Evaluation of Experimental Extended-Delivery Granular Preemergent Herbicide Formulations for Direct Application to Nursery Containers[1]

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Abstract

Studies evaluated the efficacy of experimental extended-delivery herbicide formulations for direct application to containers. The purpose for direct application to containers is to reduce non-target loss from the current practice of broadcast applications. A separate laboratory study was also conducted to evaluate the rate response of oryzalin on germination of large crabgrass (*Digitaria sanguinalis* L.). Results of the laboratory study indicate that crabgrass germination is reduced when seeds are exposed to the preemergence herbicide oryzalin at concentrations of ≥0.025 parts per million. Experimental herbicides were produced by formulating polymeric exchange resins and cellulose complex carriers with oryzalin. Experimental herbicides reduced weed shoot dry weight at 120 DAT and 150 DAT when compared to Rout®, Surflan® and the untreated control.

Key words: weed control, slow release herbicide, extended-delivery herbicide, resins, Biodac®.

Herbicides used in this study: oryzalin, 3,5-dinitro-N^4,N^4-dipropylsulfanilamide.

Significance to the Nursery Industry

Multiple over-the-top broadcast applications of granular preemergence herbicides result in a significant amount of herbicide falling to the ground as non-target loss. While this non-target loss herbicide might provide some weed control in these non-target areas, the herbicide can be washed from plastic or gravel bed surfaces at the site of application and into containment ponds and other surface waters during nursery irrigation. This non-target loss may pose a threat to the environment. Directly applying herbicides to individual containers would be a means of eliminating or at least greatly minimizing this non-target loss of herbicides. However, the high labor cost associated with multiple applications needed would no doubt prove cost prohibitive for growers. If a slow release herbicide were available that had the potential for season-long control, direct application to individual containers might then be feasible from a labor cost perspective. Studies such as the one presented here are necessary and beneficial in the efforts to solve this ongoing problem of non-target

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loss of herbicides from multiple applications of herbicides broadcast over the top of nursery containers.

Introduction

Most container nurseries today apply preemergence herbicides formulated on granular carriers. Results of a survey in Alabama indicated nurseries applied an average of three broadcast applications of granular herbicides annually, with some making up to five applications (4). Other studies have revealed that non-target losses up to 87% can occur with 16.5 cm (6.5 in) diameter containers spaced 30.5 cm (12 in) on-center in a square pattern (5, 9). Studies at a nursery in South Carolina detected oryzalin, oxyfluorfen, isoxaben, trifluralin, and pendimethalin in containment pond water and sediment (8). Wehtje et al. (10, 11) conducted studies evaluating the movement of the preemergence herbicides oxadiazon and oryzalin when applied to the container surface and found that oxadiazon and oryzalin are sufficiently adsorbed to resist leaching-based displacement and that oxadiazon and oryzalin are not likely to enter the environment from treated containers. Therefore, it is this non-target loss of herbicides from multiple broadcast applications of herbicide that is the primary contributing factor to herbicides in nursery runoff waters. Several techniques have been evaluated to reduce herbicide loss in container production, including herbicide-impregnated mulches (3), herbicide-coated fertilizers (2, 7), geotextal disks (1), and slow-release herbicide tablets (6, 14). At this time, no product is available for use as a direct application to containers for extended-activity weed control.

Oryzalin was chosen for investigation, since it is a commonly used preemergence herbicide for control of annual grasses and broadleaf weeds. Oryzalin was first evaluated for use in container production in the 1970s (12). Oryzalin is the sole active ingredient in Surflan®, as well as one of the ingredients in the granular formulations of Snapshot® XL and Rout®. Herbicide formulation was conducted following procedures previously evaluated by the authors (unpublished). There was no information in the literature on the concentration of oryzalin needed to control grasses; therefore, laboratory experiments were conducted to determine the response of large crabgrass (*Digitaria sanguinalis* L.) to oryzalin.

Our objective was to evaluate the efficacy of experimental granular herbicide formulations applied directly to containers that might offer the potential for extended weed control. Such a product, if effective, could virtually eliminate non-target loss of herbicide associated with current formulations and application techniques. Such a product would be especially beneficial to growers of large-container plants who, due to container spacing, find it necessary to apply herbicides to individual containers multiple times per year using the currently available herbicide formulations.

