不影響同化物質之形成。

5. 由純同化率與稔實率間的相關分析知，兩者間並無多大的相關性存在，但在幼穗分化到抽穗期之間，純同化率大，則穎花數增多，故稔實率降低，而抽穗後純同化率大，則可促進稔實率之提高 (二期作)。