STUDIES ON THE WEED CONTROL WITH TRIFLURALIN*

1. Experiments on the Weed Control with Trifluralin in Paddy Rice Field

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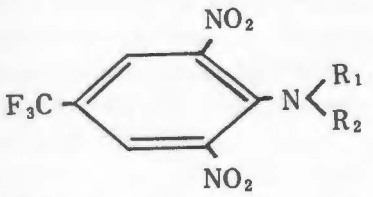
INTRODUCTION

Herbicides having the following chemical structure have been developed by Elanco Products Co., the United States of America (a division of Eli Lilly and Co.). Of these compounds, one whose R_1 and R_2 are both propyl radical has proved to be an excellent selective pre-emergence herbicide for annual weeds. This compound, α, α, α -trifluoro-2, 6-dinitro-N, N-dipropyl-p-toluidine, is called trifluralin in general name (1, 6).



Trifluralin is a orange-yellow crystal, readily soluble in acetone and sparingly soluble in water (under 1 ppm at 27°C). It is volatile and decomposed by ultraviolet light. The commercial product is called treflan in the United States and trefanocide in Japan. It is commonly used in emulsion or in granular form. Its fish toxicity in the dosage of application to the field (15g per are) is about one-eightieths to that of PCP.

Since 1963 trifluralin has been subjected to field test in crop fields and vegetable farms in Japan (2, 3, 4). It is safe for use in the field of cabbage, radish, carrot, soybean, peanut, rapeseed, wheat, tomato, chili, sweet potato, etc. (5). It can prevent the germination of annual weed seeds of Gramineae, Chenopodiaceae, Amaranthaceae, Portulacaceae, Caryophyllaceae and Aizoaceae, and also kill the seedlings of them. Trifluralin is said to be practically of no use aganist the perennial weeds and the annuals belonging to Compositae, Cruciferae, Cyperaceae and Commelinaceae.

As gramineous plants were susceptible to trifluralin, the rice cultivation in paddy field has been considered to be outside the application of trifluralin. However, we took interest in the feature of trifluralin as a herbicide because it contains fluorine in place of chlorine as structural component. Since it has been found to be effective in the control of *Echinochloa cruss-galli*, we thought that trifluralin might be useful in the paddy rice field. Experiments designed to test this possibility have been made since 1963. As fairly satisfactory results have been obtained, the outline of the experiments made from 1963 to 1965 are presented in this paper.

The writers wish to express their thanks to Agricultural Chemicals Division of Shionogi & Co. for the supply of trifluralin used in this study.

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* This is the English edition of the article published in Nogaku Kenkyu 51: 153—173.

EXPERIMENTAL METHODS

1. *Herbicide Test in the Direct-seeded Rice Fields**

The variety of rice plant used in this test was "Mihonishiki". The field was divided into plots of 1.5 m^2 to 2.0 m^2. The rice seed was firstly subjected to brine assortment. It was then mixed with 3% heptachlor for protection aganist mole-crickets and with 4% redlead for protection aganist spallows, and was placed by groups of 5 to 10 grains in each hole (15~16.7cm spacing in the row, 30cm apart), on June 17, 1963 and on June 15, 1964 and 1965. The seeds were covered with a soil-mixed compost, 2.5cm thick. The rice seeds emerged on about June 21 each year. Application of trifluralin was at three different stages, i. e. (1) pre-sowing (3 days before sowing), (2) pre-emergence (5 days before emergence), and (3) post-emergence (3~4 days after emergence). Both wettable powder and emulsifiable concentrates of trifluralin and various other herbicides were sprayed in the state of solution or in the emulsion at a rate of 10 or 15 liters per are by the use of a hand atomizer. The granular agent was broadcast by hand. Irrigation was performed 14 to 20 days after emergence. Fertilizer was given in the routine manner. Weeds were taken by hand from the middle to the end of July. The rice plants were harvested in November.

2. *Comparison of Weeding Effect of Trifluralin beiween its Soil-incorpolation and its Non-Soil-incorpolation Methods in the Direct-seeded Rice Field*

On June 28, 1965, 10 seeds were sown in each of the eight holes (12cm spacing in the row, 30cm apart) in concrete pots of 1/270 are.

a) Pre-sowing treatment was made 2 days before sowing with trifluralin (5, 7.5 and 10g per are), which was incorpolated into the surface soil at a depth of 6cm. In the other pots this was made with trifluralin (5 and 10g per are) broadcast on the soil surface without soil-incorpolation.

b) For pre-emergence treatment, trifluralin (10 and 15g per are) was broadcast without soil-incorpolation on the day following the sowing. Irrigation for a) and b) was started on July 15. The growth of rice plants was investigated in the same pots at the beginning, middle and end of July, concerning the number of plants per stand, plant height, root length, number of leaves, and weight.

3. *Herbicids Test in the Rice Transplanted Fields*

Rice seedlings of the "Mihonishiki" variety sown in the middle of May were transplanted to bottomless 1/500 are frames in a paddy field at a rate of 4 bunches per frame and to 1/270 are concrete pots also in a paddy field at a rate of 6 bunches per pot. Post-planting treatment with various herbicides was made after 12

* The rice seeds were sown on dry soils and the fields were irrigated at the early stage of growth.

days from the transplantation time in 1963, after 5 days in 1964 and after 4 and 7 days in 1965, under submerged field conditions. (In 1964 some plots were drained.) The granular agents were broadcast by hand. The wettable powder and emulsifiable concentrates were sprayed in the state of solution or emulsion at a rate of 13 liters per are, with a small sprayer. The amount of trifluralin applied was 10, 15 or 20g (active ingredient) per are each year.

When the herbicides were applied under the above-mentioned conditions the growth of weeds was as follows. In 1963 (application of herbicide, 12 days after transplantation) *Monochoria vaginalis*, 2 leaves (weed height, 1～2cm); *Rotala indica*, 1～2 leaves (0.5～1.0cm); *Dopatrium junceum*, 1～3 leaves (0.5～1.0 cm); barnyard grass (*Echinochloa cruss-galli* Beauv. var. *oryzicola* Ohwi or *E. oryzicola* Vasing), 4 leaves (5～10cm); *Cyperus Iria*, and *Cyperus difformis*, 2～3 leaves (1～3 cm). In 1964 (application of herbicide, 5 days after transplantation) barnyard grass, 1～2 leaves (2～7 cm); *Elatine triandra*, 1～2 leaves (0.5 cm); *Rotala indica* 1 leaf (0.5cm); *Cyperus difformis*, 1～2 leaves (1～2cm), *Fimbristylis miliacea*, 1 leaf (0.5～1.0 cm); *Lindernia pyxidaria*, 1～2 leaves (1cm). In 1965 (application of herbicide, 4 days after transplantation) barnyard grass, 2 leaves (5cm); other weeds, not longer than 1cm. In 1965 (application of herbicide, 7 days after transplantation) barnyard grass, 2～4 leaves (5～10cm); *Eleocharis acicularis*, 1 leaf (1cm); *Rotala indica*, 1 leaf (0.5 cm); and *Elatine triandra*, 1 leaf (0.5cm).

RESULT

Weed Controlling Effect of Trifluralin and Other Herbicides

1. *Reactions of Barnyard Grass* (*Echinochloa cruss-galli* Beauv. var. *Oryzicola* Ohwi or *E. Oryzicola* Vasing) with *herbicides in the Direct-seeded Rice Field*

It is now accepted that trifluralin is highly efficient in controlling seedling growth of gramineous weeds. In order to know the reaction of barnyard grass with trifluralin applied in the direct-seeded rice field and in 1/270 are pots in direct sowing method, the height of barnyard grass at 1 to 4 leaf stage was preliminarily measured, and observations on the effect of trifluralin were made after its application at 10, 15 and 20g (active ingredient). At the same time a comparative experiment was made with DCPA (25g). The results were shown in Fig. 1,2.

