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CONTROL OF WEEDS IN TRANSPLANTED RICE IN TAIWAN AS AFFECTED BY VARIOUS RATES AND TIMES OF APPLYING GRANULAR BENTHIOCARB AND BUTACHLOR[1]

W. L. Chang and S. K. De Datta[2]

INTRODUCTION

Weeds in rice fields are traditionally controlled by hands in Taiwan for many years. It has been estimated that about 40 and 30 man-days are needed to provide good control of weeds for one hectare of paddy field by hand weeding in the first and second crops of rice, respectively (Chang 1965). In recent years, however, due largely to the increasing cost of labor caused by the rapid industrial development, chemical weed control has become increasingly popular among rice growers. As a result, the acreage of transplanted rice controlled with herbicides has been increasing steadily. In 1966, only 485 ha out of 788,635 ha of rice field was controlled with chemicals (Chang 1969) but it increased to 15,838 ha in 1970 (Chang 1971 a), and it is increasing very rapidly.

Benthiocarb, S-(4-chlorobenzyl)-N, N-diethyl thiolcarbamate and Butachlor, N-(butoxymethyl)-2-chloro-2', 6'-diethyl acetanilide are two new herbicides officially recommended in 1970 as commercial herbicides for transplanted rice in Taiwan (Lin 1971). These two chemicals provided adequate control of weeds without causing significant damage to rice plants in both the first and second crops (Chang 1971 b). Unfortunately, they are also the most expensive herbicides now commercially available in Taiwan. In Taiwan, Benthiocarb costs US$ 25 to 30 and Butachlor costs US$ 20 per ha at the recommended rate of 30 kg formulated product per ha. These two herbicides cost more than Nitrofen which is the most widely used granular herbicide in Taiwan. Nitrofen costs only US$ 15 per ha in Taiwan. In order to make Benthiocarb and Butachlor more acceptable herbicides for transplanted rice, it is imperative that substantial reduction in the cost of chemicals should be made, and one possibility of reducing cost is through the manipulation of rate and time of applying these herbicides. This experiment was designed primarily to furnish information concerning the effects of application rates and times on the performance of Benthiocarb and Butachlor for transplanted rice.

MATERIALS AND METHODS

The field experiment was conducted in the first crop of 1971 at the Wan-tien-li farm of the Chiayi Agricultural Experiment

[1] Cooperative experiment between the Chiayi Agricultural Experiment Station of the Taiwan Agricultural Research Institute, Chiayi, Taiwan and The International Rice Research Institute, Los Banos, Philippines.

[2] Agronomist, the Chiayi Agricultural Experiment Station, and Agronomist, The International Rice Research Institute.

Station, Chiayi, Taiwan. The predominant soil type of the experimental plots is clay loam. The surface soil has pH value of 5.6 and contains 1.8% organic matter. Chianung 242, a leading ponlai commercial variety in Taiwan, was subjected to 22 weed control treatments as listed in Table 1. The variables included two granular herbicides, Benthiocarb and Butachlor; five application rates, 1.0, 1.5, 2.0, 2.5 and 3.0 kg per ha of active ingredient; and two times of application, 6 and 15 days after transplanting. Unweeded and handweeded treatments were also included for comparison. The experiment was laid out in a randomized complete block design with four replications. The plot size was 2 x 4 m and consisted of 8 rows. The plant spacing was 25 x 20 cm with approximately 5 seedlings being transplanted at each hill. Ammonium sulphate, calcium superphosphate and potassium sulphate were used as carriers of N, P_2O_5 and K_2O which were applied at the rate of 120, 60 and 60 kg per ha, respectively. Half of nitrogen and total amount of both phosphate and potassium were basic dressed before transplanting and the balance of nitrogen was top-dressed at 30 days after transplanting. Approximately 3 to 5 cm of shallow water was maintained until crop maturity. Other management practices, such as disease and insect controls, were at the optimum levels.

