15. FIELD TESTS ON SPLIT APPLICATIONS OF NITROGEN —AN APPLICATION OF FRACTIONAL FACTORIAL DESIGN—

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Introduction.

Kanagawa Prefecture is located in the southern part of Kanto districts and has about 14,000 ha paddy fields. The ordinary transplanting cultivation of rice plant has been in practice for years over 90 percent of the paddy fields and the transplanting period is between June 10th and the end of the month. The temperature in the period of transplanting is so high that rice plants are apt to overgrow at the tillering stage for a month and a half after transplanting. But, in general, the climate after heading is so unfavorable that the ripened grains ratio is low, and typhoons in Autumn often cause a decrease of the hulled rice yield. The average yield in this prefecture has been 350 kg per 10 ares for the recent five years, which is about 100 kg per 10 ares below the average at the national level. The cause of the low yield have been investigated from various points: climate, transplanting period, varieties, fertilization, soil types and so on. So far as fertilization is concerned, one of the main causes of the low yield in this prefecture is, to our thinking, the fact that too much importance has been attached to applying nitrogen as a basic fertilizer, which causes a decrease of effective tillers because of an overincrease of tillers at an early stage. The object of the present experiment is an attempt to search for a more effective application of a nitrogen fertilizer, taking into consideration periods of additional fertilization as well as basic fertilization.

In carrying out the experiment, we used 'orthogonal arrays' and constructed fractional factorial designs making the experiment more efficient and accurate, and the investigated data were analyzed by an electronic computer. Acknowledgment are due to Dr. Tadakazu Okuno and Dr. Noboru Murayama, the National Institute of Agricultural Sciences, for the

Table 1. Soil profile and chemical characters of test fields.

Layer	Depth (cm)	Gravel (%)	Sand (%)	Silt (%)	Clay (%)	Soil texture	Total carbon (%)	Total nitrogen (%)	C/N ratio (%)	Content of humus (%)	C.E.C (m.e)
1	0-18	5.85	64.4	19.0	16.6	S C L	1.55	0.16	9.7	2.7	27.21
2	18-33	8.08	68.3	18.5	13.2	F S L	1.28	0.13	9.8	2.2	26.26
3	33-57	8.87	60.7	24.9	14.4	L	1.21	0.12	10.1	2.1	28.94
4	68-100	5.46	24.8	40.9	34.3	L C	3.08	0.24	12.8	5.3	44.92

57-68: Sand

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planning of this experiment and the analysis of the result.

Planning of the experiment.

(1) The place of the test field: Paddy field at Agr. Res. Institute of Kanagawa Pref.
(2) Soil profiles and chemical characters of soil as shown in Table 1.
(3) Varity: Kusabue.
(4) Date of transplanting: June 20, 1968.
(5) Spacing: 22.2 hills per square meter (3 plants per hill).
(6) Time of drainage: July 25-30, 1968 (35 days after transplanting).
(7) Time of heading: August 24, 1968.
(8) Harvest time: October 26, 1968.
(9) Factors and levels: The following six factors and 2-3 levels for each factor are considered.

Factors	Levels		
(a) Calcium silicate: S	S_1, no application.	S_2, 400 kg per 10 area.	
(b) Basic nitrogen fertilizer: B	B_1, 4 kg per 10 ares.	B_2 6 kg per 10 ares.	
(c) Additional nitrogen fertilizer at tillering stage (20 days after transplanting): T	T_1, no application.	T_2, 2kg per 10 ares.	
(d) Amount of additional nitrogen fertilizer for head forming: H	H_1, 3 kg per 10 ares.	H_2, 6 kg per 10 ares.	
(e) Periods of application of nitrogen fertilizer for head forming: D	D_1, 20 days before head sprouting period.	D_2, 20 days and 10 days before head sprouting period, a half of the amount of additional nitrogen fertilizer for head forming applied each time	D_3, 10 days before head sprouting period.
(f) Additional nitrogen fertilizer at the heading: M	M_1, no application	M_2, 3 kg per 10 ares.	

