THE UTILIZATION OF X-RAY RADIATION FOR RICE IMPROVEMENT[1]

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Introduction

Rice is the main staple food crop of the island of Taiwan. Roughly, close to 2 million tons of brown rice are produced to sustain a population of 10 million people. However, with an increase of population of 3.5% annually, one of the highest in the world, the population pressure is keenly felt recently. It is estimated that by 1980, twenty years henceforth, the population of Taiwan would be doubled. By then food would become a hard-pressed problem.

In order to try to support such a large population with a limited arable land, the government is building more dams and reservoirs and tagging underground water so as to have more paddy fields for rice production and to facilitate better irrigation for greater yield per unit area.

In view of the fact that the feasibility for expansion of arable land is rather limited in extent, then increase in production per unit area on the same amount of arable land would have to be resorted to on the one hand, and perhaps checking the population increase would be more effective in easing up the pressure on the other. We have to solve the problem from both ends.

Increase in production per unit area may be tackled from many angles, such as better cultural methods, control of pests and diseases, better varieties and what not. It seems that improvement of varieties can play a major role in reaching this ultimate goal.

There are two major types of paddy rice grown on this island, namely, the Japonica and the Indica types. The former is more erect in habit and is grown in more fertile paddy fields. However, it is more susceptible to blast disease of rice, *Piricularia oryzae* Cav. Roughly, the Japonica type occupies 60% of the total rice acreage. Whereas the Indica type is typified by having weak straw, thus it lodges badly. However, it has a wider adaptability than the Japonica type and it occupies about 40% of the total rice acreage.

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In majority of the rice growing districts wherever irrigation is available, two crops of rice can be grown within a year. The first crop is grown in the spring, whereas the second crop is grown in the fall. In fact, within the course of a year, besides these two crops of rice, at least one or two other catch crops such as soybean, wheat, barley, green manure crop and what not are grown.

Since V-J Day, several new rice varieties, mostly Japonica types, were developed by different experiment stations. The conventional method of breeding was used. Since Gustafsson (1947) set a good example in getting erectoides and early maturing strains from X-ray irradiated barley seeds, we started in 1957 the same type of work using rice as our experimental material. Our aims were:

1. To obtain erectoides type which is lodge resistant so that heavier fertilizer can be applied, especially nitrogenous fertilizer, so as to obtain a higher yield. (Land is limited and nitrogen can be obtained unlimited from air).
2. Early-maturing types so that multi-cropping system can be better managed.
3. Disease resistant types such as resistant to rice blast, etc.

The results are hereby briefly reported.

Material and Methods

The following varieties were used in the experiment:

Japonica varieties:	Taichung No. 65 and Chianan No. 8.
First-crop Indica varieties:	Liu-chou, Pai-mi-fen and Taichung Native No. 1.
Second-crop Indica varieties:	Min-tang, Chin-kuo-chan, Shuang-chiang and Keh-tze.
Mainland Indica variety:	Nan-teh-hau.

The dosages of X-ray radiation used in this experiment are shown in Table 1.

The dosages of X-ray radiation in Roentgens were only estimated figures. No attempts therefore were being tried to study the effects of varying dosages of X-ray radiation.

Head selection was practised in X_1 generation. In the X_2 generation, however, plant selection was done in the head rows. Erectoides, early-maturing plants, plants with large panicles, plants with profused tillering, non-shattering types, etc. were selected. Unfortunately, X_1 plants were raised without isolation. Some segregates from natural crossing were discarded altogether.

In the X_3 generation, plants so selected were planted in plant rows. At definite intervals, the original varieties were planted as check rows. At maturity, those lines showing no further segregation were harvested and weighed.

The yield tests of the selected lines were done after X_4. Randomized blocks were used with one replication. Those lines outyielded the original varieties were further selected as "promising lines."

The "promising lines" were tested further toward heavy fertilization. Levels of fertilizer application are shown in Table 2. 3×3 Latin square split plots were used for testing.

Table 1. Varieties used and their X-ray treatment

Varieties	Dosage of X-ray					
	Dormant seeds				Water-soaked seeds	
	kr				kr	
Taichung No. 65	20	25	30		5.5	
Chianan No. 8	20	25	30			
Pai-mi-fen*	20	25	30		10	
Liu-chou*	20	25	30		10	
Taichung Native No. 1*	20	25	30			
Min-tang**	15	20	25	30		
Ching-kuo-chan**	15	20	25	30		
Shuang-chiang**	15	20	25	30		
Keh-tze**	15	20	25	30		
Nan-teh-hau*	15	20	25	30		

* First-crop Indica varieties.
** Second-crop Indica varieties.
Those without stars are Japonica varieties.

