Controlled Release of Oxyfluorfen from the Variously Complexed Formulations. III. Phytotoxicity and Efficacy of Selected Formulations as Affected by Application Rates

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數種의 結合劑型으로부터 Oxyfluorfen의 放出制御研究 III. 使用量에 따른 選拔劑型 Oxyfluorfen의 藥害・藥效評價

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ABSTRACT

Seven formulations of oxyfluorfen selected from the previous studies(4, 5) were tesed to evaluate crop injury and herbicidal efficacy on two rice cultivars and several annual and perennial weeds in a greenhouse. Each formulation at two different rates was applied to rice transplanted with 8-, 22- and 32-day old seedlings and to direct-seeded rice. Among the formulations, Elvan, Bentonite B, Chitosan and Coal Slag gave lower injury than a control formulation, Sand-coated oxyluorfen, and they did not have a problem with excessive release if active ingredient at once. Especially, the formulations of Elvan, Chitosan and Bentonite B controlled annual weeds (*Echinochloa crus-galli, Monochoria vaginalis, Cyperus difformis, and Scirpus juncoides*) and perennial weeds (*Sagittaria pygmaea, and Cyperus serotinus*). The surface structure of the formulations indicate the different possibilities of releasing of oxyfluorfen by different cracking and hole sizes, namely retension capacity.

Key words : controlled release, oxyfluorfen, complexed formulation, application rate, compatibillity

INTRODUCTION

In the previous reports, releasing models and controlled-release formulations of oxyfluorfen were selected, which were expected to have effective activity of oxyfluorfen as a rice herbicide(6, 7). These formulations included polymer-encapsulating Chitosan, Bentonite(A), Bentonite(B), Coal slag, Elvan, and Zeolite types that were adsorbed. They were estimated to show the slow-releasing of active ingredients as well as the activity of plant growth inhibition for a long period limiting the release right after treatment into water.

However, because the test plant used was rape (*Brassica campestris*) that is most sensitive to oxyfluorfen, further studies were needed whether oxyfluorfen formulations selected are safe to rice or whether they show consistent activity on rice weeds as a herbicide. In addition, a study was required to evaluate crop safety and efficacy of these formula tions under various cultural conditions of paddy rice. Therefore, the objective of this research was to evaluate effects of oxyfluorfen formulations selected previously on rice growth and herbicidal activity under various rice culture systems including transplanting of 8-day, 22-day and 32-day old seedlings, and direct seeding, which are or will be being practiced. In this study two rice cultivars, and annual and perennial weeds were used.

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MATERIALS AND METHODS

This experiment was conducted in the greenhouse of the Chonnam National University during the winter in 1991. Natural sunlight and artificial light were supplied for 11 hours(8 : 00 A.M. to 6 : 00 P. M.), and temperature was kept at 26±3℃ for day time and 18±1℃ at night. Trays(18×12×11cm) were used for all treatments.

Controlled-release formulations of oxyfluorfen used were shown in Table 1. Rice cultivars tested were "Jangsung", a Japonica type and"Samgang", a Hybrid type.

To evaluate the adaptability for various cultural systems of rice, seedlings of 8-day, 22-day and 32-day old were transplanted, and directed-seeding culture was included. Both rice cultivars were used for direct-seeding and transplanting of 8-day old seedlings, but a Japonica type rice cultivar was used for transplanting of 22-day and 32-day old seedling. Annual weeds tested for herbicidal activity were *Echinochloa crus-galli*, *Monochoria vaginalis*, *Scirpus juncoides*, *and Cyperus difformis*, and perennials were *Eleocharis kuroguwai*, *Cyperus serotinus*, *Sagittaria pygmaea*, and *Potamogeton distinctus*.

Seeds and tubers or rhizomes for annuals and perennials, respectively, were planted. Annual weeds were seeded 1.5cm deep, and perennial weeds were planted 2.0 to 2.5cm deep, except for *Cyperus serotinus* which was slant planted 1cm deep. Fifteen rice seedlings were transplanted in each tray.