Materials and Methods

Laboratory evaluation of oryzalin for control of large crabgrass. Laboratory experiments were conducted to evaluate the response of large crabgrass to the preemergence herbicide oryzalin. Oryzalin was evaluated at concentrations of 0, 0.025, 0.050, 0.075, 0.100, and 0.125 mg ai/liter. Twelve-cell Costar™ tissue culture plates (Fischer Scientific, Pittsburgh, PA) containing 3.5 mg acrylamid copolymer (Industrial Services International, Bradenton, FL) per 1 ml herbicide solution were utilized as growth media. Twelve seeds were placed in each cell. There were six replications per herbicide concentration in a completely randomized design. Experiments were conducted at 20C ± 1C and 24 hour fluorescent light with an average flux density of 20 mol/m/s. Data collected were percent seed germinated, root lengths, and shoot lengths of seedlings 14 days after treatment. Average root and shoot length per cell was calculated by dividing the total per cell by the number of seeds with emergence of either shoots or roots. Orthogonal polynomial coefficients were used to determine linear or quadratic response of germination, shoot length, and root length to oryzalin rate. Least significant differences were calculated using a Bonferroni adjustment to account for multiplicity of comparisons ($P = 0.05$, $k = 15$) (13).

Evaluation of experimental extended-delivery herbicides, Experiment 1. Two anion exchange resins (A300 and A400) and one sorbent resin (MN400) (The Purolite Co., Philadelphia, PA) were formulated with Surflan® yielding oryzalin active ingredient concentrations of 6.0% for the anion exchange resins and 8.0% for the sorbent resins. On April 4, 2000, 198 2.8 *l* (trade gallon) pots were filled with 6:1 pinebark:sand substrate amended per cu m (cu yd) with 3.0 kg (5 lb) of dolomitic limestone, 8.9 kg (14 lb) of 17N–3.1P–10K (Osmocote 17–7–12, Scotts Co., Marysville, OH) and 0.9 kg (1.5 lb) Micomax (Scotts Co.) micronutrients. Containers were placed in the greenhouse under overhead irrigation at the Patterson greenhouse complex in Auburn, AL.

Each of the three resins were applied at rates of 4.2 (4), 8.4 (8), 12.6 (12), 16.7 (16), 20.9 (20), 25.1 (24), 29.3 (28), and 33.4 (32) kg ai/ha (lbs ai/a). In addition, Surflan® 4AS was applied at 2.1 (2) and 4.2 (4) kg ai/ha (lb ai/a), Rout® was applied at oryzalin concentrations of 2.1 (2), 8.4 (8), and 4.2 (4) kg ai/ha (lb ai/a), and an untreated control was maintained. Each individual container received its application of experimental herbicide formulations by the use of a shaker can to ensure uniform application and distribution. Surflan® treatments were applied with a CO_2 backpack sprayer calibrated to deliver 374 liters/ha (40 gal/A), with an 8004 flat fan nozzle (Bellspray, Inc., Opelousa, LA) at a pressure of 2.0 kg sq cm (28 psi). Large crabgrass, a summer annual grass, was chosen as our weed species. Containers were overseeded with crabgrass (20 seed per container) one irrigation event after treatment application. Weeds were sprayed with 2% glyphosate to runoff 30 days after seeding. Weeds were clipped at the soil line 24 hours following application of glyphosate, and dry weights were determined. Containers were reseeded monthly, immediately after harvesting, throughout the experiment. Orthogonal polynomial coefficients were used to determine linear or quadratic response of shoot dry weight to oryzalin rate ($P = 0.05$). Contrast analysis was conducted for all pairwise comparisons averaged across the 16.7 (16), 20.9 (20), 25.1 (24), and 29.3 (28), kg ai/ha (lb ai/a) rates for the experimental herbicides and all rates of Surflan® ($P = 0.05$).

Evaluation of experimental extended-delivery herbicides, Experiment 2. This study was conducted similarly to *Experiment 1* with the following exceptions: On May 29, 2000, 252 10.2 cm (4 in) diameter pots were filled with substrate. The A300 resin was not included in *Experiment 2*. Biodac® cellulose complex carriers were also evaluated (GranTek Inc., Granger, IN). Three Biodac® size #16/30 (B1), 12/20 (B2),

Table 1. Laboratory evaluation of oryzalin on control of crabgrass (*Digitaria sanguinalis*).