Seeds of *Echinochloa crusgalli*, *Monochoria vaginalis*, and *Cyperus difformis* were sown right after transplanting at the rate of 2-3 kg per ha to ensure uniform initial weed densities in all plots. Levees were constructed around each plot. The effectiveness of the herbicide treatments in controlling weeds and their toxicity to rice were rated based on arbitrary visiual scale of 1 to 5 at 10, 20, 30 and 60 days after the application of herbicides. Scale 1 indicates either excellent weed control or no rice toxicity and scale 5, no control of weeds or complete kill of rice plants. Plant height and number of tillers per hill were measured at 50 days after transplanting. The grain yield and number of panicles per hill data were subjected to the analyses of variance and the treatment means were compared by using Duncan's multiple range test. Climatic data during the period from transplanting to 60 days after transplanting are presented in Table 2. The field experiment was transplanted in February 8, 1971 and harvested in June 14, 1971.

RESULTS AND DISCUSSION

Weed Control as Affected by Rates and Times of Application

Weed control ratings made at various stages of rice growth are presented in Table 3. Granular Benthiocarb and Butachlor gave good control of weeds at any rate of herbicides applied before emergence of weeds (6 days after transplanting). Pre-emergence application was originally scheduled at 4 days after transplanting but it was delayed for two days because of the exceptionally low temperature (Table 2) prevailing right after transplanting. There were practically no difference in weed control ratings between the rates of 1.0 kg per ha of active ingredient and 3.0 kg/ha a.i. for both herbicides. However, when granular Benthiocarb and Butachlor were applied at 2–3 leaf stage of grassy weeds or 15 days after transplanting, weed control effect of both herbicides was considerably reduced and weed control effect improved steadily with the increase in the rates of application. Good control of weeds was obtained only at the

rates higher than 2.0 kg/ha a.i. for Benthiocarb and 1.5 kg/ha a.i. for Butachlor when ratings were made 10 days after application of herbicides or 25 days after transplanting. This suggests that both granular Benthiocarb and Butachlor perform best when applied as pre-emergence to the weeds. Experiment conducted at this station in 1970 also revealed that Benthiocarb applied as pre-emergence treatment controlled weeds effectively but its weed control effect was not satisfactory when applied after the emergence of weeds (Chang 1971 b). A similar observation was also made by Chang *et. al.* (1971) in their experiment conducted at northern part of Taiwan. In a typical tropical situation however, De Datta (1970) reported that these two chemicals performed well both as pre-emergence and as post-emergence to weeds in transplanted rice.

Table 3 also shows that weed control ratings increased slightly with stages of rice growth. However, the magnitude of the increase was relatively small to be of any practical significance, indicating that weed control effect of both Benthiocarb and Butachlor can last for nearly 60 days after the application of herbicides. It can also be seen that weed control ratings associated with Butachlor were slightly smaller than those of Benthiocarb suggesting that Butachlor appears to provide better control of weeds than Benthiocarb in the first crop season.

An examination of the unweeded plots 50 days after transplanting revealed that the predominant weeds present in the experimental field were *Monochoria vaginalis, Cyperus difformis, Rotala indica, Echinochloa crusgalli, Lindernia pyxidaria,* and *Marsilea quadrifolia* in the order of their importance in terms of population density. Obviously, both Benthiocarb and Butachlor are capable of controlling a rather wide spectrum of weeds particularly in the early application for transplanted rice.

Rice Toxicity as Affected by Rates and Times of Application

Rice toxicity ratings made at various growing stages of rice are given in Table 4. It was observed that granular Benthiocarb and Butachlor caused slight injury to rice at the rates above 2.0 kg/ha a. i. and 1.5 kg/ha a.i. respectively in the pre-emergence application. Rice toxicity was manifested mostly by the stunting growth of rice plants. Chang *et al.* (1971) also reported that slight to moderate toxicity of rice was recorded for Butachlor applied 4 days after transplanting at the rate of 3.0 kg/ha a. i. in the second crop of 1969. Rice toxicity was not evident when ratings were made at 20 and 30 days after application of herbicides for Benthiocarb and Butachlor, respectively, indicating that rice injury caused by the herbicides can be recovered rather quickly. Thus, practically no trace of chemical injury was visible when the growth of rice plants was measured at late tillering stage or 50 days after transplanting (Table 5.). Plant height and number of tillers per hill of herbicide treatments did not differ appreciably with those of handweeding control. There was no evidence of rice toxicity in the post-emergence application at any rate of granular Benthiocarb and Butachlor applied after emergence of weeds.

