Bot. Bull. Academia Sinica **22**: 93-102 (1981)

STUDIES ON THE PREDICTION OF RICE YIELD IN TAIWAN[1,2]

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(Received January 12, 1981; Accepted February 12, 1981)

Abstract

Rice is the most important crop in Taiwan, its production influences the economic prosperity of the island. Earlier information of grain yield is therefore a necessity in policy making. This study was designed to find out the possibility of yield prediction of rice on a crop-specific basis by means of data analysis of the yield components. The results revealed that yield was able to be assessed at the uniform heading stage by using planting density, panicle number per plant, spikelet number per panicle in the first crop, but it was unable to assess the results until the yellowing stage in the second crop. Researching on the possible application of climatic data during 60 days before uniform heading stage in order to improve the prediction effect in the uniform heading stage, we found that the set of accumulated air temperature in 40th-20th day and the sum of sunshine hours in 60th-40th day before the uniform heading stage as well as panicle number and spikelet number was a better combination for yield prediction in the first crop. And the combination of accumulated air temperature in 60th-40th and 20th-0th day, the sum of sunshine hours in 60th-40th day before uniform heading stage and panicle number was a suitable set for the second crop.

Introduction

Rice is the most important crop in Taiwan, its production influences the economic prosperity of the island. The round cutting method of estimating total rice production is adopted by the Provincial Food Bureau at harvesting time. However, an earlier prediction of rice yield would be a great advantage to the policy making and the supply-demand adjustment.

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(1) Paper No. 251 of Scientific Journal Series, Institute of Botany, Academia Sinica. This work was partially supported by the Food Buaeau, Taiwan Provincial Goverment, Republic of China.

(2) The portion of this work was submitted by the senior author in partial fulfillment of requirement for M.S. degree from Graduate Institute of Agronomy, National Taiwan University.

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The determinant stage of each yield component of rice was well studied by many scientists (Matsushima *et al.*, 1959; Matsubayashi, 1968; Murata, 1969), accordingly, we can measure any component after its determinant stage, and then from the measurement of some yield components at their respective determinant stage, we may decide the proper stage for the best prediction. Therefore, in this study, we firstly tried to set up the prediction equation of rice yield per unit area. Since the climatic condition influences filling rate and test weight of grains especially in the second rice crop (Wu *et al.*, 1975, 1978; Luo *et al.*, 1979), hence, secondly we used panicle number and spikelet number as well as climatic data before uniform heading stage to study the possibility of yield prediction at uniform heading stage.

Materials and Methods

All data was obtained from the Food Bureau in 1979 including a total of 16 sampling paddy fields, one field for each region (hsien) except two for Changhwa, were chosen. The criteria for the sampling field were that the average unit productivity was medium and the planting variety could represent the commonly planted varieties of the region. The characters measured were planting density, panicle number per plant, spikelet number per panicle, filling rate, test weight (1,000 grains weight) and actual yield per unit area.

According to the previous experimental results (Wu, unpublished data), the coefficient of variation of each character was obtained as shown in Table 1. We calculated the sample size of each character by equation (1);

$$n = \left(\frac{cv}{d\%}\right)^2 \left(t_{1/2\alpha}\right)^2 \quad \cdots\cdots (1)$$

where n is sample size, cv is coefficient of variation, d is desired percentage of deviation from mean and $t_{1/2\alpha}$ is critical point of Student's t value at the $1-\frac{1}{2}\alpha$ probability level. The sample size of each character was also shown

Table 1. *The coefficient of variation and sample size of each trait*

	Panicle no. per plant	Spikelet no. per panicle	Filling rate[1)]	Test weight[2)]
Previous estimated CV	25%	15%	10%	3%
Sample size	100	36	12	2
Sample estmates				
The 1st crop CV	18.82%	11.32%	8.65%	5.11%
The 2nd crop CV	18.67%	12.70%	8.80%	4.21%
Sample size	54	22	12	4

1) Filled grain per 100 grains.
2) Weight per 1,000 grains.

in Table 1. Correlation coefficient among studied characters were calculated and the relationship between yields and yield components or/and climatic factors were established by two regression analysis methods: ordinary least square regression analysis (Drapper *et al.*, 1966) and ridge regression analysis (Horel *et al.*, 1970a, b).