All weed species were planted 3 days before rice transplanting, and the formulated products were applied at 20(standard) and 40g ai/ha(double rate), 3 days before transplanting. Each treatment was replicated three times. Soil was clay loam and $N-P_2O_5-K_2O$ was applied at 70-90-100kg/ha on the surface of the soil prior to planting. Water was kept at a constant depth of 3cm during the experiment.

Rice injury was visually evaluated at 7, 14, 28 and 40days after transplanting. Plant height at 40 and 50, and fresh weight at 50 days after transplanting were measured. Herbicidal efficacy for each weed species was visually evaluated at 14, 28, 40 and 50 days after transplanting, and fresh weight of each species was measured at 50 days after transplanting. All measurement were made based on untreated check.

Study of scanning electron micrograph on the surface structure of respective formulation was done as Hayat-method (4).

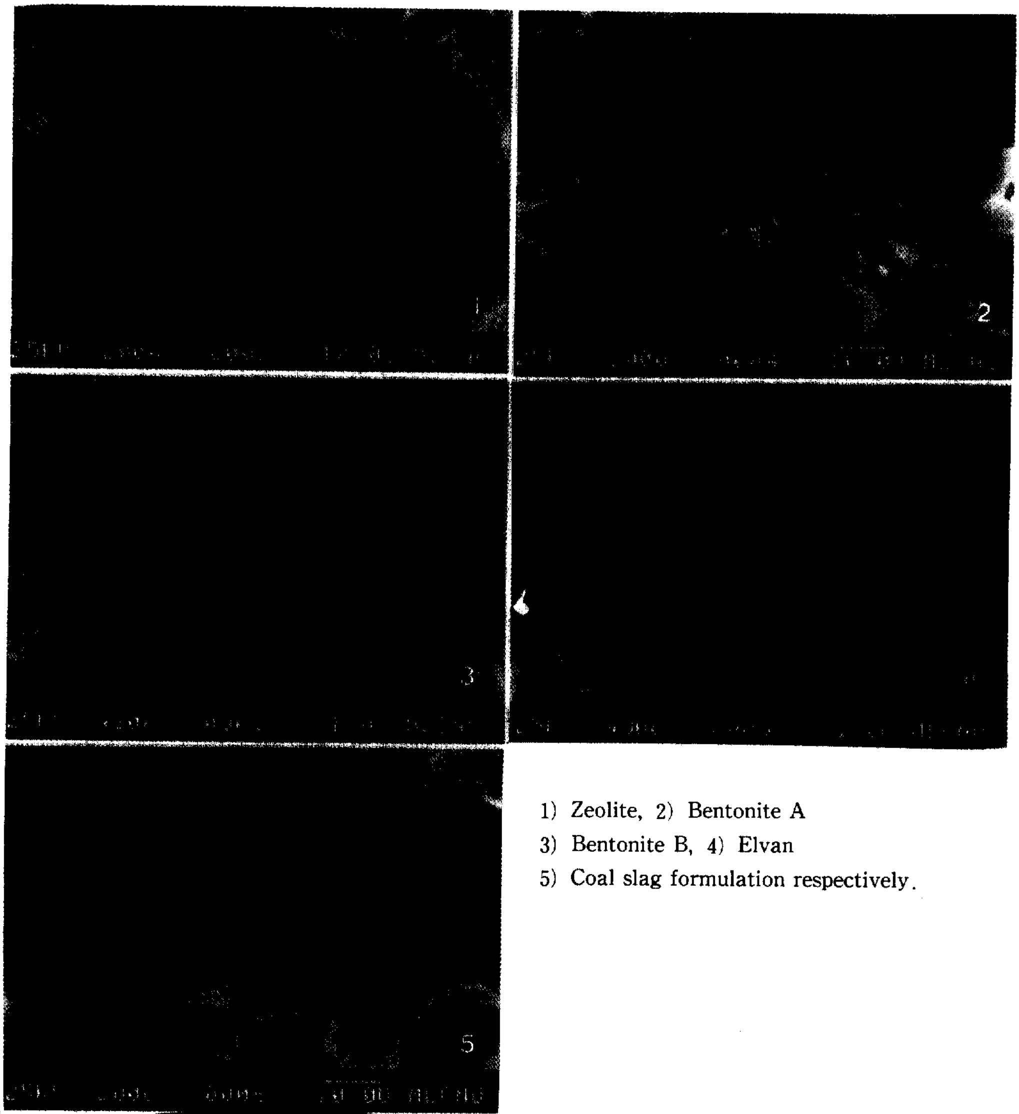
RESULTS AND DISCUSSION

1. SURFACE STRUCTURES OF THE FORMULATIONS SELECTED

The formulations, except for Chitosan formulation which was encapsulated, selected in the previous results(6, 7) were photographed to compare the morphology and surface structures of the formulations(Plate 1.). Zeolite and Bentonite A have smooth surface structures of small airspaces and crooks. But Bentonite B has many cracks with smooth surfaces, while Elvan and Coal slag have irregularly deep and samll holes on their surfaces. The differences in their surface structures can bring about the differences in the degrees of release (amount of release and speed of release) by different capacity of oxyfluorfen. Although the structure of Chitosan was not photographed, it may have similar surface structure to Bentonite B and Coal slag because Chitosan formulation was cross-linked to encapsulare the active ingredients of oxyfluorfen.