Grain Yield as Affected by the Rated and Times of Application

The growth of rice was normal in the experimental field and except unweeded

treatment, grain yields exceeded 6,000 kg per ha which is typical for Chianung 242 for the first crop at this station (Table 6). All herbicide treatments outyielded unweeded control. The difference was significant at the 1% level (Table 7). However, grain yields of the herbicide treatments were not significantly different from that of hand-weeded treatment. An examination of the number of panicles per hill revealed that treatments with higher grain yield were generally associated with more panicles per hill (Table 6), indicating that the increase in the number of panicles per hill has contributed to the increase of grain yield. The highest grain yield of 7,368 kg per ha was obtained by the early application of granular Butachlor at the rate of 2.5 kg per ha of active ingredient. Grain yield of unweeded control was 31.4% lower than that of hand-weeded control, indicating that heavy infestation of weeds has caused substantial reduction in grain yield of rice.

When averaged across all rates and times, granular Benthiocarb gave 5,501 kg per ha which was similar to 5,430 kg per ha with Butachlor (Table 7). Different rates of granular Benthiocarb did not result in significantly different yields but granular Butachlor applied at the rate of 1.0 kg/ha a. i. yielded significantly lower yields than both early and late applications at the rates of 2.5 and 2.0 kg/ha a. i., respectively. The herbicides × application rates interaction was significant at the 5% level. (Table 7). When averaged over rates, early application of granular Benthiocarb gave 114 kg per ha or 2.1% more grain yield than late application whereas granular Butachlor applied before emergence of weeds yielded 180 kg per ha or 3.3% more than applied after emergence of weeds. It appears that granular Butachlor is slightly more sensitive than Benthiocarb with respect to time of application. The difference between times of application was, however, not large enough to attain significance.

Based on the weed control, rice toxicity, and grain yield data obtained in this experiment, it seems probable that pre-emergence application of both granular Benthiocarb and Butachlor might bring in a better performance for transplanted rice. The application rate of Benthiocarb can possibly be reduced from the presently recommended rate of 3.0 kg/ha a. i. to 1.5 kg/ha a. i. without sacrificing appreciably its weed control effect and grain yield. Accordingly, the cost of Benthiocarb might be brought down to the level of approximately US$ 12.5 to 15.0 per ha which is considered acceptable to local rice growers. As for granular Butachlor, the application rate may well remain at the recommended rate of 1.5 kg per ha of active ingredient. However, in rice fields not heavily infested with weeds, a satisfactory weed control should be possible with Butachlor applied at the rate of 1.25 kg per ha of active ingredient. At 1.25 kg/ha a. i., the cost of applying granular Butachlor could also be reduced to around US$ 16 which is comparable to that of Nitrofen, a popular but less efficient herbicide used in Taiwan.

SUMMARY

Rates and times of applying granular Benthiocarb and Butachlor for transplanted rice was evaluated in the first crop of 1971 at the Chiayi Agricultural Experiment Station. Granular Benthiocarb and Butachlor gave good control of weeds at any rate of herbicides applied before emergence of weeds or at 6 days after transplanting.

When these herbicides were applied at 2-3 leaf stage of grassy weeds or at 15 days after transplanting however, the control of weeds with either herbicide was considerably reduced. Weeds control effect improved steadily with the increase in the rates of application. Adequate control of weeds was obtained only with the rates exceeding 2.0 kg per ha of active ingredient. Rice plants were slightly injured in the pre-emergence application of granular Benthiocarb and Butachlor at the rates higher than 2.0 kg per ha of active ingredient. There was no evidence of rice toxicity in the post-emergence application of the herbicides. At lower but effective rates of applying both Benthiocarb and Butachlor, the cost of weed control is comparable to that of Nitrofen which is widely used in Taiwan. More efficient control of weeds for transplanted rice appears likely in Taiwan with either Benthiocarb or Butachlor.