(10) Assignment of the effects to the columns in $L_{16}+L_{16}+L_{16}$ is shown in Table 2.
(11) Treatment combinations are shown in Table 3.

In our test field the rice plant had been cultivated in the direct sowing method for 6 years, and we had already applied in 1967, 2,500 kg activated slag, 150 kg calcium silicate and 200 kg iron slag per 10 ares respectively for the improvement of the soil. And in spring, 1968, the year of our experiment, 80 kg super phosphate of lime and 20 kg potassium chloride per 10 ares were applied before irrigation.

First we divided the test field into two blocks and then divided each block into two parts. Calcium silicate was applied to a part of each block, and only basic nitrogen fertilizer (ammonium sulfate) was applied in a submerged condition to all parts and then each part was divided into 12 plots, about 6 are paddy field partitioned off into 48 plots with boards (2 meters wide and 5 meters long).

Table 2. Assignment of factorial effects to the arrays.

Array number / Key symbol	1 a	2 b	3 a b	4 c	5 a c	6 b c	7 a b c	8 d	9 a d	10 b d	11 a b d	12 c d	13 a c d	14 b c d	15 a b c d
(Factorial effect)															
D_1	R ‖ H M	S	T B	H	M	S H	S M	T	S B	S T	B	H T	M T	M B	H B
D_2	R ‖ T H	S	M B	T	H	S T	S H	M	S B	S M	B	T M	H M	H B	T B
D_3	R ‖ T M	S	H B	T	M	S T	S M	H	S B	S H	B	T H	M H	M B	T B

Table 3. 48 treatment combination for nitrogen applications.

(kg per 10 ares)

No.	B	T	D_1H		M	B	T	D_2H		M	B	T	D_3H		M
1	4	0	3	0	0	4	0	1.5	1.5	0	4	0	0	3	0
2	6	2	3	0	0	6	0	1.5	1.5	3	6	0	0	6	0
3	4	0	6	0	3	4	2	3	3	0	4	2	0	3	3
4	6	2	6	0	3	6	2	3	3	3	6	2	0	6	3
5	6	0	3	0	0	6	0	1.5	1.5	0	6	0	0	3	0
6	4	2	3	0	0	4	0	1.5	1.5	3	4	0	0	6	0
7	6	0	6	0	3	6	2	3	3	0	6	2	0	3	3
8	4	2	6	0	3	4	2	3	3	3	4	2	0	6	3
9	6	0	3	0	3	6	0	3	3	0	6	0	0	3	3
10	4	2	3	0	3	4	0	3	3	3	4	0	0	6	3
11	6	0	6	0	0	6	2	1.5	1.5	0	6	2	0	3	0
12	4	2	6	0	0	4	2	1.5	1.5	3	4	2	0	3	0
13	4	0	3	0	3	4	0	3	3	0	4	0	0	3	3
14	6	2	3	0	3	6	0	3	3	3	6	0	0	6	3
15	4	0	6	0	0	4	2	1.5	1.5	0	4	2	0	3	0
16	6	2	6	0	0	6	2	1.5	1.5	3	6	2	0	6	0

Data obtained and Analysis of variance.

By the use of the table of $L_{16}+L_{16}+L_{16}$ orthogonal arrays, we got the following 48 treatment combinations and the obtained data on items of D_1 (20 days before head sprouting period), D_3 (10 days before head sprouting period) and D_2 (20 days and 10 days before head sprouting period, a half of the amount of additional nitrogen fertilizer for head forming applied each time), to be analyzed are shown in Tables 4, 5 and 6 respectively.

Table 4. Obtained data of D_1 (16 combinations) treatment.