Table 1. Oxyfluorfen formulations used in the experiment.

Formulations	Type	A.I.(%)	Remarks
Bentonite-A	Adhesion	0.11	Pumice type
Bentonite-B	Adhesion	0.11	Use for Alachlor
Chitosan	Binding	14.00	-
Coal slag	Adhesion	0.11	7-40 mesh
Elvan	Adhesion	0.11	7-40 mesh
Zeolite	Adhesion	0.11	Use for Alachlor
Sand	Coating	1.00	Rohm & Haas made



1) Zeolite, 2) Bentonite A
3) Bentonite B, 4) Elvan
5) Coal slag formulation respectively.

Plate 1. Scanning electron micrographs of the surface structure of 5 differently manufactured oxyfluorfen formulations.

2. PHYTOTOXICITY

Table 2. shows the visual ratings on rice injury at 7, 14, 28 and 40 days after transplanting as affected by 7 oxyfluorfen formulations on rice plants when direct-seeded, and transplanted at 3 different ages of seedlings. Regardless of the formulations used, direct-seeded rice of both cultivars was injured slightly at 7 days after transplanting, but all plants did die completely at 14 days after transplanting. Because oxyfluorfen is not a germination inhibitor, small white plants right after germination were dead with excitation of oxyfluorfen by light during the greening stages(8). Also, it seemed that complete death occurred due to a large area for light excita tion(5).

However, 8 day old seedlings werew tall as much as 8 to 10cm at transplanting, and relative contact plant area by oxyfluorfen released in water was small, so that the injury was probably slight. That a hybrid type of rice was injured more than a Japonica type was due proably to a difference in plant growth after transplanting, where a hybrid seedling age at

Table 2. Change in visual rates (0-9 ; Check=0) on rice phytotoxicity as affected by various oxyfluorfen formulations with different application rates.