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Table 1. Treatment of rate and time of herbicide application, first crop, 1971.

Treatment number	Herbicide	Formulation concentration %	Quantity of formulation (kg/ha)	Application rate (kg/ha ai)	Application time
1	Benthiocarb	10	10	1.0	6 DAT
2	"	"	15	1.5	"
3	"	"	20	2.0	"
4	"	"	25	2.5	"
5	"	"	30	3.0	"
6	"	"	10	1.0	15 DAT (2-3 lsg)
7	"	"	15	1.5	"
8	"	"	20	2.0	"
9	"	"	25	2.5	"
10	"	"	30	3.0	"
11	Butachlor	5	20	1.0	6 DAT
12	"	"	30	1.5	"
13	"	"	40	2.0	"
14	"	"	50	2.5	"
15	"	"	60	3.0	"
16	"	"	20	1.0	15 DAT (2-3 lsg)
17	"	"	30	1.5	"
18	"	"	40	2.0	"
19	"	"	50	2.5	"
20	"	"	60	3.0	"
21	Untreated control	–	–	–	–
22	Handweeded control	–	–	–	–

DAT = Days after transplanting.
lsg = Leaf stage of the grassy weeds.

aTable 2. Climatic data during the early growing stages of the first crop, 1971.

Days after transplanting	Rainfall (mm)	Number of rainy days	Number of sunshine hours	Relative humidity (%)	Temperature (°C) Maximum	Minimum	Mean
1 – 5	3.4	2	15.8	82	22.4	14.7	18.6
6 – 10	0	0	16.0	76	22.7	14.2	18.5
11 – 15	0	0	17.1	67	27.3	16.4	21.9
16 – 20	12.5	2	6.0	82	22.4	16.6	19.5
21 – 25	2.0	1	7.4	74	24.0	16.3	20.2
26 – 30	1.4	1	1.1	85	20.6	14.8	17.7
31 – 35	0	0	8.8	69	21.0	13.1	17.1
36 – 40	0	0	22.9	61	24.2	14.2	19.2
41 – 45	0	0	19.1	55	26.4	14.4	20.4
46 – 50	0	0	19.3	56	29.0	18.4	23.7
51 – 55	7.9	1	8.4	73	28.5	21.2	24.9
56 – 60	9.5	1	8.2	76	28.4	20.4	24.4

Table 3. Weed control ratings, first crop, 1971.

Herbicide	Rate (kg/ha)	10 DAA		20 DAA		30 DAA		60 DAA	
		6 DAT	15 DAT	6 DAT	15 DAT	6 DAT	15 DAT	6 DAT	15 DAT
Benthiocarb	1.0	1.4	3.1	1.7	3.2	1.8	3.6	1.9	2.7
	1.5	1.4	3.0	1.5	2.9	1.7	3.2	1.7	2.4
	2.0	1.3	2.3	1.5	2.2	1.7	2.1	1.7	1.8
	2.5	1.2	2.1	1.4	1.8	1.5	1.8	1.5	1.7
	3.0	1.1	1.7	1.3	1.5	1.4	1.5	1.4	1.4
Butachlor	1.0	1.3	2.5	1.3	3.0	1.4	3.3	1.7	3.0
	1.5	1.2	2.1	1.2	2.3	1.2	2.7	1.3	2.2
	2.0	1.1	2.0	1.1	2.0	1.1	2.3	1.2	2.2
	2.5	1.0	1.8	1.0	1.8	1.0	2.0	1.1	1.8
	3.0	1.0	1.6	1.0	1.6	1.0	1.7	1.1	1.5
Unweeded control	–	5.0		5.0		5.0		5.0	
Hand weeding	–	1.0		1.0		1.0		1.0	

DAA = Days after application (date of weed control ratings).
DAT = Days after transplanting (Time of herbicide application).