No.	Amount of ntirogen					S	Plant height at the maximum tillering stage (cm)	Number of tillers at max. tillering stage (per m²)	Length of stems (cm)	Length of panicles (cm)	Number of panicles (per m²)	Ratio of effective tillers (%)	Date of heading	Weight of leaves and stems (kg per are)	Weight of rough rice (kg per are)	Weight of hulled rice (kg per are)	Weight of 1,000 grains of hulled rice (g)	Number of ripened grains(×100 per m²)
	B	T	D_1H		M													
													Aug.					
1	4	0	3	0	0		70.2	360	80.6	19.9	318	88	24	69.2	61.8	51.3	23.1	240
2	6	2	3	0	0		70.5	390	81.6	19.7	274	70	26	82.4	73.2	50.6	22.9	304
3	4	0	6	0	3		68.2	300	82.7	21.1	314	105	25	78.8	65.3	53.9	23.5	251
4	6	2	6	0	3		71.7	416	87.2	21.1	394	95	25	90.3	73.4	60.4	23.3	314
5	6	0	3	0	0	*	71.9	418	86.0	19.8	321	77	26	80.7	70.5	58.1	23.0	318
6	4	2	3	0	0	*	69.5	390	84.2	20.5	278	71	26	68.8	65.2	53.5	23.1	261
7	6	0	6	0	3	*	71.6	403	87.4	21.3	381	95	25	87.5	73.0	60.3	23.3	283
8	4	2	6	0	3	*	70.2	418	86.5	21.1	332	79	26	83.3	70.1	57.9	23.1	299
9	6	0	3	0	3		71.7	362	85.0	21.9	280	77	22	79.9	68.7	56.4	23.6	264
10	4	2	3	0	3		75.4	407	80.0	20.8	318	78	22	88.9	73.8	61.5	23.5	271
11	6	0	6	0	0		73.3	422	89.2	22.3	323	77	24	86.6	73.6	58.7	23.3	283
12	4	2	6	0	0		74.3	371	87.9	21.6	354	96	23	76.0	75.6	60.9	23.3	294
13	4	0	3	0	3	*	67.9	380	80.6	21.0	387	76	26	82.7	65.6	54.3	23.1	221
14	6	2	3	0	3	*	74.5	438	85.9	19.7	305	70	26	94.4	70.5	58.3	22.8	276
15	4	0	6	0	0	*	68.1	382	80.6	21.4	330	86	26	75.5	72.9	60.3	22.8	284
16	6	2	6	0	0	*	73.3	463	86.5	20.7	359	67	26	84.0	75.8	61.9	22.8	289
	mean						71.4	395	84.9	20.9	323	82	—	81.8	70.6	58.0	23.3	278

*: Calcium silicates are applied in these treatments.

Twenty hills out of each plot were used for measuring, in the growing stage of rice plant, plant height, number of tillers, length of and number of panicles and length of stems, and the weight of the production and other items were investigated following the standard method.

The comparison of the averages on some main items of investigation of each D (periods of application of nitrogen fertilizer at the head forming stage) as shown in Tables 4 - 7 and summerized in Fig. 1 shows that the difference among D treatments proved highly significant.

An additonal nitrogen fertilizer applied 20 days before the head sprouting period (D_1 treatment) proved to lengthen the stems, but in this experiment, we did not recognize the lodging of plants to be affected by typhoons in autumn and the ratio of effective tillers, the length and number of panicles and the number of hulled grains surpassed those in other treatments. What was better, the weight of leaves and stems was the least. And these contributed to increasing the yield of hulled rice.

An additional nitrogen fertilizer applied 10 days before the head sprouting period (D_3 treatment) resulted in the least yield of hulled rice because the main items of components for increasing the yield were the worst. It was due to the fact that the number of defective tillers was larger than those in the other treatment.

D_2 treatment (20 days and 10 days before the head sprouting period, a half of the

Table 5. Obtained date of D_2 (16 combinations) treatment.