Results

Prediction by Yield Components

1. Correlations among yield components and yield

The correlation coefficients among yield components and yield in the first and second crop were shown in Table 2. In the first crop, the correlation between panicle number and planting density was negative ($r=-.37$), so was panicle number and spikelet number. Filling rate had little correlation with other yield components and planting density. Test weight was positively related to spikelet number. In the second crop, panicle number was negatively related to planting density. Spikelet number showed a negative relationship to panicle number and also to filling rate. The correlation was negative between test weight and panicle number, but positive between test weight and filling rate ($r=.32$) and also positive between planting density and test weight ($r=.37$).

In the first crop, yield was positively related to panicle number, spikelet number and test weight in which the largest r value was found to be with panicle number ($r=.53$). However, filling rate and planting density were insignificantly related to yield. In the second crop, yield was positively related to test weight and planting density, but negatively related to panicle

Table 2. *The correlation coefficients among yield and yield components in the 1st (lower triangle) and 2nd (upper triangle) crop*

	X_1	X_2	X_3	X_4	X_5	Y
X_1		−.46**	−.11	−.41**	−.80**	−.51**
X_2	−.27*		−.25*	.18	.00	.18
X_3	.21	−.10		.32**	.30*	.05
X_4	.05	.49**	.19		.37**	.62**
X_5	−.37**	−.18	.03	−.23		.45**
Y	.30*	.53**	.14	.46**	.13	

X_1=Panicle no. X_2=Spikelet no. X_3=Filling rate. X_4=Test weight. X_5=Plant density. Y=Yield per unit area (ha).
** and * indicate significance at 1% and 5% level, respectively.

number and insignificantly related to spikelet number and filling rate.

2. Regression analysis

We used ordinary least square regression methods to analyze the data collected by the Food Bureau and found the proper regression equations, determined by R^2 (coefficient of multiple determination) and F value for testing the overall regression. Two sets of six equations for the first and second crops respectively were shown in Table 3. When spikelet number was omitted from the equations for the first crop and test weight omitted for the second crop, the value of F and R^2 were decreased. When the significance of regression coefficients was not considered, the 3rd equation may be selected as the best among the 6 equations for each crop. The equation consists of panicle number, spikelet number, test weight and planting density. However we were not able to use the 3rd equation for much early prediction, because test weight was inaccessible until 35 days after heading or about 5 days before harvest. Therefore, in the first crop, the 4th equation could be chosen since it had the second largest F value and high R^2 value when compared with the 5th and 6th ones. One advantage of choosing the 4th equation was that we could predict yield of the first crop only by using planting density, panicle number and spikelet number at uniform heading stage or 14 days after heading. In the second crop, we could not select the 4th equation

Table 3. *The regression coefficients, F value and R^2*

The 1st crop $n=64$	X_1[1)]	X_2	X_3	X_4	X_5	b_0	F	R^2
1	.93071**	.99201**	.08591	.61793**	.76412**	−10.14	50.01**	.812
2	.93136**	1.17390**	.18969		.71430**	− 8.79	47.40**	.763
3	.39920**	.97677**		.65782**	.77187**	− 9.94	62.51**	.809
4	.95179**	1.16551**			.72516**	− 8.12	59.62**	.749
5	.64029**			1.34952**	.58246**	− 4.70	18.53**	.481
6	.52400**				.36796**	2.59	5.92**	.183
The 2nd crop $n=48$								
1	.38735	.23577	.75417**	1.37312**	.58282*	− 8.43	14.48**	.633
2	.31562	.31380	.99318**		.58410	− 5.16	6.46**	.375
3	.11936	.06171		1.58241**	.41479	− 2.37	11.14**	.509
4	−.07062	.08941			.35186	4.05	2.58	.150
5	.03692			1.58541**	.33782	− 0.84	15.11**	.507
6	−.19068				.24009	− 6.15	3.86*	.146