(1) *Effect of trifluralin*

1-Leaf stage—On application of trifluralin, the bases of stems and the leaves swelled and turned reddish brown color. Most of the weeds not taller than 1.5 cm died within 14 days after application of 10g. The first leaf of the weeds taller than 1.5cm discolored when they grew to 3-leaf stage. The weeds taller than 2～3cm later died 14 days after application. Trifluralin, when used at 15g,

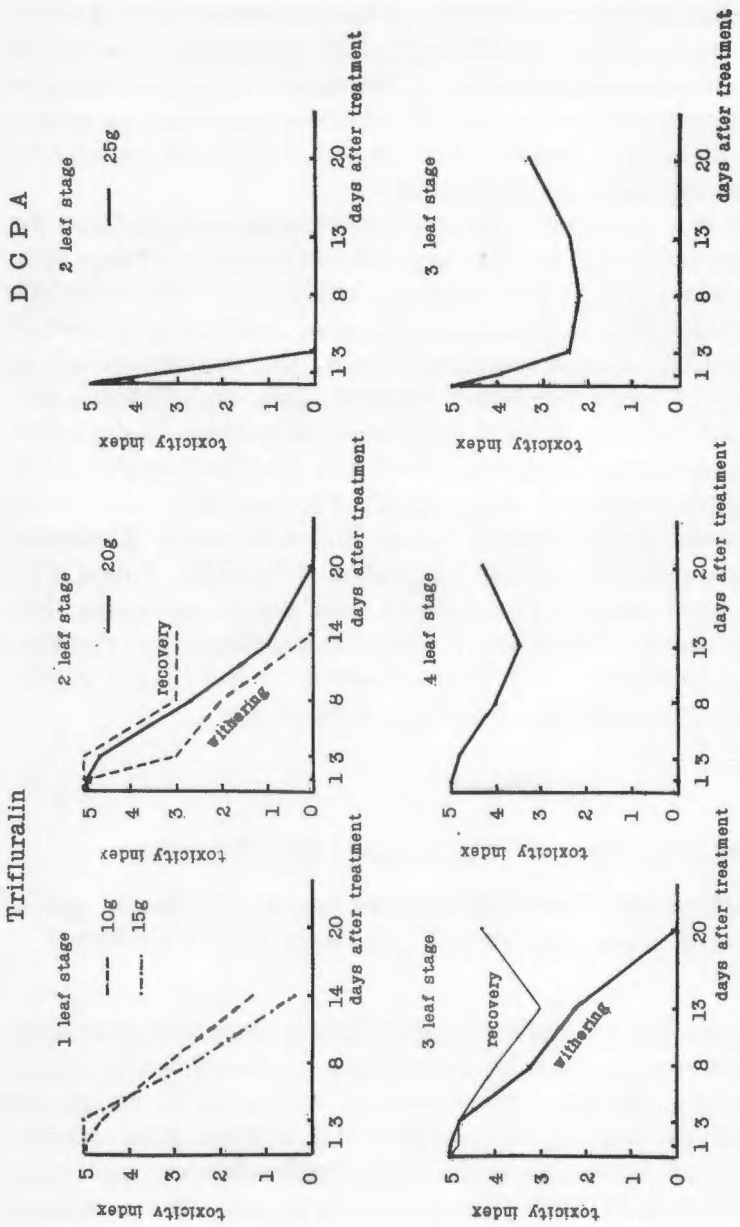

Fig. 1. Reaction of barnyard grass with trifluratin and DCPA (an average of several plants).
Toxicity index
5 : non-reaction
4 : discoloration of the first and second leaves
3 : discoloration of all leaves or withering of submerged leaves
2 : malformation or medial withering
1 : withering almost
0 : withering

showed its effect several days later and the weeds died in 14 days or so. (Plate I -A)

2-Leaf stage—After application of the herbicide (10g), the weed 1.5cm or shorter, died, while those, 1.7cm or taller, recovered. When 20g of the herbicide was applied, the reaction was observed 3 days after the herbicide application in the earliest case and after several days in most cases. All of the weeds, 2 to 5 cm in height, died within 14 to 20 days after the application of trifluralin.

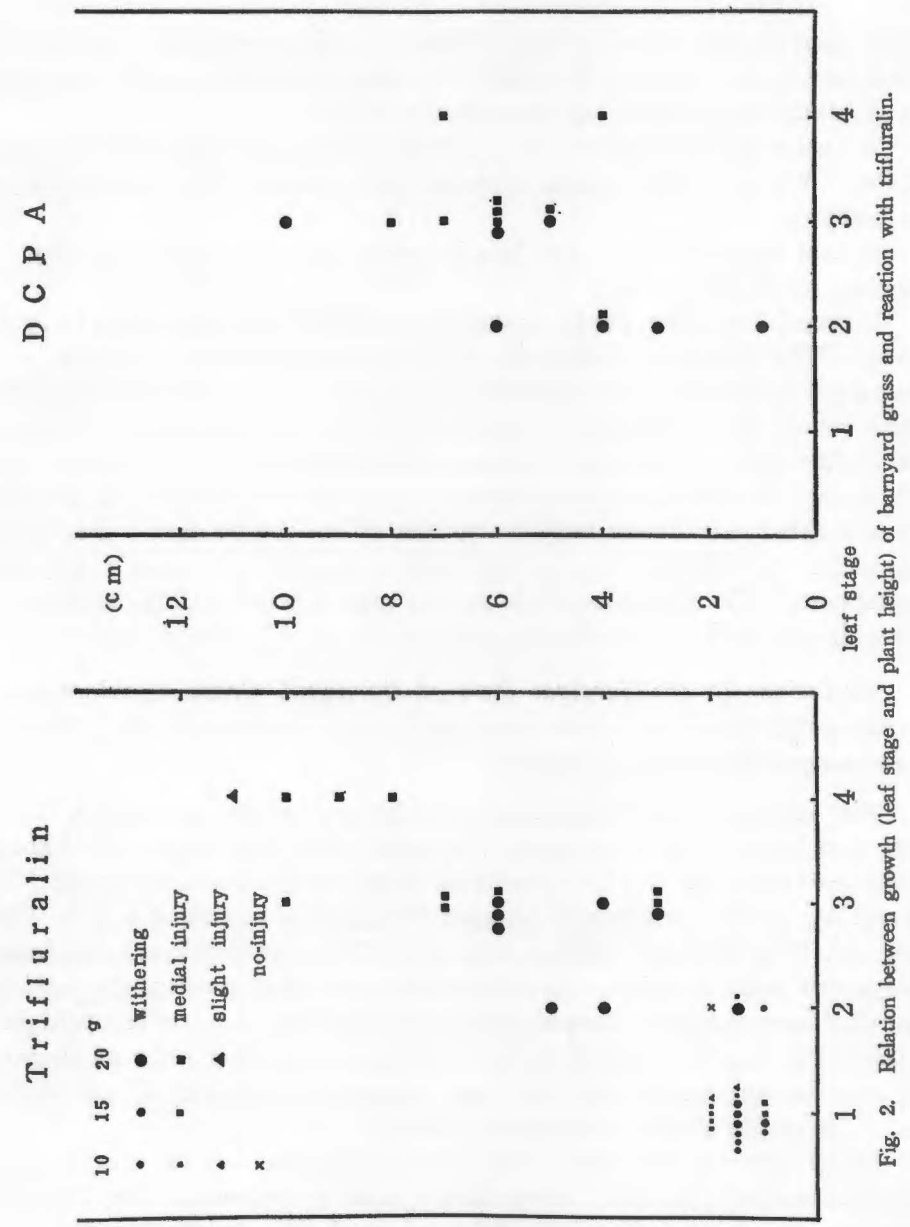

Fig. 2. Relation between growth (leaf stage and plant height) of barnyard grass and reaction with trifluralin.