Table 2. Levels of fertilizer application in the fertilizer response test.

	Levels	N	P_2O_5	K_2O
		kg/ha	kg/ha	kg/ha
For mutant lines derived from Japonica varieties	(1)	100	50	50
	(2)	150	75	75
	(3)	200	100	100
For mutant lines derived from Indica varieties	(1)	33	16.5	16.5
	(2)	66	33	33
	(3)	100	50	50

Experimental Results

The progress of selection in X_1 to X_3 generation is shown in Table 3 and the grain yields of the "promising lines" are shown in Table 4.

From Table 4, it can be seen that there were two erectoides lines selected from Taichung No. 65 which outyielded their original variety. The early-maturing lines were about 5–7 days earlier in heading. In some selected lines, even though the phenotypic appearance had no apparent difference from that of their original varieties, yet they outyielded them. These lines were termed "high-yielding" lines. Most of the more promising lines were derived either from Taichung No. 65 or from Liu-chou. Mutant lines derived from other varieties other than

these two were mostly retrogressive in nature and were subsequently discarded. One mutant line derived from Liu-chou outyielded Liu-chou by more than 30%. This was rather remarkable.

Table 3. The progress of selection from X_1 to X_3 generation

Original varieties	X_1	X_2				X_3			
	No. of plants raised	No. of plants raised		No. of plants selected		No. of lines raised		No. of lines selected	
	'57 I*	'57 II	'58 I	'57 II	'58 I	'58 I	'58 II	'58 I	'58 II
Taichung No. 65	3,428		12,168		126		123		17
Chianan No. 8	1,613		2,090		20		16		4
Pai-mi-fen	1,992	14,476	82,678	45	294	24	297	3	50
Liu-chou	2,038	15,562	55,749	75	208	67	206	14	29
Taichung Native No. 1	902		16,680		77		77		0
Nan-teh-hau	2,366		69,402		168		163		31
Total	13,339	30,038	238,767	120	893	91	882	17	131

* '57 I=1st crop 1957, '57 II=2nd crop 1957, and so on.

Table 4. Grain yields in indices of "promising lines" selected from yield tests

Serial No.	Mutant type	Index (original variety=100)	
		2nd crop 1958	1st crop 1959
T 5.5-14- 8	Erectoides		123.0
T 5.5-19-23	Erectoides		117.3
T 5.5- 9-26	High-yielding		118.6
T 5.5-16-22	High-yielding		116.9
T 5.5-23-23	High-yielding		119.4
L 10- 4- 4	Early-maturing	114.8	
L 10- 1- 3	High-yielding	103.3	
L 10- 3- 1	High-yielding	116.2	
L 10- 4- 1	High-yielding	102.2	
L 20- 2- 2	High-yielding	107.1	
L 20- 2- 5	High-yielding	113.4	
L 20- 6- 1	High-yielding	108.5	
L 25-25-10	High-yielding	125.7	
L 25-25-16	High-yielding	132.3	
L 30-16- 1	High-yielding	122.4	
L 30-21- 2	High-yielding	102.7	
L 30-21-20	High-yielding	106.8	
L 30-10- 4	High-yielding	106.8	

Notes: (1) The T-lines were derived from Taichung No. 65.
(2) The L-lines were derived from Liu-chou.

The grain yields in indices of promising lines in the fertilizer response test are shown in Table 5.

Table 5. Grain yields in indices of some promising lines in fertilizer response tests
(yield of original variety from check plot=100)