1): X_1-X_5 are shown as Table 2.
** and * indicate significance at 1% and 5% level, respectively.

due to its insignificant F value. Although some equation had higher F values but since they inevitable consisted of test weight, we could not make an earlier prediction than the 3rd equation did. The 6th one had significant F value and did not include test weight, but its R^2 value was too small. Hence, it is difficult to choose a good yield estimation by using yield components only for the second crop.

Prediction at Uniform Heading Stage with Climatic Factors

Research on the possibility of yield prediction at uniform heading stage by using panicle number, spikelet number, the accumulated air temperature (ST) and the sum of sunshine hours (SH) during 60 days before uniform heading stage, was carried out in an unit of 20-day period. For convenience, we designated ST_1 or SH_1, ST_2 or SH_2 and ST_3 or SH_3 to the accumulated air temperature or the sum of sunshine hours in 60th-40th day, 40th-20th day and 20th-0th day before uniform heading stage, respectively. Because there was no suitable climatic data for the sampling paddy in Miaoli, we could only analyze the data with 15 sampling paddies.

1. Correlation among yield components and climatic factors

Correlation coefficients among yield components and climatic factors for each crop are shown in Table 4 and Table 5. In the first crop, spikelet number had a smaller correlation with ST_1 and ST_2, whereas it was significantly related to SH_1. Test weight was positively correlated with ST_1, ST_2, ST_3 and SH_1, but negatively correlated with SH_3. There was no correlation between panicle numbe or filling rate and climatic factors during the period of 60 days before uniform heading. In the second crop, panicle number was

Table 4. *Correlation coefficient of yield with yield components in relation to radiation and sum of daily mean temperature during the 60 days prior to uniform heading stage*

1st crop $n=60$	ST_1 1)	ST_2	ST_3	SH_1	SH_2	SH_3
X_1	.248	.098	.242	.125	.102	−.038
X_2	.271*	.277*	.122	.503**	−.157	.072
X_3	.146	−.115	.057	−.009	.063	−.245
X_4	.450**	.597**	.282*	.333**	.229	−.256*
Y	.547**	.424**	.169	.631**	.238	−.176

** and * indicate significance at 1% and 5% level, respectively.

1): ST_1, ST_2 and ST_3 indicate the sum of temperature in 60-40th day, 40-20th day and 20-0th day before uniform heading stage.

SH_1, SH_2 and SH_3 indicate the sum of sunshine hours in 60-40th day, 40-20th day and 20-0th day before uniform heading stage.

Table 5. *Correlation coefficient of yield with yield components in relation to solar radiation and sum of daily mean temperature during the 60 days prior to uniform heading stage*

2nd crop $n=60$	ST_1[1)]	ST_2	ST_3	SH_1	SH_2	SH_3
X_1	−.332**	.127	.117	.020	−.299*	.386**
X_2	−.376**	.081	.144	.310*	.575**	−.561**
X_3	.246	−.460**	−.141	−.082	−.076	.511**
X_4	.370**	−.211	.018	.071	.233	−.026
Y	.409**	.027	.284**	.102	.119	−.330**

** and * indicate significance at 1% and 5% level, respectively.
1): ST_i and SH_i are shown as Table 4, (i=1, 2, 3).

negatively related to ST_1 and SH_2, but positively related to SH_3. Spikelet number had negative with ST_1 and SH_3, but it was positively related to SH_1 and SH_2. Filling rate had negative relationship with ST_2, but positive relationsh with SH_3. A positive relation was found for test weight and ST_1. By examining the relationship between yield components and climatic factors during the 60 days before uniform heading stage, we found that SH_2 had no apparent relationship with yied components in the first crop, nor did ST_3 in the second crop.