Oryzalin rate (ppm[y])	14 DAT[z] % Germination[x]	Shoot length[w]	Root length[v]
0.000	54a[u]	15.3a	24.2a
0.025	45ab	7.7c	2.4b
0.050	37ab	11.5b	1.5b
0.075	40ab	7.3c	1.1b
0.100	37ab	4.7cd	1.0b
0.125	27b	2.3d	1.1b
Significance	L**[t]	L***	L***

[z]DAT = days after treatment.
[y]ppm = parts per million.
[x]Seeds were considered germinated when shoots were visible.
[w]Average shoot length (mm) of germinated seeds.
[v]Average primary root length (mm) of germinated seeds.
[u]Similar letters were not significantly different (Bonferroni: $P = 0.05$).
[t]NS and L represents not significant and linear responses within a response variable (*, **, ***: Significant where $P \leq 0.05, 0.01, 0.001$, respectively).

Table 2. Effect of rate of experimental herbicide formulations on crabgrass (*Digitaria sanguinalis*) shoot dry weight, 2000.

Formulation	Rate[z]	Shoot dry weight (grams) 60 DAT[y]	90 DAT	120 DAT	150 DAT
MN400	4	2.65	9.08	5.65	2.80
	8	1.01	2.54	2.18	1.12
	12	1.41	3.40	3.09	1.62
	16	1.24	1.09	3.67	2.16
	20	0.56	1.21	2.82	1.22
	24	0.82	0.53	2.09	1.90
	28	0.03	0.54	2.62	0.88
	32	0.05	0.23	0.10	1.56
		L*[x]	L***	L*	NS
A300	4	0.37	1.61	2.96	1.96
	8	0.00	0.44	1.93	0.46
	12	0.58	0.94	0.26	0.66
	16	0.09	1.88	1.57	2.90
	20	0.08	0.68	1.12	1.38
	24	0.00	1.16	0.69	0.86
	28	0.02	0.49	0.31	0.44
	32	0.24	0.40	0.92	0.28
		NS	NS	L*	NS
A400	4	0.18	2.28	2.43	1.12
	8	0.02	3.64	2.96	1.50
	12	0.02	1.98	1.56	1.44
	16	0.04	1.42	1.59	1.34
	20	0.01	0.26	2.36	1.16
	24	0.07	0.12	0.30	1.00
	28	0.01	0.15	0.31	0.22
	32	0.01	0.72	0.08	0.18
		NS	L*	L*	NS

[z]Rate of oryzalin in lbs ai/A.
[y]DAT = days after treatment.
[x]NS and L represents not significant and linear responses within a response variable (*, **, ***: Significant where $P \leq 0.05, 0.01, 0.001$, respectively).

and 20/50 (B3) were used, and they were formulated using technical grade oryzalin, to active ingredient concentrations of 9.4, 9.2, and 9.3%, respectively. Each of the five experimental carriers (2 resins, 3 Biodac®) was applied at rates of 4.2 (4), 8.4 (8), 12.6 (12), 16.7 (16), 20.9 (20), 25.1 (24), and 29.3 (28) kg ai/ha (lb ai/a). Rout® treatments were applied at oryzalin concentrations of 2.1 (2), 4.2 (4), and 8.4 (8) kg ai/ha (lb ai/a). Rout® and Biodac® treatments were applied in the same manner as the resins. Containers were over-seeded with large crabgrass (15 seeds per container) one irrigation event after treatment application. Statistical analysis was conducted as described in *Experiment 1*.

Results and Discussion

Laboratory evaluation of oryzalin on control of large crabgrass. Percent germination, shoot length, and root length decreased linearly with increasing oryzalin rate (Table 1). Percent germination was 27% for 0.125 ppm compared to 54% for the untreated control. With the 0.125-ppm treatment, shoot length was decreased 85%, compared to the nontreated control. Roots were stunted, thick, and unbranched in all herbicide treatments. Root length ranged from 1.0 to 2.4 mm for all herbicide treatments compared to 24.2 mm for the nontreated control. Results indicated that oryzalin concentrations as low as 25 ppb oryzalin provided control of large crabgrass.

Evaluation of experimental extended-delivery herbicides, Experiment 1. Shoot dry weight of large crabgrass decreased linearly with increasing oryzalin rate at 60, 90, and 120 DAT for the MN400 formulation (Table 2). Shoot dry weight also decreased linearly with increasing oryzalin rate at 90 and

Table 3. Effect of experimental herbicide formulations on crabgrass (*Digitaria sanguinalis*) shoot dry weight, 2000.