Serial No.	Mutant type	Levels of fertilizer treatment**					
		1st crop 1959			2nd crop 1959		
		(1)	(2)	(3)	(1)	(2)	(3)
CK_1 (Taichung No. 65)		100.0	103.1	85.2	100.0	93.6	86.4
T 30-2*	Erectoides	88.7	88.3	77.9			
T 5.5-14-8	Erectoides				92.7	99.8	88.2
T 5.5-19-23	Erectoides				94.3	88.7	86.8
T 5.5-11*	Large-panicled	104.8	101.5	97.4	103.8	99.8	76.1
T 5.5-12*	Large-panicled	111.1	104.0	96.8	93.9	92.2	92.2
T 5.5-40*	Large-panicled	106.2	106.2	88.9	94.4	86.6	73.7
T 5.5-53*	Large-panicled	107.7	102.9	89.5	97.2	89.2	79.7
T 5.5-10*	High-yielding	107.3	98.7	75.6	91.2	77.5	79.4
T 5.5-22*	High-yielding	109.9	101.3	80.1	86.8	83.7	94.4
T 5.5-24*	High-yielding	100.4	101.8	82.3	91.7	97.4	94.6
T 5 5-33*	High-yielding	106.0	99.6	94.4	94.6	97.7	77.3
T 5.5- 9-26	High-yielding				101.6	82.3	89.9
T 5.5-16-22	High-yielding				96.0	92.7	89.4
T 5.5-23-23	High-yielding				100.0	78.7	99.5
T 5.5-29- 7	High-yielding				94.4	98.1	92.0
CK_2 (Chianan No. 8)					100.0	93.5	92.9
C 25-15	Early-maturing				90.9	61.6	71.8
CK_3 (Liu-chou)		100.0	77.5	68.4	100.0	102.9	93.5
L 25-86*	Erectoides				93.8	94.1	86.2
L 25-87*	Erectoides				102.0	97.6	97.6
L 25-88*	Erectoides				91.7	97.0	90.9
L 10- 4- 4	Early-maturing	92.6	89.0	68.9	115.6	107.3	91.8
L 20-24*	Multi-branched				104.1	101.2	111.4
L 20-25*	Multi-branched				100.6	94.7	87.9
L 20-26*	Multi-branched				110.3	109.7	114.1
L 10- 1- 3	High-yielding	113.2	101.5	88.7	114.1	107.3	99.4
L 10- 3- 1	High-yielding	87.3	94.1	93.4	128.8	114.1	119.1
L 10- 4- 1	High-yielding	94.6	85.3	80.9	110.3	99.7	110.3
L 20- 2- 2	High-yielding	114.5	90.9	77.5	128.5	111.2	114.7
L 20- 2- 5	High-yielding	91.2	85.5	54.7	116.8	116.2	112.6
L 20- 6- 1	High-yielding	117.4	118 1	104.7	112.1	122.3	110.9
L 25-25-10	High-yielding	91.4	100.5	98.1	123.5	120.3	117.9
L 25-25-16	High-yielding	99.0	88.2	70.1	122.6	114.4	126.8
L 30-10- 4	High-yielding	100.0	86.0	80 .4	112.9	116.2	122.6
L 30-16- 1	High-yielding	85.0	90.2	93.4	123.2	126.1	122.6
L 30-21- 2	High-yielding	115.2	103.7	108 3	103.8	109.7	96.5
L 30-21-20	High-yielding	102.2	115.7	92 4	99.1	112.1	105.3

* These lines were all selected directly from the plant-row test of X_3.

** For details see Table 2.

The levels of fertilizer treatment as mentioned in Table 5 were shown in Table 2. Level (1) was the standard level of fertilization and could be used as basis of comparison with other levels.

As can be seen from Table 5, there was seasonal variation in productivity from the same mutant line. Taking for instance, those mutant lines derived from Liu-chou, L 30-21-2 and L 30-21-20, outyielded their original variety in

the first crop, but did not do so in the second crop. On the other hand, those mutant lines as L 10-4-4, L 10-3-1, L 10-4-1, L 20-2-5, L 25-25-10, L 25-25-16, L 30-10-4 and L 30-16-1 did outyield their original variety in the second crop even though they failed to do so in the first crop. It is remarkable to note that mutant lines L 10-1-3, L 20-2-2 and L 20-6-1 outyielded their original variety in both crops.

Most of the mutant lines derived from Taichung No. 65, a Japonica type, did outyield their original variety in the first crop but failed to do so in the second crop. It seemed to indicate that among the mutant lines, there were in existence already the so-called "season ecotype."

The erectoides (Fig. 1) derived from either the Japonica variety Taichung No. 65 or from the Indica variety Liu-chou, did not respond to heavy fertilization. There seemed to have no explanation for the non-responsiveness to heavy fertilization for the erectoides of Japonica type. But for the Indica type, all the erectoides were susceptible to sheath rot (*Acrocylindrium oryzae* SAWADA). Perhaps, this alone could acount for their non-responsiveness.