The integrated outcome of yield components can be expressed by final yield. It was therefore natural to look at the relationship between yield and climatic factors. In the first crop, yield had significantly positive correlation with ST_1, ST_2 and SH_1. In the second crop, yield had a significantly positive relation with ST_1 and ST_3, but negative relation with SH_3. Thus climate may be one of the important factors which cause the differences between the two crops.

2. Ridge regression analysis

The results of ridge regression analysis were shown in Table 6 and 7 for the first and second crop, respectively. In the first crop, the 6th equation was the best one. However, the regression coefficient of SH_2 was not significant. When looking at significance of regression coefficient of each factor, it revealed that panicle number (X_1), spikelet number (X_2), planting density (X_5), ST_2 and SH_1 were all significant in the equations. Based on these five factors, the following equation was obtained;

$$Y_1 = -13{,}011.44 + 130.47\,X_1 + 47.67\,X_2 + 0.014\,X_5 + 17.76\,ST_2 + 16.04\,SH_1 \quad \cdots\cdots (2)$$

$F = 43.00^{**}$, $R^2 = .71$

Table 6. *The ridge regression coefficients, F value and R^2*

1st crop	Ridge regression coefficient					b_0	F	R^2
1 X=1, 2, 5, 6, 7,[1] 8, 9, 10, 11	89.10** 4.86	39.90** 17.16**	.0096** 7.15	1.18 −8.44	11.85*	−10,675.67	19.39**	.617
2 X=1, 2, 5, 6, 7, 9, 10	113.44** 15.23**	46.14** 5.33**	.0122**	2.50	14.49**	−12,300.97	27.71**	.666
3 X=1, 2, 5, 7, 8, 10, 11	173.96** 7.33	69.80** −6.22	.0176**	13.67*	.70	−13,496.19	25.13**	.640
4 X=1, 2, 5, 6, 8, 9, 11	113.27** 14.57**	48.87** −8.90	.0110**	7.23	6.02	− 9,293.38	20.38**	.611
5 X=1, 2, 5, 6, 9	132.79**	55.76**	.0131**	12.14*	10.37*	−10,799.01	30.08**	.624
6 X=1, 2, 5, 7, 10	194.47**	74.86**	.0202**	14.96**	.29	−15,482.78	39.70**	.715
7 X=1, 2, 5, 8, 11	207.22**	80.90**	.0191**	5.35	−9.29	−10,162.10	28.08**	.649

** and * indicate significance at 1% and 5% level, respectively.
1): X_1, X_2 and X_5 are shown as Table 1.
$X_6=ST_1$, $X_7=ST_2$, $X_8=ST_3$, $X_9=SH_1$, $X_{10}=SH_2$, $X_{11}=SH_3$.

Table 7. *The ridge regression coefficients, F value and R^2*

2nd crop	Ridge regression coefficient				b_0	F	R^2
1 X=1, 2, 6, 7,[1] 8, 9, 10, 11	− 54.14* 24.80	−1.19 14.07	17.03** 13.15**	−2.81 .64	−18,251.42	20.38**	.510
2 X=1, 2, 6, 7, 9, 10	− 54.61* 10.89*	7.75 1.95	11.90**	9.93*	− 7,743.07	6.65**	.297
3 X=1, 2, 7, 8, 10, 11	− 95.30** 5.34	−7.49 −8.10	−8.78	16.33**	3,574.38	5.71**	.246
4 X=1, 2, 6, 8, 9, 11	− 78.10** 19.22**	7.14 9.08	15.64**	20.92	−17,169.72	21.51**	.532
5 X=1, 2, 6, 9	− 55.63	9.74	9.55**	8.72	− 642.19	7.61**	.280
6 X=1, 2, 7, 10	− 90.49**	3.25	2.11	−1.52	5,590.46	3.65*	.154
7 X=1, 2, 8, 11	−103.55**	−2.71	9.99**	−4.26	2,292.54	6.78**	.254

** and * indicate significance at 1% and 5% level, respectively.
1): X_1 and X_2 are shown as Table 1.
X_i (i=6, 7, 8, 9, 10, 11) are shown as Table 6.