Formulations	7DAT[1/]				14DAT				28DAT				40DAT			
	S[2/]	8[3/]	25[4/]	35[5/]	S	8	25	35	S	8	25	35	S	8	25	35
	······ RATE OF 20G AI/HA ······															
Bentonite A	1(1)	2(3)	1	1	9(9)	3(4)	1	0	9(9)	2(3)	0	0	9(9)	1(2)	0	0
Bentonite B	1(1)	2(3)	1	1	9(9)	2(3)	0	0	9(9)	1(1)	0	0	9(9)	1(1)	0	0
Chitosan	1(1)	1(3)	1	1	9(9)	2(4)	1	0	9(9)	1(2)	0	0	9(9)	0(1)	0	0
Coal slag	1(1)	1(1)	1	1	9(9)	1(1)	0	0	9(9)	1(2)	0	0	9(9)	0(0)	0	0
Elvan	1(1)	1(1)	1	1	9(9)	1(0)	0	0	9(9)	0(1)	0	0	9(9)	0(0)	0	0
Zeolite	1(1)	1(2)	1	1	9(9)	1(2)	1	0	9(9)	1(1)	0	0	9(9)	1(2)	0	0
Sand	1(1)	1(1)	1	1	9(9)	1(1)	1	0	9(9)	1(2)	1	0	9(9)	1(2)	1	0
	······ RATE OF 20G AI/HA ······															
Bentointe A	1(1)	3(4)	2	1	9(9)	3(4)	2	1	9(9)	3(4)	1	1	9(9)	3(3)	1	1
Bentointe B	1(1)	2(3)	1	1	9(9)	2(3)	2	0	9(9)	2(3)	1	1	9(9)	2(3)	1	1
Chitosan	1(1)	2(3)	1	1	9(9)	2(4)	1	0	9(9)	2(2)	1	1	9(9)	1(2)	1	0
Coal slag	1(1)	1(3)	2	1	9(9)	1(1)	1	0	9(9)	1(2)	0	0	9(9)	1(1)	0	0
Elvan	1(1)	1(2)	1	1	9(9)	0(0)	0	0	9(9)	1(1)	0	0	9(9)	0(0)	0	0
Zeolite	1(1)	3(4)	2	1	9(9)	3(4)	1	1	9(9)	3(3)	1	1	9(9)	0(2)	1	0
Sand	1(1)	2(3)	1	1	9(9)	2(2)	2	0	9(9)	3(3)	1	1	9(9)	2(2)	1	0

Abb.) 1/ : Day assessed (days after transplanting), 2/ : seeds, 3/, 4/, 5/ : Seedling ages (days after seeding), respectively. Number in parenthesis indicates the data from Hybrid rice variety.

seedling age at transplanting and time after treatment increased.

For all formulations used, the injury was some what increased but was not increased so much when the application rate was increased from 20 to 40 g ai/ha. This injury could be proportional to contact areas of plants with oxyfluorfen rather than rates of application.

In general, formulations that showed the slightest injury to rice plants included Elvan, Coal Slag, Chitosan and Bentonite B, which showed crop safety similar to or greater than Sand-coated formulation that is commercialized. The similar result was also appeared in data of rice plant height at 40 and 50 days after treatment (Table 3) and of fresh weight of rice at 50 days after transplanting (Table 4).

The formulaions that showed high safety as in Table 2 gave plant height and fresh weight of rice similar to or greater than the Sand-coated formulation. In particular, the formulation of Elvan showed high safety to rice seedlings of all ages tested. This was propably because Elvan has spatial lattices and adsorptive ability for oxyfluorfen penetration, and then has ability to slowly release of oxyfluorfen by exchanging with water molecules. Especially, oxyfluorfen has different properties from other hydrophilic herbicides (2, 9).

However, Bentonite and Coal slag had a characteristic inducing rice injury to rice seed and 8-day old seedlings. An important thing was that older rice seedlings treated with high rates were prominently bleached but they grew rapidly after being recovered, so that rice seedlings treated with high rates produced taller plant height and greater fresh weight than those treated with low rates at 50 days after treatment. The similar results were observed in the other field experiments by the authors (4) or in the study of acifluorfen by Murphy *et al* (12).

3. HERBICIDAL EFFICACY

According to Beste *et al*. (1), oxyfluorfen is active on annual dicotyledons and grass weed species when applied preemergence or postemergence. In this study, the reason that oxyfluorfen was applied at 20 and 40 g ai/ha was because this range of application rates was selectively active beween rice and weeds including barnyardgrass and *Monochria vaginalis* in the transplanted rice previously (7). Herbicidal activity of each oxyfluorfen formulation for 4 annuals and 3 perennials applied at 20 and 40 g ai/ha is shown in Table 5.

Although control of *Scirpus juncoides* was not enough at low rates at 40 to 50 days after transplanting, *Echinochloa crus-galli*, *Monochoria vaginalis*

Table 3. Change in plant height(cm) of rice as affected by various oxyfluorfen formulations with different application rates.