Table 4. Rice toxicity ratings, first crop, 1971.

Herbicide	Rate (kg/ha)	10 DAA		20 DAA		30 DAA		60 DAA	
		6 DAT	15 DAT	6 DAT	15 DAT	6 DAT	15 DAT	6 DAT	15 DAT
Benthiocarb	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
	1.5	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
	2.0	1.1	1.0	1.0	1.0	1.0	1.0	1.0	1.0
	2.5	1.1	1.0	1.0	1.0	1.0	1.0	1.0	1.0
	3.0	1.2	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Butachlor	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
	1.5	1.1	1.0	1.0	1.0	1.0	1.0	1.0	1.0
	2.0	1.1	1.0	1.0	1.0	1.0	1.0	1.0	1.0
	2.5	1.2	1.0	1.1	1.0	1.0	1.0	1.0	1.0
	3.0	1.2	1.0	1.1	1.0	1.0	1.0	1.0	1.0
Unweeded control	–	1.0		1.0		1.0		1.0	
Hand weeding	–	1.0		1.0		1.0		1.0	

DAA = Days after application (date of rice toxicity ratings).
DAT = Days after transplanting (Time of herbicide application).

Table 5. The growth of rice plants recorded at late tillering stage, first crop, 1971.

Herbicide	Rate (kg/ha)	Flant height (cm)		Number of tillers per hill	
		6 DAT	15 DAT	6 DAT	15 DAT
Benthiocarb	1.0	53.7	51.3	28.9	26.9
	1.5	50.2	51.6	29.5	25.6
	2.0	52.1	53.6	26.6	28.4
	2.5	53.5	52.9	29.6	28.1
	3.0	53.0	51.4	28.5	29.3
Butachlor	1.0	53.1	51.9	27.7	28.0
	1.5	54.9	53.6	29.7	27.6
	2.0	53.5	50.8	29.7	27.1
	2.5	51.5	51.7	27.0	27.9
	3.0	53.4	52.1	29.5	28.3
Unweeded control	–	52.4		21.2	
Hand weeding	–	54.1		27.8	

Table 6. Grain yield and number of panicles per hill, first crop, 1971.

Herbicide	Rate (kg/ha)	Grain yield (kg/ha)		Panicles per hill	
		6 DAT	16 DAT	6 DAT	16 DAT
Benthiocarb	1.0	6,951 abc *	6,606 abc	17.8 a	16.0 ab
	1.5	7,189 abc	7,072 abc	18.0 a	15.0 b
	2.0	6,708 abc	6,708 abc	14.9 b	16.1 ab
	2.5	6,981 abc	6,761 abc	16.6 ab	16.2 ab
	3.0	6,907 abc	6,875 abc	16.8 ab	17.5 a
Butachlor	1.0	6,544 bc	6,387 c	16.3 ab	16.1 ab
	1.5	6,771 abc	6,488 bc	16.9 ab	16.3 ab
	2.0	7,030 abc	7,245 ab	17.1 ab	16.5 ab
	2.5	7,368 a	6,753 abc	16.9 ab	15.9 ab
	3.0	6,786 abc	6,503 bc	16.8 ab	16.4 ab
Unweeded control	–	4,451 b		12.5 c	
Hand weeding	–	6,639 abc		17.6 a	

*Grain yields and number of panicles with letters in common are not significantly different from each other at the 5 % level.

Table 7. Analysis of variance for grain yield, first crop, 1971.

Source of variance	D.F.	Mean square	Level of significance
Herbicides (H)	1	99,899	NS
Rates of application (R)	4	196,600	NS
Times of application (T)	1	432,033	NS
H × R	4	378,267	5 %
H × T	1	21,550	NS
R × T	4	92,732	NS
H × R × T	4	47,157	NS
H × Unweeded control	1	13,815,243	1 %
H × Handweeded control	1	90,449	NS