No.	Amount of nitrogen					S	Plant height at the maximum tillering stage (cm)	Number of tillers at max. tillering stage (per m²)	Length of stems (cm)	Length of panicles (cm)	Number of panicles (per m²)	Ratio of effective tillers (%)	Date of heading	Weight of leaves and stems (kg per are)	Weight of rough rice (kg per are)	Weight of hulled rice (kg per are)	Weight of 1,000 grains of hulled rice (g)	Number of ripened grains(×100 per m²)
	B	T	D_2H		M													
													Aug.					
1	4	0	1.5	1.5	0		69.7	367	80.2	20.2	278	76	25	64.7	56.4	46.4	23.8	210
2	6	0	1.5	1.5	3		73.9	338	80.9	20.3	328	97	25	82.6	63.3	52.2	23.2	250
3	4	2	3	3	0		70.8	432	83.4	20.4	332	77	24	77.7	65.6	54.3	23.6	233
4	6	2	3	3	3		73.9	387	85.5	20.7	335	87	24	89.4	66.4	55.3	23.5	285
5	6	0	1.5	1.5	0	*	72.1	482	84.2	20.1	336	70	26	79.2	65.9	53.8	23.3	296
6	4	0	1.5	1.5	3	*	69.7	347	82.6	19.8	278	80	26	87.8	63.3	52.6	23.4	251
7	6	2	3	3	0	*	75.1	427	88.1	20.5	324	76	26	93.1	69.4	57.5	23.3	299
8	4	2	3	3	3	*	72.1	414	85.5	20.2	314	76	26	94.2	70.4	58.7	23.8	303
9	6	0	3	3	0		70.7	370	82.6	20.7	314	85	25	77.5	66.0	54.4	23.8	235
10	4	0	3	3	3		72.5	340	81.0	21.5	320	94	23	82.7	70.1	58.8	23.9	256
11	6	2	1.5	1.5	0		77.8	483	9..1	19.4	316	65	25	75.5	65.3	53.8	22.8	275
12	4	2	1.5	1.5	3		72.7	336	81.5	19.5	252	75	23	86.8	61.4	51.0	23.4	234
13	4	0	3	3	0	*	72.9	372	82.0	20.8	265	71	24	78.8	69.8	58.3	23.9	239
14	6	0	3	3	3	*	73.7	429	84.7	20.2	298	70	25	95.1	73.2	60.8	23.4	297
15	4	2	1.5	1.5	0	*	69.9	396	81.8	20.6	259	67	26	78.1	55.3	45.3	23.4	232
16	6	2	1.5	1.5	3	*	71.6	456	83.3	20.0	316	69	26	92.4	66.3	55.6	23.2	279
	mean						72.4	399	83.6	20.3	304	77	—	83.5	65.5	54.3	23.5	261

amount of an additional nitrogen fertilizer for head forming applied each time) showed halfway data between D_1 and D_3 in the main items, with the only exception that the weight of 1,000 grains of hulled rice was the heaviest.

The analysis of variance for the yield of hulled rice is shown in Table 8. In describing the main effects and two-factor interactions, D, H, B, S×T, T, B×H, H×D and T×D are arranged in order of significance. D, H (nitrogen fertilizer for head forming) and B (basic nitrogen fertilizer) are highly significant.

A study of Fig. 2 shows that factors of an increase in the yield of rice are the application of 6 kg per 10 ares nitrogen as a basic fertilizer and the application of 6 kg per 10 ares nitrogen as an additional fertilizer 20 days before the head sprouting period. ($B_2D_1H_2$)

An application of calcium silicate, instead of an application of an additional nitrogen fertilizer at the tillering stage, increases the yield because it promotes the increase in the number of tillers at an early stage of growing.

As for nitrogen application at the heading cursorily, its effect on yield increase was found to be limited in D_2 treatment. Moreover, the weight of leaves and stems was increased by nitrogen application at the heading.

Discussion

By keeping down the amount of a basic nitrogen fertilizer and by draining the field after we had enough tillers to get effective tillers, an overgrowth of rice plant and an

Table 6. Obtained data of D_3 (16 combinations) treatment.