Formulations	S[1]		8[8]		25[3]		35[4]	
	40[5]	50[6]	40	50	40	50	40	50
	..................RATE OF 20G AI/HA							
Bentonite A	0(0)	0(0)	22(9)	32(12)	21	26	24	28
Bentonite B	0(0)	0(0)	22(10)	29(14)	22	24	26	29
Chitosan	0(0)	0(0)	26(9)	31(12)	24	25	25	29
Coal slag	0(0)	0(0)	23(11)	35(12)	19	27	25	26
Elvan	0(0)	0(0)	25(13)	33(15)	22	25	23	30
Zeolite	0(0)	0(0)	26(10)	25(13)	22	27	25	29
Sand	0(0)	0(0)	24(11)	29(13)	22	26	23	29
Check	16(9)	20(10)	25(11)	32(17)	22	29	23	33
	..................RATE OF 40G AI/HA							
Bentonite A	0(0)	0(0)	17(8)	26(12)	21	29	24	30
Bentonite B	0(0)	0(0)	21(9)	30(15)	22	29	25	30
Chitosan	0(0)	0(0)	25(10)	30(15)	21	28	27	36
Coal slag	0(0)	0(0)	28(11)	31(16)	24	32	27	33
Elvan	0(0)	0(0)	25(12)	34(18)	25	34	26	34
Zeolite	0(0)	0(0)	20(9)	30(13)	23	31	23	31
Sand	0(0)	0(0)	23(11)	30(13)	23	28	28	33
Check	16(9)	20(10)	25(11)	32(17)	22	29	23	33

Abb.) : Refer to table 2.

Table 4. Variation in fresh weight(g) of shoots per plant at 50DAT as affected by various oxyfluorfen formulations with different application rates.

Formulations	20G AI/HA				40G AI/HA			
	S	8	25	35	S	8	25	35
Bentonite A	0(0)	0.44(0.21)	0.49	0.71	0(0)	0.46(0.45)	0.73	0.78
Bentonite B	0(0)	0.55(0.35)	0.49	0.68	0(0)	0.58(0.45)	0.63	0.78
Chitosan	0(0)	0.62(0.42)	0.62	0.75	0(0)	0.60(0.60)	0.63	0.78
Coal slag	0(0)	0.54(0.49)	0.54	0.75	0(0)	0.75(0.64)	0.68	0.79
Elvan	0(0)	0.68(0.54)	0.67	0.75	0(0)	0.71(0.77)	0.78	0.79
Zeolite	0(0)	0.58(0.43)	0.62	0.69	0(0)	0.68(0.56)	0.70	0.73
Sand	0(0)	0.53(0.51)	0.67	0.70	0(0)	0.67(0.46)	0.64	0.79
Check	0.36(0.2)	0.65(0.43)	0.71	0.71	0.71(0.4)	0.61(0.48)	0.73	0.76

Abb) : Refer to Table 2.

and *Cyperus difformis* were completely controlled by all formulations used even at low rates, which agreed with other results(7, 16). Espercially, Chitosan, Bentonite B and Zeolite that injued rice gave better control of *Scirpus juncoides* than Elvan formulation that was safe to rice. Therefore, it was thought that both safety and efficacy should be considered in determination of appropriate formulations. Similar trends were seen in control of *Sagittaria pygmaea and Cyperus serotinus*. Improved control of *Scirpus juncoides*, *Sagittaria pygmaea* and *Cyperus serotinus* by oxyfluorfen at 40g ai/ha (double rate) was probably due to delayed emergence and uneven growth(16) of weeds and increased residual activity at high rates. On the other hand, control of *Potamogeton distinctus* was not satisfied even at high rates because of delayed emergence and uneven growth more than other perennials.

Among the formulations used, control of perennial weeds was lower by Elvan and Coal slag than by other formulations, but this was overcome by increase rates of application. On the basis of fresh weight production of weeds at 50 days after trans planting, all formulations gave better control of

Table 5. Change in visual rates(0-9 ; check=0) on weeding efficacy as affected by various oxyfluorfen formulations with different application rates.