3-Leaf stage—The weeds, 7cm or taller, recovered after once exhibiting susceptibility to the herbicide (20g), and those, shorter than 7cm, died. All the leaves turned brownish red and all the weeds died within about 20 days.

4-Leaf stage—On application of the herbicide (20g), a few leaves of weeds, 8~12cm, turned brown, the submerged leaves were killed, and the other leaves were not killed and recovered later.

(2) *Effect of DCPA*

2-Leaf stage—The reactions of 1~6cm weeds with 25g of DCPA were bro-

wnish color change of the leaf tips, followed by discoloration and scorch of the whole leaves, and death of the weeds. The progression of the reaction was rapid; the weeds died 3 days after the application of DCPA.

3-Leaf stage—Weeds 5 to 6cm in height, were generally killed with 25g of DCPA. Weeds 6 to 8cm tended to recover after once exhibiting susceptibility to the herbicide.

4-Leaf stage—Weeds, 4 to 6cm in height once showed susceptibility but later recovered and survived.

Susceptibility of the weed to trifluralin and DCPA was found to be fairly different. The reaction of weed with DCPA was characteristic. DCPA had a contact action and the reaction proceeded very rapidly. On the other hand trifluralin whose action was initiated after being absorbed through the weed root showed at first slight activity. But the reaction proceeded rapidly later. Activity of trifluralin toward the weed during 3-leaf stage depends upon the weed height; the taller weeds respond to trifluralin more slowly than do the shorter ones. But, in the case of DCPA, the taller weeds occasionally responded to it more rapidly than shorter ones. The reason for this is that, in cases in which DCPA comes in contact with plant well, the taller weeds respond more rapidly than shorter ones.

2. *Variations in the Survival Rate of Barnyard Grass (Echinochloa cruss-galli* Beauv. var. *Oryzicola* Ohwi or *E. Oryzicola* Vasing) *in the Submerged Transplanted Field*

Rice seedlings were transplanted to 1/500 are frames on June 29, 1965. Two days later, germinating seeds of barnyard grass were scattered in frames. Under 3～4cm submerged field conditions, trifluralin (emulsion and granule) 10, 15 and 20g per are, prometryne (granule) 300g (active ingredient 4.5g), CNP (granule), 500g (30g) and NIP (granule), 400g (28g) were broadcast in the frames 4 days after transplantation. In order to determine to what extent the herbicide controlled barnyard grass, the percentage of the surviving stands of barnyard grass in the treated frames to those in the control frames (consisting of the stands growing from the germinating seeds and from spontaneous germination) was worked out. The results obtained are shown in Fig. 3.

When trifluralin was used at 10, 15 and 20g, the survival rate decreased from 2 days after application, except for its granular agent used at 10g. (The decrease seemed to be caused by the inhibition of germination and the herbicide effect on the weed seedlings.) The reaction of weeds with trifluralin proceeded more rapidly in the transplanted rice field than in the direct-seeded rice field. Almost all the weeds died in about 10 days. In the case of trifluralin granule used at 10g, the weeds reacted with the herbicide at first slightly. The curve of time-surviving rate did not show rapid linear decrease until it began suddenly to decrease after 10 days or so. The minimum survival rate was attained after 26 days, its value being 12%. Weed reaction of the plots of CNP and NIP was similar to that of trifluralin until about 10 days after application. Almost all the weeds were killed,

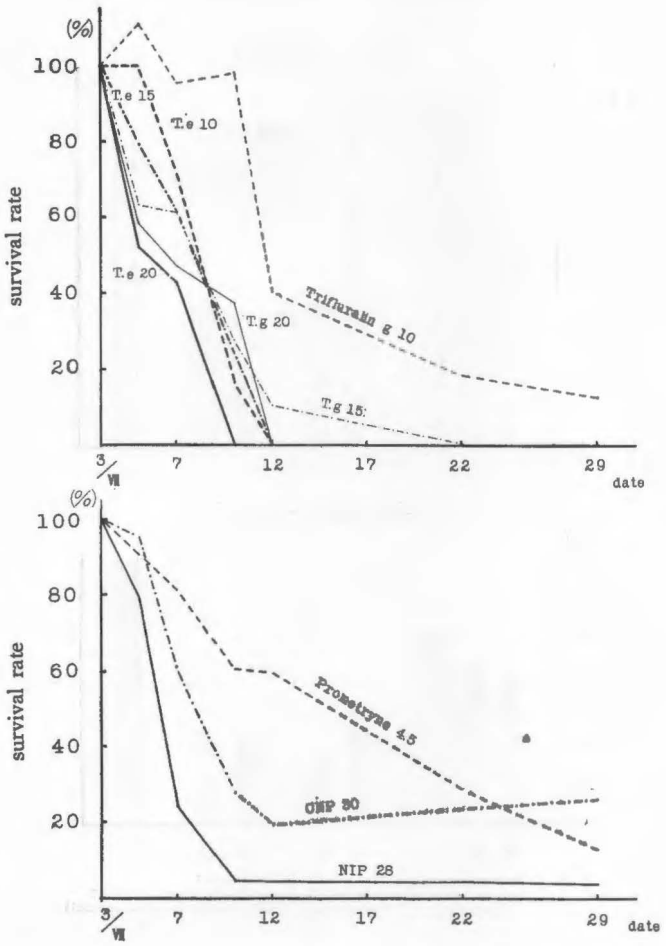

Fig. 3. Variations in the survival rate of barnyard grass in the submerged transplanted field with several herbicides. (g: granule e: emulsion)

showing very low survival rate of 5 to 20%. The survival rate in the plots of prometryne decreased slowly to 12%. This finding contrasted markedly with above results. Prometryne exhibited slowly a herbicidal activity aganist barnyard grass.

3. *Changes in the Vegetation Ratio of Weeds Including Barnyard Grass*

In 1965, under submerged field conditions, the herbicides were applied at the following doses 4 days after transplantation of rice seedling in 1/500 are frames. The changes in the vegetation ratio of weed in all the frames were measured later. The applied herbicides were trifluralin (emulsion and granule), 10, 15 and 20g; prometryne (granule), 300g (active ingredient, 4.5g); MCPCA (granule), 300g (7.5g); CNP (granule), 500g (30g); NIP (granule), 400g (28g); submerged MCP (granule), 300g (4.2g). (Figure is not reproduced in this paper.) The vegetation

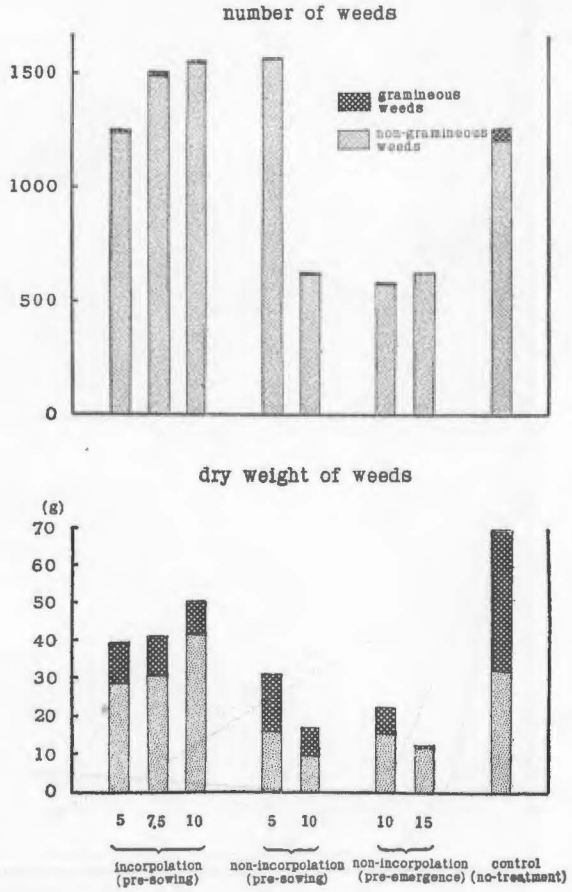

Fig. 4. Relations between amount of survived weeds and the methods of soil-incorpolation or non-soil-incorpolation of trifluralin.