This new equation is better than all previous ones for its higher F and R^2 values. In the second crop, the same attempt was made to find significant factors in all sets. Only two factors were qualified; ST_1 and ST_3. However, the regression equation of these two factors had smaller F value of 14.04. Since panicle number (X_1) and SH_1 were significant in most of the equations, we added these two factors into the regression equation, and obtained;

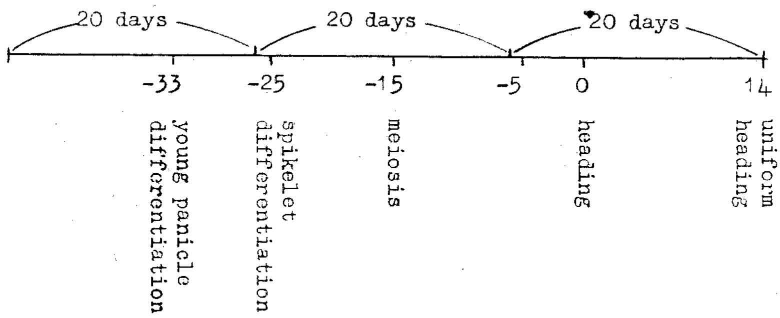
$$Y = -16{,}254.34 - 79.36\, X_1 + 15.14\, ST_1 + 22.21\, ST_3 + 21.53\, SH_1 \quad \ldots (3)$$
$$F = 32.97^{**},\ R^2 = .64$$

where F and R^2 values were higher than the seven others for the second crop in Table 7. Moreover, each regression coefficient was significant at 1% level.

Discussion

In order to examine the sufficiency of sample size, the cv for each character studied was calculated and shown in Table 1. The sample size of panicle number could be decreased from 100 to 54, as for spikelet number, it may also be decreased from 36 to 22. However, those for filling rate and test weight should be kept unchanged (size=12).

The growth stage in 60 days before uniform heading stage may be determined as follows:



Based on the relationship between yield and climatic factors, it is easy to know at which growth stage the climatic factors may influence one or some particular components, which in turn combine to determine the final yield. In the first crop, the sum of temperature near the stage of young panicle differentiation and meiosis had a high correlation with yield. This was in accordance with the result from *maximal growth rate experiments* (Kudo, 1975) and Wu *et al.* (1975). It is understandable that appropriately high temperatures may encourage grain filling in rice plant. Also, yield was enhanced if the plant attained more sunshine hours during young panicle differentiation stage. On the contrary, sunshine hours had little connection with yield in Japan. It also revealed that climatic factors during 60 days before uniform heading stage displayed its function on spikelet number and test weight in the first crop. In the second crop, yield was positively related to the sum of temperature near the stage of young panicle differentiation and also near heading, but it was negatively related to the sunshine hours near heading. This is different from the viewpoint of Chen (1976), who considered yield of the second crop to be correlated with temperature but had no correlation with sunshine. The relation between climatic factors and yield components in the second crop is so complicated that we were not able to distinguish actually how many yield components were influenced by the climatic factors at each stage. It is impossible to make good estimations by using only a few components for the yield of the second crop. However, suitable estimation is possible when certain appropriate factors, such as physiological factors, effective climatic factors and their function period, e.g., can be fouud and added to the estimation processes.

Total areas of harvest in 1979 were 338,804 hectares and 381,808 hectares for the first and second crop, respectively. When estimated by the sampling data, the total yield of rice were 1,532,343 and 1,579,952 metric tons for each crop. However, the actual yield were 1,276,539 and 1,173,278 metric tons, the percentages of over-estimation were 20.02 and 34.66 for each crop. Considering the discrepancy, attention must be paid to disease, variety, irrigation time, fertilizers shattering, planting time or concentrating the sampling region in order to decrease the difference between actual and estimated total yield. However, if the percentage of over estimation is stable, the estimating process might be accept.