No.	Amount of nitrogen					S	Plant height at the maximum tillering stage (cm)	Number of tillers at max. tillering stage (per m²)	Length of stems (cm)	Length of panicles (cm)	Number of panicles (per m²)	Ratio of effective tillers (%)	Date of heading	Weight of leaves and stem (kg per are)	Weight of rough rice (kg per are)	Weight of hulled rice (kg per are)	Weight of 1,000 grains of hulled rice (g)	Number of ripened grains(×100 per m²)
	B	T	D_3H		M													
													Aug.					
1	4	0	0	3	0		68.9	298	75.7	19.2	282	95	26	63.2	50.5	42.0	23.1	178
2	6	0	0	6	0		71.0	392	79.8	18.4	311	79	24	90.5	58.6	48.8	23.2	228
3	4	2	0	3	3		71.5	387	81.4	18.8	256	66	26	87.5	56.1	46.6	23.1	217
4	6	2	0	6	3		73.2	454	81.8	18.9	335	74	25	95.7	63.4	53.3	23.0	242
5	6	0	0	3	0	*	71.8	427	85.3	18.8	276	65	26	83.1	64.0	53.1	22.9	263
6	4	0	0	6	0	*	71.0	356	80.0	18.9	278	78	26	82.7	59.8	50.2	23.4	226
7	6	2	0	3	3	*	74.9	487	87.3	18.7	313	64	26	99.2	66.2	53.9	23.0	287
8	4	2	0	6	3	*	72.6	418	82.4	18.9	271	65	26	95.9	63.3	53.1	23.2	267
9	6	0	0	3	0		74.0	380	81.6	19.3	256	67	23	90.9	58.9	48.8	23.2	247
10	4	0	0	6	0		71.5	354	75.0	18.7	247	70	23	89.2	59.4	49.7	22.9	255
11	6	2	0	3	3		74.9	425	82.9	18.6	298	70	25	86.8	63.7	53.0	23.1	226
12	4	2	0	6	3		76.2	398	78.6	19.5	260	65	24	91.8	61.3	50.9	23.6	232
13	4	0	0	3	0	*	70.3	370	78.6	19.0	258	70	26	86.2	56.7	47.0	23.1	208
14	6	0	0	6	0	*	74.7	372	80.4	19.2	278	75	24	97.2	64.7	53.7	23.1	232
15	4	2	0	3	3	*	71.3	412	79.8	18.2	269	65	27	83.4	61.9	52.1	23.1	223
16	6	2	0	6	3	*	72.0	414	78.9	19.0	264	64	27	92.3	63.9	52.4	22.9	211
	mean						72.5	397	80.6	18.9	278	71	—	88.5	60.8	50.5	23.1	234

Table 7. Average data of each D treatment.

Period of an additonal fertilizer for head forming stage	Length of stems (cm)	Length of panicles (cm)	Number of panicles (per m²)	Ratio of effective tillers (%)	Weight of leaves and stems (kg per are)	Weight of rough rice (kg per are)	Weight of hulled rice (kg per are)	Weight of 1,000 grains of hulled rice (g)	Number of ripened grains (×100 per m²)
D_1	84.9	20.9	323	82	81.8	70.6	58.0	23.3	278
D_2	83.6	20.3	304	77	83.5	65.5	54.3	23.5	261
D_3	80.6	18.9	278	71	88.5	60.8	50.5	23.1	234
mean	83.0	20.0	302	77	84.6	65.6	54.3	23.3	257
l.s.d	1.6	0.4	24	—	2.1	—	1.9	0.2	16