ratio of weeds in the plots used at 10, 15 and 20g of trifluralin showed scarcely any increase for about 20 days, but later increased rapidly at 10 and 15g. The reason for this is that other weeds such as *Cyperus* spp., *Eleocharis acicularis* survived and germinated more than barnyard grass. On the contrary, there was little increase in the ratio in the case of NIP, MCPCA, prometryne etc., indicating little germination of these weeds. In the case of submerged MCP, the ratio increased from fairly early stage, because of the survival of *Dopatrium junceum.*

4. *Comparison of the Weed Controlling Activity of Trifluralin Applied by the Methods of Soil-incorpolation and Non-soil-incorpolation in the Direct-seeded Rice Field*

Fig. 4 shows that trifluralin used at 5g, whether soil-incorpolated or not, has an insufficient controlling activity aganist the weeds of paddy field, but that,

by non-soil-incorpolation method, a little better result in the dry weight is obtained than by soil-incorpolation method. With 10g of trifluralin the non-soil-incorpolation method proved to be better than the soil-incorpolation method. When trifluralin was not incorpolated into soil, the survival rate of the weeds is nearly the same whether its application (10g) was made before emergence or before sowing. The survival rates were found to be 22% in the former case and 29% in the latter case to non-weeding plot. The controlling effect aganist the gramineous weeds was especially high. The controlled weeds other than the gramineous weeds were *Dopatrium junceum* and *Monochoria vaginalis*, but *Rotala indica* and *Cyperus* spp. surviving in considerable numbers.

From the above results, it may be said that trifluralin, when soil-incorpolated, has little or no activity aganist the development of paddy weeds in the direct-seeded rice field. In the case of non-soil-incorpolation of the herbicide, there was almost no difference in the weed controlling effect of trifluralin between its application before sowing and before emergence.

Effect of Trifluralin and Other Herbicides on the Growth of Rice Plant in the Early Stage

The results of the experiments (in 1965) with trifluralin used at 5 to 10g, as regards its phytotoxicity on the growth of rice plant in the early stage, were as follows.

1. *Pre-sowing Treatment in the Direct-seeded Rice Field*

When trifluralin, emulsion and granule, was used at 10 and 15g per are, the germinating roots were club-shaped, failed to become longer and turned light brown. The sheaths and leaves became abnormaly thick and short, and many of them died. Thus, much phytotoxicity was observed (Plate I-B). Another experiment was made by applying 5 and 10g of trifluralin in pots, and by sowing rice seeds 7 days after the application. At the beginning and the end of July, the number of leaves, the height of plants, the root length, weight, etc. were measured. (Table of these results was not reproduced in this paper.) The paddy rice in the pots of pre-sowing treatment showed a lower growth rate than the control; especially smaller was the root length. The phytotoxic effect was less with trifluralin not soil-incorpolated than with trifluralin soil-incorpolated. The exceptions in this set of experiments were the results obtained with trifluralin used at 5g and soil-incorpolated, and trifluralin used at 5 and 10g and not-soil-incorpolated, in the pots where the rice seeds were sown 7 days after the herbicide application. In these pots, the number of rice plants leaves was a little more than in the control pots. Similar results were obtained on the height of the rice plant with trifluralin used at 10g and not-soil-incorpolated. These findings may be interpreted as follows. The concentration of trifluralin in the soil became lower by its volatilization and submersion, and as the result trifluralin stimulated the growth of rice plants, and increased the number of leaves and the height when the rice plant

recovered the juvenile roots.

2. *Pre-emergence Treatment in the Direct-seeded Rice Field*

The effect of trifluralin (emulsion and granule, 15g) in the field and in 1/270 are pots was as presented in Plate I-C, D. The growth of plumules and radicles was almost the same as that of the control. The height of rice plant, root length and weight were also practically not different from those of the controls, indicating that no phytotoxic effect was brought about.

3. *Post-transplanted Treatment in the Rice Transplanted Field*

Rice seedlings were transplanted to paddy pots on June 24, 1964. Water was drained from some of the pots 5 days later, while the other pots were kept under 3cm-submerged conditions. In both cases, the effect of trifluralin (emulsion, 10 and 15 g) was examined in terms of the height of rice plants and their tillering number. (The relative table and figure were not cited in this paper.) The plant height and tillering number were found to be a little more in the water-drained pots treated with 10 and 15 g of trifluralin than in the pots of DCPA 30 g and in the control pot. From these results it may be said that trifluralin have some stimulative effect on the growth of rice plants. The result observed in the submerged pots was, however, the same as the control, though it was a little better than with PAM 300 g (PCP 40.2 g + MCP 3.6 g). Another experiment with trifluralin granule used at 10 and 15 g treated 3 days before rice transplantation and 5 days after transplantation under submerged conditions, showed no phytotoxic effect on the growth of rice plants.

Effect on Rice Yield and Surviving Weed Amounts

1. *Results in the Direct-seeded Rice Field*

(a) *Post-emergence treatment.* Solutions of trifluralin 7.5g per are, DCPA 60g, NIP 25g, PCP 75g and DBN 10g were sprayed at a rate of 10 liters per are on direct-seeded rice field 4 or 5 days after emergence in 1963. These post-emergence treatment gave the following results (Table 1 a). Trifluralin used at 7.5g showed no phytotoxic effect on rice plant, whose yield was the same as in the weeded plot, while about half of the barnyard grasses were killed. Trifluralin was thus found to have practically the same effect as DCPA, but was little effective aganist *Cyperus* spp. and *Rotala indica*. These weeds were present three times as much as in the non-weeded plots. (The growth of these weeds was depressed by gramineous weeds which were present in large number.) Therefore, the survival amount of weeds was a little more than when DCPA, NIP and PCP was used. The low effect of trifluralin above described may be partly brought about by its rather too little dose. But, since the herbicide activity of trifluralin used by the post-emergence treatment method decreased as the weeds grew larger, the above mentioned treatment was discontinued.

(b) *Pre-sowing treatment.* Pre-sowing trearment of trifluralin (emulsion and

granule, 10 and 15g per are) in 1/270 are pots in 1965, as described in the previous section, was found to bring about a high phytotoxic effect on rice plant in its early growth stage, no matter whether trifluralin was soil-incorpolated or not. In the field experiment, the amount of gramineous weeds, when trifluralin was used at 10g, was 18.7% of that found in the non-weeded plot, while the yield of rice (4 of 36 bunches had to be supplemented) was 70.3% in total weight and 81.4% in grain weight of those obtained in the weeded plot, respectively. Thus, trifluralin caused much decrease in yield. Trifluralin used at 15g reduced the amonnt of gramineous weeds by 13% and that of other weeds by 70 %, and the rice yields were 87.3% to 93% in total weight and 92.2% to 95.8% in grain weight of those obtained in weeded plot, respectively. (All the rice bunches had to be supplemented 19 days later.) In contrast to trifluralin, NIP 30g which was used as a control herbicide made at first fairly much harm on the sheath and leaf tips of rice plant. This damage was soon recovered. NIP 30g controlled barnyard grass and other weeds very well at first, but later did not suppress the growth of weeds. Consequently, the rice yields in the field experiment were 89.7% in total weight and 91.1% in grain weight of those obtained in the weeded plot, respectively.