Formulations	EC[1]				MV[2]				CD[3]				SJ[4]				SP[5]				PD[6]				CS[7]			
	14[8]	28[9]	40[10]	50[11]	14	28	40	50	14	28	40	50	14	28	40	50	14	28	40	50	14	28	40	50	14	28	40	50
RATE OF 20G AI/HA																												
Bentonite A	9	9	9	9	9	9	9	9	9	9	9	9	9	9	7	8	9	9	5	7	1	1	4	2	9	7	7	5
Bentonite B	9	9	9	9	9	9	9	9	9	9	9	9	9	9	8	8	9	9	9	9	0	1	5	3	9	5	8	7
Chitosan	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	8	8	0	1	5	0	9	2	8	7
Coal slag	8	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	5	7	1	1	5	2	7	4	6	3
Elvan	7	9	9	9	9	9	9	9	9	9	9	9	9	9	8	8	9	9	8	6	1	1	7	4	8	3	7	6
Zeolite	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	8	9	9	8	9	1	1	5	0	9	1	7	5
Sand	6	7	7	7	9	9	9	9	9	9	9	9	9	9	8	8	9	9	9	8	2	1	3	1	1	1	3	2
RATE OF 40G AI/HA																												
Bentonite A	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	2	3	8	5	8	6	8	6
Bentonite B	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	4	3	7	6	9	3	8	8
Chitosan	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	8	8	2	4	7	4	9	3	8	8
Coal slag	9	9	9	9	9	9	9	9	9	9	9	9	9	9	8	9	9	9	7	9	2	2	6	1	9	8	8	8
Elvan	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	2	2	7	3	9	2	8	8
Zeolite	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	8	9	9	9	9	4	1	5	1	8	1	8	8
Sand	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	1	1	4	0	9	1	8	7

Abb) 1/ : *Echinochloa crus-galli*, 2/ : *Monochoria vaginalis*, 3/ : *Cyperus difformis*, 4/ : *Scirpus juncoides*, 5/ : *Sagittaria pygmaea*, 6/ : *Potamogeton distinctus*, 7/ : *Cyperus serotinus*, 8/, 9/, 10/, 11/ : Day assessed (days after transplanting).

Table 6. Variation in fresh weight(g/pot) of emerged weeds at 50 DAT as affected by various oxyfluorfen formulations with different application rates.

Formulations	Annuals					Perennials				Total Efficacy(%)[3]
	EC	MV	CD	SJ	%[1]	SP	PD	CS	%[2]	
RATE OF 20G AI/HA										
Bentonite A	0	0	0	0.04	99.0	1.05	1.23	1.74	50.4	68.0
Bentonite B	0	0	0	0.04	99.1	0	1.11	0.30	82.6	88.6
Chitosan	0	0	0	0.01	99.8	0.12	1.77	0.30	73.0	82.7
Coal slag	0.01	0	0	0.01	99.6	0.60	1.26	2.34	48.2	66.8
Elvan	0.02	0	0	0.05	98.5	0.60	1.08	1.20	64.4	76.8
Zeolite	0	0	0	0.01	99.8	0.30	1.77	1.38	58.4	72.7
Sand	0.41	0	0	0.04	90.2	0	1.20	2.61	53.0	66.4
Check	4.29	0.02	0.03	0.25	0	2.31	1.35	4.44	0	0
RATE OF 40G AI/HA										
Bentonite A	0	0	0	0	100.0	0	0.54	1.56	74.1	83.5
Bentonite B	0	0	0	0	100.0	0.03	0.39	0.33	90.7	94.1
Chitosan	0	0	0	0	100.0	0.18	0.63	0.75	80.7	87.7
Coal slag	0	0	0	0	100.0	0.42	1.59	0.15	73.3	83.0
Elvan	0	0	0	0.02	99.6	0	0.84	0.72	80.7	.87.6
Zeolite	0	0	0	0	100.0	0	1.05	1.32	70.7	81.3
Sand	0	0	0	0.04	99.1	0	1.53	1.80	58.9	73.4
Check	4.29	0.02	0.03	0.25	0	2.31	1.35	4.49	0	0

Abb) Name of weeds : refer to Table 5. 1/ : Efficacy(%) on annuals sub-total, 2/ : Efficacy(%) on perennials sub-total, and 3/ : Efficacy(%) on total weed species to the check(0%), respectively.

annual weeds than the Sand-coated formulation. This effective control of annual weeds was similar in both rates of application(20 and 40 g ai/ha).