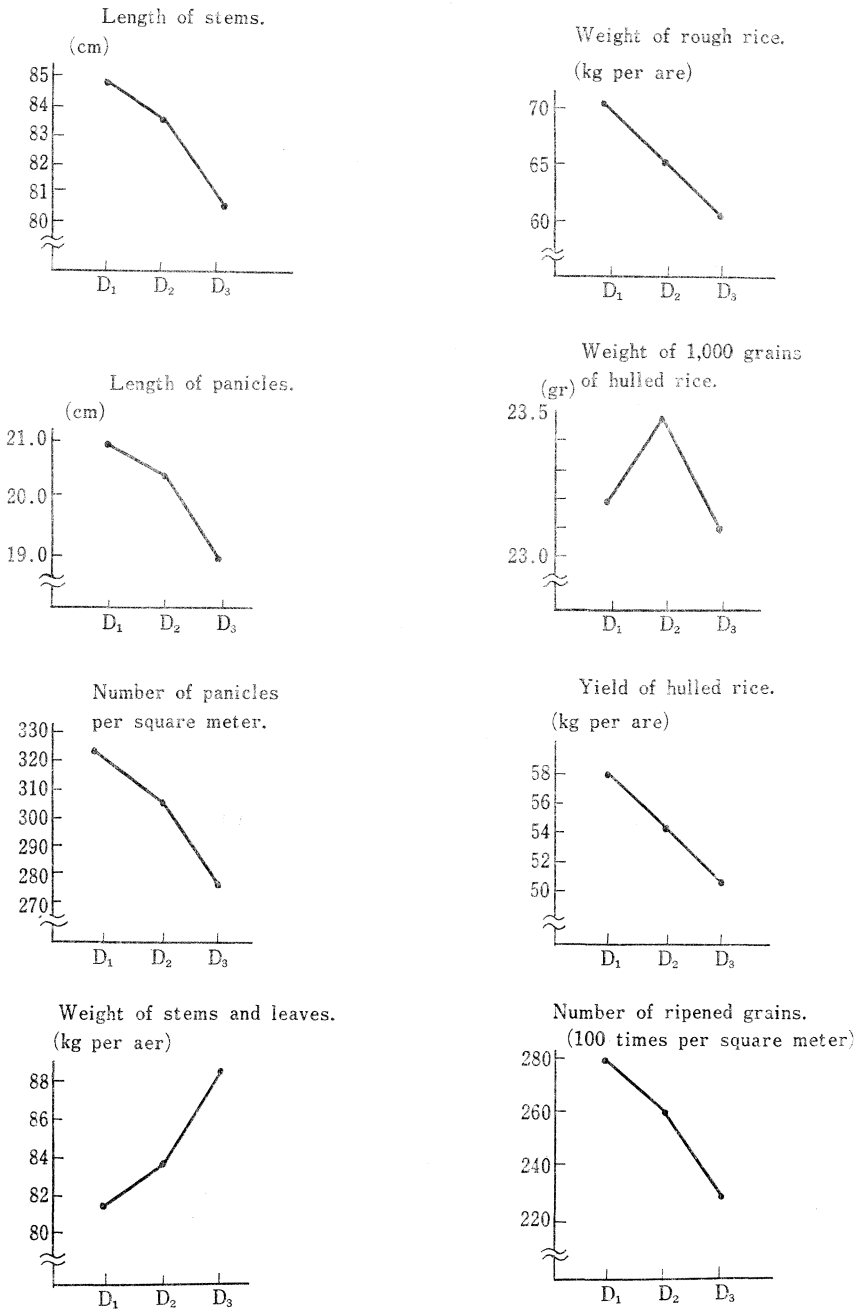


Fig. 1. The effects of D for main items.

Table 8. Analysis of variance for yield of hulled rice.

Source of variation	Degrees of freedom	Sums of squares	Mean square	F
R: (Block)	1	19. 38		—
S: (Calcium Silicate)	1	32. 51		< 2
e_1	1	25. 96	25. 96	
B: (basic N)	1	87. 75		>20**
T: (Tillering stage)	1	29. 30		8*
D: (Periods)	2	451	226	>50**
H: (Head forming stage)	1	143. 18		>30**
M: (Heading)	1	10. 36		3
S × B	1	1. 30		—
S × T	1	37. 99		>10**
S × D	2	15. 89	7. 95	2
S × H	1	2. 76		—
S × M	1	0. 26		—
B × T	1	0. 17		—
B × D	2	1. 67	0. 84	—
B × H	1	21. 62		6*
B × M	1	0. 50		—
T × D	2	31. 75	15. 88	> 4*
T × H	1	5. 78		< 2
T × M	1	0. 23		—
H × D	2	38. 86	18. 43	> 5*
H × M	1	2. 26		—
M × D	2	19. 23	9. 62	3
e_2	18	66. 06	3. 67	

** Double asterisk denotes significance at the 1% level.
* Single asterisk denotes significncance at the 5% level.

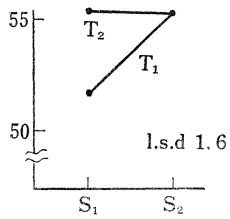
overincrease of ineffective tillers were prevented. And we got about 300 panicles per square meter. An addition of a nitrogen fertilizer about 20 days before the head sprouting period effectively promotes an increase of the length of panicles and, what was better, an increase of the number of ripened grains, resulting in a production of hulled rice of 550-600 kg per 10 ares.