(c) *Pre-emergence treatment.* Field experiment in 1964 was carried out as follows. Rice seeds were sown on June 15, and trifluralin (emulsion, 10g and 15 g per are) was sprayed upon the covering soil at a rate of 15 liters per are on the next day. As control herbicides, PCP wettable powder (100g) and DBN wettable powder (15g) were sprayed in the same manner. Aganist trifluralin, rice plant showed no phytotoxicity as already mentioned and, at 10 and 15g per are, the rice yields were 105% in total weight and 105 to 108% in grain weight of those obtained in the weeded plot, respectively (Table 1 b). Experiment in 1965 in the direct-seeded rice fields was made by sowing on June 15 and by spraying of the herbicide upon the covering soil on the next day. Immediately after spraying, trifluralin was incorpolated into the surface soil between the rows by a rake. As was shown in Table 1 c, trifluralin used at 15g showed a little better weed controlling effect than did NIP 30g (Plate II-A, B, C, D, Plate III-A, B). But when used at 10g it had scarcely any weed controlling activity. In the case of trifluralin used at 15g, the rice yields were 97% in total weight and 90.5% to 94% in grain weight of those obtained in the weeded plots, respectively; the results were a little better than with NIP. The early phytotoxicity recovered rapidly as was observed with NIP before sowing. At first, it controlled weeds well, but later germination of weeds increased.

2. *Results of post-planting treatments in the Paddy Rice Field*

(a) *Treatment 12 days after transplantation.* When trifluralin granule (10 and 15g per are) was applied under submerged field conditions 12 days after transplantation in 1/500 are frames in 1963, gramineous weeds were depressed by about 30% (Plate III-C, D). But trifluralin showed little controlling activity aganist

TABLE
Results of weed control experiment with trifluralin and other

a) Post-emergence treatment (1963)

Treatment		plots	Yield of rice: Total weight (g)	%	Grain weight (g)	%	Injury	Supplement ***
Trifluralin	E**	7.5	2285	105.2	803	105.7	−	0.7
DCPA	〃	60	2203	101.4	777	102.2	−	0
	〃	90	2537	116.8	857	112.7	+	0.3
NIP	〃	25	2197	101.1	770	101.3	++	2.3
	W**	25	2300	105.9	763	100.4	+	0.7
PCP	〃	75	2077	96.6	755	99.3	+	0.3
DBN	〃	10	2225	102.4	807	106.1	−	1.7
Weeded			2173	100.0	760	100.0		1.0
Non-weeded			1317	60.6	403	53.0		0.3
b) Pre-emergence treatment (1964)								
Trifluralin	E**	10	2826	105.3	966	105.0	−	2.0
	〃	15	2793	104.1	995	108.2	−	0.7
PCP	W**	100	2603	97.0	925	100.5	−	5.7
DBN	〃	15	2423	90.3	892	97.0	−	3.3
Weeded			2683	100.0	920	100.0		0
Non-weeded			975	36.3	280	30.4		0
c) Pre-emergence treatment (1965)								
Trifluralin	E**	10	3335****	92.0	928****	78.3	−	0 ****
	〃	15	3435	94.8	1073	90.5	−	0
	G**	15	3518	97.0	1125	94.9	−	0
NIP	E**	30	3348	92.3	1053	88.8	−	0.5
Weeded			3625	100.0	1185	100.0		0
Non-weeded			1980	54.6	665	56.1		0

a) Area of a plot is 1.5m². Experiment was made in three blocks repetition. Sowing, June 17; treatment of herbicides, June 25; submergence, July 11. Emergence of seedling was observed on June 21.

b) Area of a plot and number of blocks repetition were the same as a). Sowing, June 15; treatment of herbicides, June 16; submergence, July 6. Emergence of seedling was observed on June 21.

c) Area of a plot is 2.0m². Experiment was made in two blocks repetition. Sowing, June 15; treatment of herbicides, June 16; submergence, July 3. Emergence of seedling was observed on June 21.

*** Number of bunches supplemented after treatment of herbicides for the injury

Cyperus microiria. The total weight and the grain weight of rice plant were less than those obtained in the weeded frame, respectively (Table 2 a).

(b) *Treatment 5 days after transplantation.* Trifluralin (10 and 15g per are) was applied under water-drained and submerged field conditions in 1/270 are

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herbicides in the direct seeded paddy rice field

Gramineae*		Cyperaceae*		Rotala*		Others*		All weeds	
Dry weight (g)	%	Dry weight (g)	%	Dry weight (g)	%	Dry weight (g)	%	Dry weight (g)	%
Weeds (investigated on July 15)									
96.87	49.5	84.3	304.3	7.52	375.0	7.55	107.3	196.24	84.4
92.80	47.4	0.3	1.1	16.37	816.7	19.74	280.6	129.26	55.6
55.81	28.5	1.5	5.4	14.20	708.3	6.35	90.2	77.85	33.5
113.71	58.1	—	—	2.51	125.0	0.33	4.7	116.85	50.1
155.90	79.6	0.3	1.1	10.86	541.7	1.70	24.2	168.76	72.6
124.17	63.4	—	—	—	—	0.84	11.9	125.01	53.8
155.99	79.7	30.7	110.8	0.84	41.7	0.87	12.3	189.39	81.4
—	—	—	—	—	—	—	—	—	—
195.81	100.0	27.7	100.0	2.00	100.0	7.04	100.0	232.55	100.0
Weeds (investigated on July 22)									
54.7	26.5	130.3	94.0	—	—	11.7	33.3	196.7	51.7
15.8	7.6	150.3	108.4	—	—	30.1	85.8	196.2	51.6
100.5	48.6	3.3	2.4	—	—	1.7	4.8	105.5	27.7
68.2	33.0	35.1	25.3	—	—	10.0	28.5	113.3	29.8
—	—	—	—	—	—	—	—	—	—
206.8	100.0	138.6	100.0	—	—	35.1	100.0	380.5	100.0
Weeds (investigated on July 19)									
54.79	105.9	10.6	55.8	6.16	73.7	0.99	29.0	72.50	88.0
28.18	54.5	4.4	23.3	8.31	100.0	2.31	67.7	43.25	52.5
19.41	37.5	4.1	23.3	2.86	34.2	0.33	9.7	27.00	32.8
68.24	131.9	0.88	4.7	6.38	76.3	1.54	45.2	77.04	93.5
—	—	—	—	—	—	—	—	—	—
51.74	100.0	18.92	100.0	8.36	100.0	3.41	100.0	82.43	100.0

* Gramineae : *Echinochloa cruss-galli* Beauv. var. *Oryzicola* Vasing
Echinochloa cruss-galli Beauv. var. *caudata* Kitagawa
Leptochloa chinensis Nees, *Digitaria adscendens* Henr.
Cyperaceae : *Cyperus Iria* L., *Fimbristylis mililacea* Vahl
Eleocharis acicularis Roem. et Schult.
Others : *Lindernia procumbens* Philcox, *Dopatrium junceum* Hamilt.
Monochoria vaginalis Presl., *Elatine triandra* Schk.