Literature Cited

Chen, C. S. 1976. Studies on the characteristics of tillering for the first and second crops of rice. M. S. Thesis, Graduate Institute of Agronomy, National Taiwan University.

Draper, N. R. and H. Smith. 1966. Applied Regression Analysis, John Wiley and Sons, New York.

Horel, A. E. and R. W. Kennard. 1970a. Ridge regression: biased estimation for nonorthogonal problem. Technometrics, **12**: 55-68.

Horel, A. E. and R. W. Kennard. 1970b. Ridge regression: application to nonorthogonal problem. Technometrics, **12**: 69-82.

Kudo, K. 1975. Economic yield and climate, Part 3: Results of analysis of maximal growth rate experiments. JIBP Synthesis **11**: 199-210.

Luo, C. C., H. P. Wu and S. S. Yao. 1979. Fundamental research for higher yield of rice in Taiwan—Studies on the difference of rice ripened rate between two crop seasons under various growth condition. Nat. Sci. Council Monthly **7**(7): 691-699.

Matsubayashi, M., R. Ito, T. Takase, T. Nomoto and N. Yamada. 1968. Theory and Practice of Growing Rice. Fuji Publishing Co. Ltd. Tokyo, Japan.

Matsushima, S. and T. Manaka. 1959. Analysis of developmental factors determining yield and its application to yield prediction and culture improvement of lowland rice. LI., Proc. Crop Sci. Japan, **27**: 432-434.

Murata, Y. 1969. Physiological response to nitrogen in plants. *In*, Physiological Aspects of Crop Yield. eds. J. D. Eastin, F. A. Haskins, C. Y. Sullivan and C. H. M. Van Bavel., ASA & CSSA, Madison, Wisconsin, pp. 235-259.

Wu, H. P. *et al.* 1975. The investigation on the causes of low yielding in the second crop of rice. Nat. Sci. Council Monthly, **3**(10): 5-39.

Wu, H. P. and C. C. Luo. 1978. Fundamental research for higher yield of rice in Taiwan —Studies on the climatic factors, new germplasm and growth controls of the yield performance. Nat. Sci. Council Monthly, **6**(8): 738-755.

臺灣水稻產量預測之研究

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水稻爲本省最主要的糧食作物，其總產量的高低對本省經濟的穩定，深具關鍵性的地位。若能提前預知本省兩期作水稻產量，即可提早擬定糧食政策及物資供調工作，有助於國家經建之穩定成長。

依 Murata (1969) 及 Matsubayashi 等 (1968) 對水稻產量之界說：

單位面積產量 = 單位面積穗數 × 充實百分率 × 千粒重 ÷ 1,000

再由 Matsushima 等 (1959) 對水稻產量構成因素之發育過程研究知，在抽穗期時可知每株穗數，齊穗期時可知每穗頴花數，而於抽穗後35日左右方可知充實百分率及千粒重。因此本研究第一個目的在利用水稻產量構成因素預測產量。結果發現一期作於齊穗期時，以每公頃株數，每株穗數及每穗頴花數之組合來預測產量之效果較佳，大約可提早40日左右預估產量。但二期作必須至黃熟期時，以每公頃株數、每株穗數、每穗頴花數、充實百分率及千粒重之組合方能獲得較佳之產量預測估式，即只能提前 5 日左右。

爲改善二期作提前於齊穗時期預測之效果，是以加入齊穗前60日至齊穗時之氣象因素，溫度及日照；即加入對充實百分率及千粒重有部份影響力之因子。其結果發現，一期作以每公頃穗數、每株穗數、每穗頴花數，齊穗前40日至前20日之積溫以及齊穗前60日至前40日之日照時數之組合爲最佳。而二期作以每株穗數，齊穗前60日至前40日和前20日至齊穗時之積溫以及齊穗前60日至前40日之日照時數之組合爲最佳單位面積產量估式。