The fertilization and management in our experiment, if applied to the transplanting rice plant cultivation generally practised in Kanagawa prefecture, will be effective to raise the yield of hulled rice.

From the above conclusion our principle of guiding the farmers in our prefecture will be to encourage them to apply about 200 kg calcium silicate per 10 ares, to limit the amount of nitrogen as a basic fertilizer at 3 - 6 kg per 10 ares varying according to soil types and drainage conditions, not to apply an additional fertilizer at the tillering stage, to drain the field 35 - 40 days after transplanting, to dry the field completely, and to give an additional nitrogen fertilizer of about 3 kg per 10 ares 20 days before the head sprouting period (about August 5).

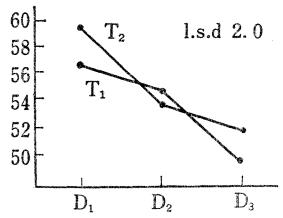
S x T

	T_1	T_2
S_1	51.8	55.2
S_2	55.2	55.1



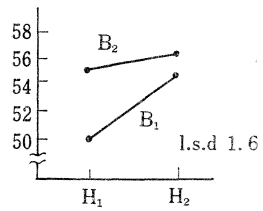
T x D

	D_1	D_2	D_3
T_1	56.7	54.7	49.2
T_2	59.3	53.9	51.9



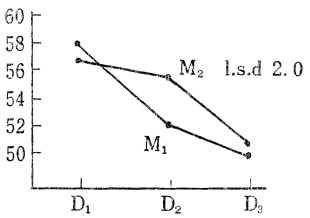
B x H

	H_1	H_2
B_1	50.4	55.5
B_2	54.7	56.5



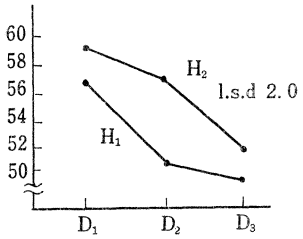
M x D

	D_1	D_2	D_3
M_1	58.2	52.9	50.3
M_2	57.8	55.7	50.8



D x H

	D_1	D_2	D_3
H_1	56.8	51.3	49.6
H_2	59.3	59.2	51.5



Effect of S, B, T and H.

Level	S	B	T	H
1	52.5	51.9	52.5	51.6
2	54.1	54.7	54.1	55.0

Fig. 2. The two-factor interactions and the effect of S, B, T and H.

Discussion

H. Fukui, Japan: What is the meaning of calculating F value for the main effect when there is the significant interaction between the two factors and one of which is the said main effect?

Answer: When the two factor interaction was significant, the main effect was insignificant, for example in Table 8 S×T was significant, and then S and T were insignificant respectively, except on the main effect (S or T sums squares) were shown 4-5 times more than S×T.

H. Fukui, Japan: What is the basis of the hypothesis that the interaction among more than three factors is insignificant?

Answer: In general agricultural field tests, three factor interaction would be rarely observed, and for planning of the experiment, we should investigate factors and levels in varying according to the object of the experiment.

H. Ishikura, Japan: Table 5 shows rather remarkable difference in the percentage of effective tillers. Could you tell any reasons for inducing this difference? Did you make any observation on the incidence, for example of the stem borers or rice blast, I suspect application of rather big amount of calcium silicate would influence the occurrence of pests?

Answer: D_1 and D_2 treatments show high ratio of effective tillers more than D_3 treatment. I suppose that the top-dressing of nitrogen at the period of 20 days before the heading (D_1 and D_2 treatments) decreases the number of degenerated tillers more than D_3 treatment. For the second questions, although close observation was not made in this experiment regarding the occurrence and influence of application of calcium silicate, but we could not observe the lodging of plant and plants were not damaged by pests in all 48 treatments.

H. Ito, Japan: Please introduce the cost for the calculation by an electronic computer.

Answer: Rental cost is 1,500 yen per minute and it takes less than 10 seconds for calculating data and analysis of L_{16} each item.