** E : Emulsion, W : Wettable powder, G : Granule

**** 36 stands

pots 5 days after transplantation. All the gramineous weeds were killed in all the pots except for the water-drained pots in which trifluralin was used at 10g. On the other hand, the rice yield was 97 to 120% in total weight and 101 to 133% in grain weight of those obtained in the weeded pots, respectively. The

TABLE

Results of weed control experiment with trifluralin and other

a) Treatment 12 days after transplantation under submerged field conditions (1/500 are frame 1963)

Treatment plots		Yield of rice (per stand)				Gramineae*	
		Total weight (g)	%	Grain weight (g)	%	Dry weight (g)	%
Trifluralin G**	10	68.8	74.5	31.0	81.2	14.22	30.9
〃	15	77.9	84.4	32.3	84.6	16.78	36.4
MCPCA 〃	7.5	94.9	102.8	42.0	109.9	16.56	35.9
N I P 〃	21	85.1	92.2	38.4	100.5	33.27	72.2
D B N W**	7.5	82.6	89.5	36.7	96.1	17.91	38.9
〃	10	88.5	95.9	39.8	104.2	3.73	8.1
〃	15	95.6	103.6	39.0	102.1	2.45	5.3
P C P 〃	75	100.0	108.3	41.4	108.4	20.12	43.7
Prometryne G**	7.5	92.7	100.4	39.9	104.5	11.50	25.0
Weeded		92.3	100.0	38.2	100.0	18.14	39.4
Non-weeded		66.4	71.9	27.6	72.3	46.08	100.0
b) Treatment 5 days after transplantation under drained field conditions (1/270 are pot 1964)							
Trifluralin E**	10	143.9	106.0	60.9	107.8	54.95	89.1
〃	15	163.2	120.2	74.9	132.6	—	—
D C P A 〃	30	120.3	88.6	49.9	88.3	57.48	93.3
Treatment 5 days after transplantation under submerged field conditions (1/270 are pot 1964)							
Trifluralin E**	10	145.4	107.1	59.9	106.0	—	—
〃	15	132.0	97.3	57.3	101.4	—	—
MCPCA G**	7.5	152.6	112.4	64.5	114.2	13.50	22.2
PAM*** 〃		142.4	104.9	66.4	117.5	24.00	11.1
N I P 〃	21	137.6	101.3	60.3	116.7	54.73	27.8
Weeded		135.8	100.0	56.5	100.0	—	—
Non-weeded		108.7	80.0	41.4	73.3	61.65	100.0
c) Treatment 4 days after transplantation under submerged field condition (1/500 are frame 1965)							
Trifluralin E**	10	87.2	98.6	37.1	95.8	—	—
〃	15	88.1	99.6	38.1	98.4	—	—
〃	20	83.9	94.9	33.6	86.8	—	—
G**	10	89.8	101.6	38.0	97.9	1.11	11.8
〃	15	82.5	93.2	33.5	86.3	—	—
〃	20	89.8	101.6	38.6	99.5	—	—
N I P 〃	28	95.9	108.4	39.8	102.7	0.07	0.7
MCPCA 〃	7.5	86.7	98.0	39.2	101.1	3.20	34.2
PAM*** 〃		82.6	93.4	35.0	90.3	7.76	82.8
Prometryne 〃	4.5	89.9	101.6	36.7	94.6	0.45	4.8
C N P 〃	30	84.9	95.9	35.4	91.3	2.55	27.2
Submerged MCP 〃	4.2	88.9	100.4	35.9	92.5	4.20	44.8
Weeded		88.5	100.0	38.8	100.0	—	—
Non weeded		69.1	78.2	29.8	76.8	9.37	100.0

a) Experiment was made in three blocks repetition. Transplantation, June 27; treatment of herbicides, July 9 under 3cm submerged field conditions.

b) Experiment was made in two blocks repetition. Transplantation, June 25; treatment of herbicides, June 30 under water-drained and 3cm submerged field conditions.

2
herbicides in the paddy rice transplanted field

Weeds (investigated on August 12)							
Cyperaceae*		Rotala*		Others*		All weeds	
Dry weight (g)	%	Dry weight (g)	%	Dry weight (g)	%	Dry weight (g)	%
1.90	65.3	0.22	19.5	2.53	14.8	18.87	28.1
8.14	279.7	0.78	69.0	1.95	11.4	27.65	41.2
0.02	0.1	0.01	0.1	0.70	4.1	17.29	25.7
0.25	8.6	0.01	0.1	1.35	7.9	34.88	51.9
2.22	76.3	0.15	13.3	2.71	15.9	22.99	34.2
0.08	0.3	0.03	0.3	1.8	10.6	5.64	8.4
—	—	—	—	—	—	2.45	3.6
0.41	14.1	—	—	0.38	2.2	20.91	31.1
0.10	3.4	—	—	0.93	5.5	12.53	18.7
1.11	38.1	0.21	18.6	5.59	32.8	25.05	37.3
2.91	100.0	1.13	100.0	17.04	100.0	67.16	100.0
Weeds (investigated on August 21)							
—	—	3.8	25.7	6.76	11.6	65.51	48.6
—	—	3.1	21.1	5.64	9.7	8.76	6.5
61.44	384.00	3.6	24.3	70.72	121.7	193.24	143.4
Weeds (investigated on August 21)							
—	—	—	—	31.2	51.7	31.20	23.2
36.92	23075	—	—	0.12	0.2	37.04	37.2
0.52	325	0.12	0.8	0.32	0.6	14.46	10.7
—	—	—	—	0.16	0.3	24.16	19.9
—	—	0.12	0.8	0.52	0.9	55.37	41.1
—	—	2.72	18.4	3.00	5.2	5.72	4.2
0.16	100.0	14.80	100.0	58.12	100.0	134.73	100.0
Weeds (investigated on August 17)							
2.64	73.1	1.04	47.3	0.29	5.0	3.97	18.9
1.53	42.4	0.81	36.8	0.51	8.8	2.85	13.6
1.89	52.4	0.36	16.4	0.16	2.8	2.41	11.5
5.40	149.6	0.75	34.1	1.03	17.8	8.29	39.5
0.93	25.8	0.29	13.2	0.09	1.6	1.31	6.2
1.40	38.8	0.24	10.9	0.14	2.4	1.78	8.5
0.01	0.3	0.16	7.3	0.08	1.4	0.32	1.5
0.17	4.7	0.19	8.6	0.32	5.5	3.88	18.5
0.27	7.5	0.01	0.5	0.26	4.5	8.30	39.6
0.44	12.2	0.10	4.5	0.40	6.9	1.39	6.6
0.10	2.8	0.20	9.1	0.60	10.3	3.45	16.4
0.17	4.7	0.40	18.2	2.09	36.0	6.86	32.7
—	—	0.17	7.7	0.66	11.4	0.83	4.0
3.61	100.0	2.20	100.0	5.80	100.0	20.98	100.0

c) Experiment was made in three blocks repetition. Transplantation, June 29; treatment of herbicides, July 3 or 6 under 3cm submerged field conditions.
* and ** are the same as those in Table 1, respectively.
*** Component of PAM 300g is PCP 40.2g+MCP 3.6g.

results were not inferior to those obtained with DCPA 30g in the water-drained pots, MCPCA 50g and PAM 300g (PCP 40.2g + MCP 3.6g) in the submerged pots (Table 2 b).

(c) *Treatment 4 days after transplantation.* When trifluratin (emulsion and granule, 10, 15 and 20g per are) was applied under submerged field conditions 4 days after transplantation in 1/500 are frames in 1965, the rice yield was 93 to 102% in total weight and 86.3 to 99.5% in grain weight of those obtained in the weeded frame, respectively. All the gramineous weeds were killed in treated frames except for trifluralin granule used at 10g. But 26 to 73% of the weeds belonging to Cyperaceae, especially *Cyperus Iria.* were found surviving. Treatment of MCPCA 75g and PAM 300g, (PCP 40.2g + MCP 3.6g) gave a little heigher survival rate of gramineous weeds; but these herbicides were found to control Cyperaceae well (Table 2 c).

DISCUSSION

Trifluralin is a derivative of toluidine, containning fluorine as structural component. It is a selective pre-emergence herbicide for annual weeds. To this herbicide, the annual weed seedlings of Gramineae, Chenopodiaceae, Amaranthaceae, Portulacaceae, Caryophyllaceae and Aizoaceae are susceptible. But several weeds of Solanaceae, Malvaceae and Caricoideae are non-susceptible. Gramineous plants are said to be susceptible to trifluralin. This was found to be true of barnyard grass. The barnyard grass at 1-leaf stage, and that of 3-leaf stage, lower 6cm, were killed with trifluralin used at 10g and 20g, respectively. The herbicide effect is brought about at first by the absorption of trifluralin which moves from the soil surface (on which the herbicide was applied) to the superficial layer through weed roots. For this reason trifluralin had no weeding effect on the weed which root ranged in the soil layer under 2~3cm from surface. Barnyard grass has the characteristic of elongating its mesocotyl to soil surface and of germinating there. Trifluralin is present in the surface soil where its root distributes. As the result, the grass is killed. While rice seeds suffer no phytotoxicity, because trifluralin is absent in the soil layer under 2~3cm from surface where the rice seeds are sown and germinate.