Fig. 1. Erectoides lines in the experimental field (X_4 material)

In the "early" mutant lines, the one derived from Liu-chou, L 10-4-4, did not fare so well in the first crop, but responded fairly well in the second crop. However, the "early" line derived from Chianan No. 8, C 25-15, yielded fairly well in standard fertilizer, but very poorly under heavier fertilization.

Mutant lines such as "large-panicled," "multi-branched" and others were also selected and their respective responses to fertilization were also being tried out. Since these yield tests for all these mutant lines were all preliminary

in nature that nothing can be concluded from them.

The Indica varieties as a rule suffer badly from shattering. Three mutant lines were obtained which would be classified as non-shattering in character. These mutants of course are good parents for eventual cross breeding work to be done later.

Discussion

Gustafsson (1947) of Sweden was the first pioneer worker to obtain positive results in plant breeding by the use of X-ray radiation. Of his mutant lines in barley induced by X-ray irradiation such as erectoides, early-maturing, high protein, disease-resistant, mention should be made of the erectoides which could respond excellently to heavy dressing of nitrogenous fertilizers. More recently, Stubbe (1958) used X-rays on barley seeds and obtained more or less the same results as those obtained by Gustafsson. In rice, Mashima and Kawai (1958) by the use of P^{32} obtained mutant lines such as were characterized by short-culmed, long-panicled, dense-panicled. The yields of these mutant lines were comparable to that of the original variety.

In our experiment with X-ray irradiation on dormant or watersoaked seeds of rice of both Japonica and Indica varieties, mutant lines as erectoides, early-maturing, high-yielding, non-shattering were found. Our yield tests so far did not bear out the fact that erectoides would respond favorably to heavy nitrogenous fertilizer. Yet these mutant lines would serve very favorably as parents in eventual cross breeding work to be done later. This is in progress. It is also planned that more fertilizer response tests will be made to evaluate the erectoides regarding their ability to react to heavy fertility.

At least one of the early-maturing lines of the Indica type yielded favorably in response to heavy fertilization in the second crop as compared to its original variety. This indicates that in a multi-cropping agriculture, early-maturing would play an important role in contributing toward the success of such a system.

Seeds of the Japonica variety, Taichung No. 65, being sent to Brookhaven National Laboratories of U. S. A., were treated by thermal neutrons. The X_2 and X_3 plants were grown in a region with natural rice blast "epidemic." Some lines were picked out to be rather resistant. This work is still in progress.

Summary

X-ray radiation was used to produce mutant lines in rice such as erectoides, early-maturing, rice-blast-resistant and other types in 1957. Varying dosages of X-ray radiation were being used on 10 varieties of rice belonging to both Japonica and Indica types. Comparative test was done with the original varieties in the X_4 generation. Fertilizer response tests were done in later generations.

Erectoides were found, but they did not respond favorably to heavy fertility. Some early-maturing mutant lines yielded comparable to or better than their original varieties. Many "high-yielding lines" outyielded their original varieties in either or both of the first and the second crops. It was interesting that three non-shattering mutant lines were found in one of the X-ray-treated Indica varieties. Testing and selection of mutant lines resistant to rice blast disease have been in progress since the spring of 1959. Further fertilizer response tests for the mutant lines will be carried out in the future to evaluate their potentiality.

利用X光線以改進水稻品種的研究

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本試驗開始於1957年，用不同量的X光線處理日本型及印度型水稻計10個品種，由此獲得了許多有用的突變品系，有的直立不倒伏，有的早熟，有的能抗稻熱病，有的產量較原品種增加，有的由易脫粒變爲不脫粒。從 X_4（即X光線處理後的第4代）起作一兩次產量比較試驗，繼而進行肥料反應試驗，以測驗各突變品系的生產力和耐肥力。

本試驗所選出的直立不倒伏品系，原以爲可以經耐重肥，而試驗結果殊不令人滿意。此外有若干早熟品系其產量足與原品種相抗衡；還有若干所謂「高產品系」，有的在第一期作或第二期作優於原品種，有的兩期作皆優於原品種。更值得一述的是在印度型品種的後代中找到了三個不脫粒的突變品系，這是用以改良原品種的脫粒性的寶貴材料。

本試驗中的抗病品系選育工作始於1959年春季（第一期作），現仍繼續進行中。肥料反應試驗也要繼續實施。（摘要）

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