Resin	Shoot dry weight (grams) 60 DAT[z]	90 DAT	120 DAT	150 DAT
MN400	0.36[y]	0.63	1.91	1.38
A300	0.08	0.68	0.76	0.72
A400	0.03	0.31	0.76	0.64
Surflan	0.03	0.62	1.35	1.58
Control	8.25	8.77	4.22	4.16
Contrast				
MN400 v A300	NS[x]	NS	*	*
MN400 v A400	NS	NS	*	*
A300 v A400	NS	NS	NS	NS
MN400 v Control	***	***	*	***
A300 v Control	***	***	**	***
A400 v Control	***	***	**	***
MN400 v Surflan	NS	NS	NS	NS
A300 v Surflan	NS	NS	**	*
A400 v Surflan	NS	NS	**	*
Surflan v Control	***	***	NS	**

[z]DAT = days after treatment.
[y]Means are an average across rates for Surflan and rates 16, 20, 24, and 28 lbs ai/A for all experimental herbicides.
[x]Contrast analysis used for comparisons between formulations; NS, *, **, ***: Not significant, or significant where $P \leq 0.05, 0.01, 0.001$, respectively).

Table 4. Effect of rate of experimental herbicide formulations on crabgrass (*Digitaria sanguinalis*) shoot dry weight, 2001.

		Shoot dry weight (grams)			
Formulation	**Rate[z]**	**30 DAT[y]**	**60 DAT**	**90 DAT**	**120 DAT**
B1	4	0	0.0300	0.595	0.418
	8	0	0.0060	0.367	2.145
	12	0.004	0.0040	0.270	1.018
	16	0	0.0008	0.498	1.525
	20	0	0.0012	0.170	1.118
	24	0	0.0012	0.360	1.220
	28	0	0	0.120	0.890
		NS[x]	L*	NS	NS
B2	4	0.21	0.0130	0.606	1.023
	8	0	0.0018	0.296	1.168
	12	0	0.0060	0.208	0.548
	16	0	0.0880	0.851	1.228
	20	0	0.0140	0.699	1.335
	24	0	0.0008	0.198	0.510
	28	0	0	0.211	0.758
		L**	NS	NS	NS
B3	4	0.365	0.480	0.769	1.448
	8	0	0.051	0.802	0.798
	12	0	0.002	0.347	1.388
	16	0	0.002	0.035	0.613
	20	0	0	0.642	0.688
	24	0	0.003	0.349	0.438
	28	0	0.001	0.185	0.585
		L**	L***Q***	NS	L*
A400	4	0.191	0.847	1.113	1.970
	8	0.239	0.290	0.907	1.845
	12	0.202	0.021	0.863	1.340
	16	0.130	0.124	1.456	1.248
	20	0	0.013	0.542	0.943
	24	0.039	0.004	0.498	0.830
	28	0.017	0.008	0.301	0.804
		L*	L***Q*	L*	L**
Rout	2	0.001	0.209	0.162	1.396
	4	0	0	0.037	0.711
	8	0	0	0.004	0.385
Surflan	2	0	0	0.115	0.515
	4	0	0	0.044	0.536
Control	0	0.55	1.244	1.46	2.23

[z]Rate of oryzalin in lbs ai/A.

[y]DAT = days after treatment.

[x]NS, L, and Q represents not significant, linear, and quadratic responses within a response variable (*, **, ***: Significant where $P \leq 0.05$, 0.01, 0.001, respectively).

120 DAT for the A400 formulation, and at 120 DAT for the A400 formulation. There was no rate response on shoot dry weight for any experimental formulation at 150 DAT. Contrast analysis revealed that there was no difference in shoot dry weight among any experimental formulation when averaged across the indicated rates (Table 3). Likewise, there was no difference between any experimental formulation and Surflan® at 60 or 90 DAT; however, at 120 and 150 DAT A300 and A400 provided greater control than Surflan®. At 120 DAT, shoot dry weight was 79% less for the A300 and A400 formulations when compared to Surflan®. Likewise, shoot dry weight at 150 DAT for A300 and A400 were 55 and 60% less than Surflan®, respectively.