Factors influencing the herbicidal activity of trifluralin in the soil were studied by Wright W. L. (6), Wright W. L. and Warren G. F. (7). They demonstrated that photochemical decomposition of the compound occured as a result of exposure to sunlight or mercury vapour lamps. It is said that herbicide applied to soil or plant surfaces may volatilize into the atomosphere or into the soil surface. They also studied volatilization of trifluralin from the surface of soil. Rate of loss was influenced by temperature, the highest rate being given above its melting point. By the application of trifluralin in a granular form the loss was much less than in spraying its emulsion. The highest rate of loss occured during the first two hours after application, with a gradual decrease thereafter. Adsorption of trifluralin by

clays were studied by the above workers. This was found to have little influence on the availability of trifluralin for germinating seeds.

The efficacy of trifluralin is lost gradually by the decomposition with sunlight and by volitilization. Incorpolation with soil prevents the loss of trifluralin and keeps the efficacy of this herbicide unweakened in field (8, 9, 10, 11, 12). In this experiment, however, the incorpolation of trifluralin with the soil in paddy rice field was inferior to the non-incorpolation in weeding effect. The reason for this seemed to be as follows. The soil of rice paddy field, even that of direct-seeded rice field, is more wet than in upland field. This may suppress the volatilization of trifluralin. In the case of non-incorpolation, the superficial soil layer where the majority of microscopic weed seeds in rice paddy field are present contains high concentration of this herbicide. Accordingly the weeding effect is high in this layer. When trifluralin is incorpolated, the concentration of the herbicide become lower in incorporated soil layer. This causes a decrease of the weeding effect. On the other hand, phytotoxicity to the rice plant increase by the incorpolation of trifluralin, owing to the extensive spreading and contacting with the root of rice plant. This phenomenon was observed in the experiments of non-incorpolation with soil in 1964 and of incorpolation with soil in 1965. For the reason above-mentioned, the weeding effect in the latter case is inferior to that observed in the former case and, as a result, the yield of rice decreased.

Trifluralin is more absorbed by roots than by leaves. It produces inhibitory effects on germination of wheat and Italian-rye-grass. Especially, the germination of the latter is almost completely suppressed. The former grew to a malformation. Trifluralin showed no inhibitory effects on germination of pea, common vetch, rape and spinach, but root growth of pea and common vetch were suppressed. In the experiment of absorption by leaf, trifluralin suppressed the growth of spinach, but no effect was observed on the growth of the others (13). As mentioned above, trifluralin is well absorbed by the root, and showed a selective phytotoxic effects on the gramineous plants.

On application of trifluralin in the paddy field, the following facts were found in this experiment. In the direct-seeded rice field, pre-sowing treatment of trifluralin produced a severe phytotoxicity on the rice seed, exerting an injurious influence on seed root. Then the seed swelled, turned light brown and died. Accordingly, this treatment was not practical. In post-emergence treatment, the phytotoxicity was not seen. But the weeding activity decreased owing to the growth of weeds. In pre-emergence treatment, the phytotoxicity was not seen and without any injurious influence of triflualin the rice seedling grew through the soil layer where the herbicide was applied. Little movement of trifluralin thus produced favourable effects on the rice plants. In the rice transplanted field, treatment 3 days before transplantation was found to be followed by the sprouting of *Rotala indica*. As a result, it was thought that the weeding activity of the herbicide decreased. In treatment 12 days after transplantation, the weeding activity toward weeds, especially the gramineous weeds, decreased owing to the

growth of these weeds. By treatment 4 or 5 days after transplantation, almost all the gramineous weeds were killed and only Cyperaceae survived. For the cultivation of paddy rice, the pre-emergence treatment in the direct-seeded rice field and the treatment 4 or 5 days after transplantation proved to be the best of the weeding methods tried with trifluralin in this study. In the paddy field where Cyperaceae and *Rotara indica* sprout much, the application in combination of trifluralin with other herbicides which kill these weeds is desirable.

SUMMARY

Trifluralin, which contains fluorine as structural component, is a selective pre-emergence herbicide for annual weeds. It is effective in weeding of the annual weed seedlings of Gramineae, Chenopodiaceae, Amaranthaceae, Portulacaceae and Aizoaceae. The gramineous weeds are especially susceptible to trifluralin. The movement of trifluralin in the soil is little, and this herbicide shows a increased weeding effect when incorpolated with soil.

The reaction of barnyard grass with trifluralin is as follows. The weeds in 1-leaf stage react slowly and die after 14 days with 10 g per are and die in 7 to 14 days with 15g per are. The weed in 2-leaf stage react rapidly and die in 14 to 20 days with 20g per are. The weed in 4-leaf stage react once, but recover later. In contrast to the weed reaction with DCPA which proceed rapidly, the weed reaction with trifluralin seems to start after the absorption of this herbicide through root and proceed slowly at the beginning, but later it is relatively rapid. Cyperaceae and Rotala indica scarcely react with trifluralin.

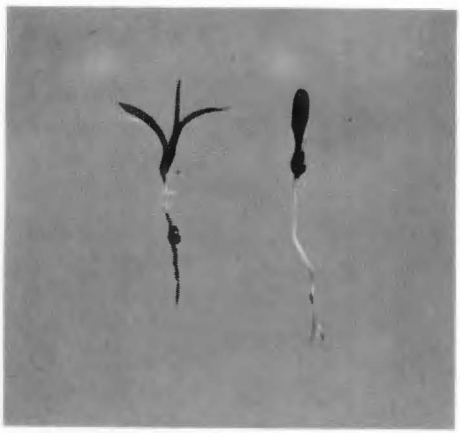
Pre-sowing treatment of trifluralin in the direct seeded rice field showed high phytotoxic effects on weeds, no matter whether the herbicide was applied in the form of emulsion or granule. Especially, the dose of 15g per are showed fairly much inhibitory effects on the germination of weeds. Gramineous weeds were reduced in weight by 10 to 20% and the other weeds by 70%. Pre-emergence treatment of trifluralin did not interfere with germination and growth of rice plants, whose yield turned out equal to or somewhat superior to that obtained in the weeded plots. Gramineous weeds were reduced by 10 to 35% and the other weeds by 25 to 60%. Post-emergence treatment of trifluralin (3 to 5 days after rice plant emergence; *Echinochloa crus-galli* in 3-leaf stage, 3 to 10cm tall, other weeds, 2 to 5cm tall) did not interfere with the growth of rice plant, whose yield was equal to or somewhat inferior to those obtained in the weeded plots. Gramineous weeds were reduced by 50%, while the other weeds was resistant to the action of Trifluralin. Trifluralin treated under submerged field conditions in the early stage (4 or 5 days after transplantation) had no phytotoxicity on rice plant, no matter whether applied in the form of emulsion or granule. The yield of rice was equal to or somewhat superior to that obtained in the weeded plots. Gramineous weeds was almost completely killed. For the other weeds, the granule was better than the emulsion, reducing the weeds by 12 to 30%. Applica-

tion of trifluralin in the intermediate stage (after 12 days) under submerged field conditions reduced gramineous weeds by 30%. The herbicide activity was considerably lower aganist the other weeds, and the rice yield decreased for this reason.