However, control of perennial weeds was low with the treatment of Bentonite B and Chitosan. Coal slag showed low and erratic perennials, implying that because structure of Coal slag is unstable, release of oxyfluorfen may be irregular and great at once. As the results, the formulation that gave high control of weeds and low injury to rice were Elvan, Chitosan, and Bentonite B, which may be practicable.

Oxyfluorfen, a 3'-substituted diphenyl ether compound such as nitrofen and chlornitrofen(15), has a mode of action leading to chlorosis and necrosis by peroxidation selectively among plant species, and it can be applied preemergence or postemergence(1).

Because this study was tried to develop oxyfluorfen as a rice herbicide at extremely low rates of application, the evaluation was focused on the interaction between herbicide and soil particles in the water to find out better granular formulations. Peterson (13) reported that granular formulation after application into the water must be released more than 20% in 30 seconds. But Guh *et al*. (6) suggested that excessive release of herbicides at a time right after application into the water should be controlled to increase efficacy and to decrease crop injury. The results in this study imply that the formulations used controlled weeds for a long period of time by whether they released excessively right after application to keep herbicidal activity or whether they showed a characterisitic of controlled release for a long time(Plate 1.).

Therefore, the formulations of Elvan, Chitosan, Bentonite and Coal slag injured rice slightly and showed promise for reducing crop injury by decrease rate of release or by decreased amount of release more than Sand-coated oxyfluorfen. This was probably because Sand, Zeolite, Bentonite, Elvan and Coal slag have different spatial lattices in their structures(Plate 1.). Also, Chitosan limits momentary releasing by encapsulating. However, this is closely related with water solubility of oxyfluorfen, so that we think to be conducted further studies on this aspect. However, injury differences among formulations were not always due to differences of amount of release because crop injury was not doubled when application rate was increased from 20 to 40g/ha.

In addition, it is known that oxyfluorfen is rapidly adsorbed to soil particles and organic matter, so that further study is required on soil adsorption and release in water of oxyfluorfen to find out the characteristics of slow-releasing phenomena. Nevertheless, Bentonie B, Chitosan and Elvan were promising formulations that gave good control of all annual weeds tested and of perennial weed although perennials emerged slowly and erratically. In a study with oxyfluorfen(2% Emulsifiable Concentrate) in rice by Zhaoxiang(16), most annuals were controlled at 9 to 18g/ha of oxyfluorfen, but double rates of application were required to control *Scirpus spp*. and *Alismas* spp. because of delayed emergence. Rice injury was negligible even at application rates of 36 to 54 g/ha when applied 5 days after transplanting with rice seedling of 15cm plant height and of 30-days old. This results was similar to the results from this study. However, Elvan formulation controlled all annual weeds when applied 20g/ha, and at 40g/ha rice injury was slight, so that this formulation was improved greater than Sand-coated formulation or 2% emulsifiable Concentrate in terms of weed control and rice injury. Also, the formulations of Coal slag, Bentonite B and Chitosan can be improved by reexamining the rate and amount of release in relation with internal and external structure of binders (13).

摘　要

筆者들의 前報(6, 7)에서 選拔하였던 Oxyfluorfen의 6劑型을 溫室條件下에서 2 水準으로 供試하여 苗令이 다른 直播 및 移秧벼의 主要 雜草種에 대한 藥害 및 藥效를 검토하였다. 供試劑型 가운데 對照劑型인 sand coated oxyfluorfen보다 藥害가 적어 一時 過多 溶出의 問題가 解消된 劑型으로는 Elvan, Bentonite B, Chitosan 및 Coal Slag 劑型을 들 수 있었고, 당시 이들 가운데 除草效果가 一年生(피, 물달개비, 알방동사니, 올챙고랭이) 전반과 일부 多年生(올미 및 너도방동사니)에서 認定되었던 것으로는 Elvan, Chitosan, Bentonite B 劑型을 들 수 있었다.

각 제형에 대한 SEM연구 결과, 약효 지속 및 약해 감소의 영향은 각 제형이 갖는 표면구조상의 차이, 즉 표면 균열이나 다공성 및 공극 깊이 등에 따라 달라지는 것으로 보였다.

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