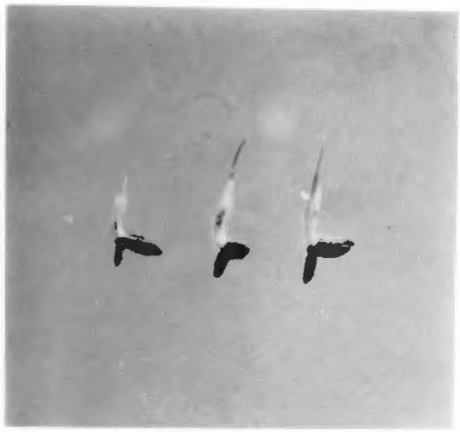
Generally speaking, trifluralin applied before direct-sowing in the fields produced much phytotoxic effects. But its application before emergence and after transplantation (early after transplantation) brought about no phytotoxicity and resulted in a good yield of rice. Trifluralin was especially effective aganist barnyard grass but little effective aganist *Cyperus microirea* (at 10 and 15g) and *Rotala indica* (at 10g). When used in paddy field by soil-incorpolation, trifluralin was not so effective in weeding.

LITERATURE CITED

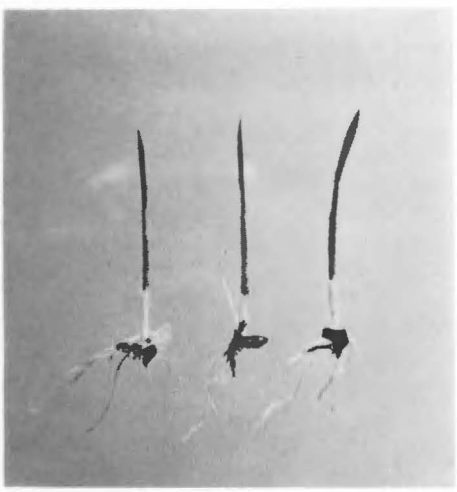
1. Thompson, W. T. 1964. Agricultural chemicals. Book II, Herbicides. 63~65, The Simmons Publishing C. California.
2. Japanese society for chemical regulation of plants, 1965. Results in experiment on the selection of herbicides in upland field for 1964. Summary of a general meeting 60~65.
3. Japanese society for chemical regulation of plants, 1965. Results in experiment on the selection of herbicides in the cultivation of vegetables and flowers for 1964. Summary of a general meeting 26—37.
4. Japanese society for chemical regulation of plants, 1966. Results in experiment on the selection of herbicides in upland field for 1964. Summary of a general meeting.
5. Chapman, W. H. 1963. Chemical weed control for commercial vegetable production. Annu. Rep. Florida agric. Exp. Stas. 311, (Weed Abstract).
6. Wright, W. L. 1964. Factors influencing the herbicidal activity of trifluralin in the soil. University Microfilms Inc.
7. Wright, W. L. and Warren, G. F. 1964. Factors influencing the herbicidal activity of trifluralin in the soil. Abst. Mtg. Weed Soc. Amer., 8, (Weed Abstract 13)
8. Schwer, J. F. and Parka, S. J. 1964. Field studies on soil incorpolation of trifluralin for pre-emergence weed control in cotton and soybeans. Abstr. Mtg. Weed Soc. Amer., 26~27, (Weed Abstract 13).
9. Shionogi & Co. 1963. On the incorpolation with soil in the pre-emergence treatment of treflan.
10. Oliver, L. R. and Frans, R. E. 1965. Influence of trifluralin rate and depth of incorpolation on cotton and soybean lateral root development. Proc. 18th sth. Weed Control Conf., 85~91, (Weed Abstract 14).
11. Thompson, J. T. and Hardcastle, W. S. 1965. Influence of incorpolated trifluralin on cotton in Georgia. Proc. 18th sth Weed Control Conf., 79—84, (Weed Abstract 14).
12. Hamilton, K. C. and Arle, H. F. 1964. Lay by application of DCPA and trifluralin in irrigated cotton. Res. Prog. Rep., west Weed Control Conf., 82—83, (Weed Abstract 14).
13. National agricultural experiment station, 1964. Studies on the activity in absorption of herbicides (treflan) by root and leaf.



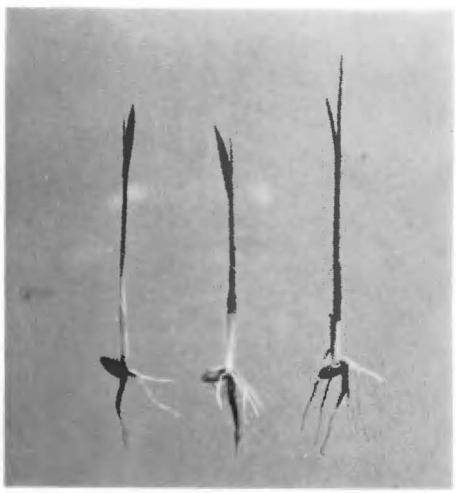
A. Barnyard grass
Pre-sowing treatment with trifluralin (granule 15g). Photographed 11 days after the treatment.



B. Paddy rice
Pre-sowing treatment with trifluralin (granule 15g). Photographed 11 days after the treatment.

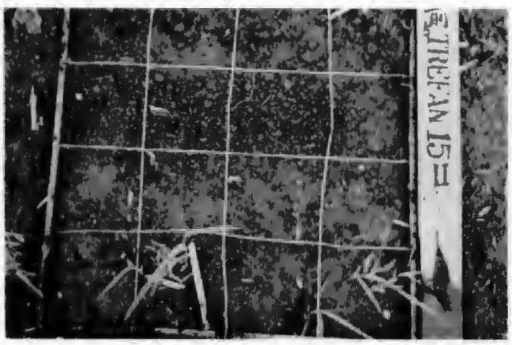


C. Paddy rice
Pre-emergence treatment with trifluralin (emulsion 15 g). Photographed 7 days after the treatment.



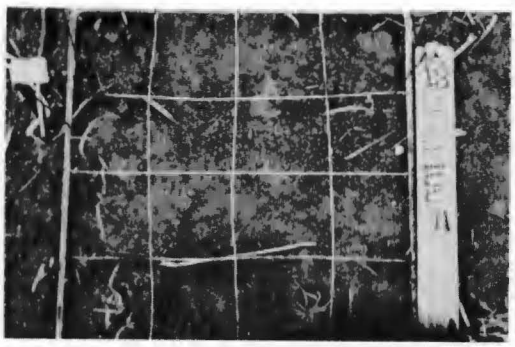
D. Paddy rice
Control (no treatment).

Plate I. Reactions of barnyard grass and paddy rice with trifluralin.

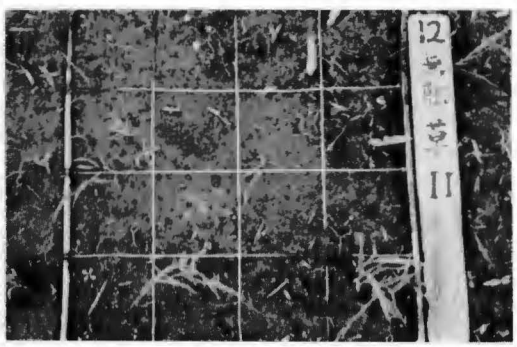


A. Pre-emergence treatment with trifiuralin (emulsion 15g). Photographed 16 days after the treatment.

B. Pre-emergence treatment with trifluralin (granule 15g). Photographed 16 days after the treatment.



C. Post-emergence treatment with DCPA (emulsion 25g). Photographed 7 days after the treatment.



D. Control (no treatment).

Plate II. weeding action of trifluralin and DCPA in the direct seeded rice field.

A. Pre-emergence treatment with trifluralin (emulsion 15g) in the direct seeded rice field. Photographed 15 days after the treatment.

B. Control (no treatment) in the direct seeded rice field.

C. Post-plonting treatment with trifluralin (granule 15g) 12 days after transplantation in the rice transplanted pot. Photographed 23 days after the treatment.

D. Control (no treatment) in the rice transplanted pot.

Plate III. Weeding action of trifluralin in the direct seeded rice field and in the rice transplanted pot.