Evaluation of experimental extended-delivery herbicides, Experiment 2. Shoot dry weight of large crabgrass decreased linearly with increasing oryzalin rate at all dates for the A400 formulation and all dates, except 90 DAT, for the B3 formulation (Table 4). There was no rate response at any date for B1 and B2 formulations, except for a linear response at 60 DAT and 30 DAT, respectively. Contrast analysis revealed that there was no difference in shoot dry weight among any experimental formulation when averaged across the indicated rates for 30 and 60 DAT (Table 5). The only difference in shoot dry weight for any experimental formulation at 90 DAT

Table 5. Effect of experimental herbicide formulations on crabgrass (*Digitaria sanguinalis*) shoot dry weight, 2001.

	Shoot dry weight (grams)			
Formulation	**30 DAT[z]**	**60 DAT**	**90 DAT**	**120 DAT**
B1	0[y]	0	0.287	1.188
B2	0	0.025	0.470	0.958
B3	0	0.001	0.303	0.581
MN400	0.026	0.037	0.700	0.956
A400	0	0.007	0.247	0.350
Rout	0	0.070	0.067	0.831
Surflan	0	0	0.080	0.520
Control	0.553	1.244	2.190	2.230
Contrast[x]				
B1 v B2	NS	NS	NS	NS
B1 v B3	NS	NS	NS	*
B2 v B3	NS	NS	NS	NS
B1 v Control	***	***	***	NS
B2 v Control	***	***	***	*
B3 v Control	***	***	***	**
B1 v Surflan	NS	NS	NS	NS
B2 v Surflan	NS	NS	NS	NS
B3 v Surflan	NS	NS	NS	NS
Surflan v Control	***	***	***	NS
B1 v MN400	NS	NS	**	NS
B2 v MN400	NS	NS	NS	NS
B3 v MN400	NS	NS	*	NS
B1 v A400	NS	NS	NS	**
B2 v A400	NS	NS	NS	*
B3 v A400	NS	NS	NS	NS
B1 v Rout	NS	NS	**	*
B2 v Rout	NS	NS	NS	NS
B3 v Rout	NS	NS	*	*
MN400 v Rout	NS	NS	***	NS
A400 v Rout	NS	NS	NS	*
Surflan V Rout	NS	NS	NS	NS
MN400 v Control	***	***	**	*
A400 v Surflan	NS	NS	NS	*
A400 v Control	***	***	***	**
Rout v Control	***	***	***	*

[z]DAT = days after treatment.

[y]Means are an average across rates for Rout and Surflan and rates 16, 20, 24, and 28 lbs ai/A for all experimental formulations.

[x]Contrast analysis used for comparisons between formulations; NS, *, **, ***: Not significant, or significant where $P \leq 0.05$, 0.01, 0.001, respectively).

Table 6. Herbicide active ingredient concentration, particles per gram, and particle distribution when applied at a rate of 2 lbs ai/A oryzalin.

Formulation	Concentration[z]	2 lbs ai/A		
		particles/gm	grams/sq ft	particles/sq in
Biodac 1	9.4%	4904	0.22	7.5
Biodac 2	9.2%	1655	0.23	7.6
Biodac 3	9.3%	706	0.22	1.1
MN-400	8.0%	12626	0.26	22.8
A-300	6.0%	4943	0.35	12.0
A-400	6.0%	5246	0.35	12.8
Rout	1.0%	2613	2.08	37.7

[z]Concentration of the active ingredient oryzalin

was that B1 and B3 had lower dry weights than MN400. All experimental formulations had lower shoot dry weights than the control for all dates, with the exception of B1 at 120 DAT.

In summary, most of the experimental formulations showed significantly lower weed shoot dry weights than the control, so that by 150 DAT in the 2000 study and 120 DAT in the 2001 study, the higher rates of the experimental formulation were providing some weed control. However, this level of control would not likely be acceptable at most production nurseries. It is speculated that the reason for lack of acceptable control at 120 and 150 DAT was partly due to a combination of low oryzalin water solubility of 1 mg/*l* at 25C and distribution of the granules on the media surface that resulted in zones of no herbicidal activity, especially on the lower ai/A treatments (Table 6). Also, the slow release characteristics of the carriers, along with high adsorption characteristics of the herbicide to the container substrate (10, 11), might be resulting in too little oryzalin in solution to provide effective weed control. Although not quantified in this experiment, it is speculated that the level of oryzalin present in the container substrate solution might be well below the 25 ppb concentration shown to provide control in the laboratory experiment. Previous work by the authors (unpublished) indicate that after 30 simulated laboratory irrigation events, the A400 experimental formulation released between 6 and 9% of the active ingredient and that Biodac® carriers released between 7 and 11%. In comparison, a separate study indicated that 71% of the active ingredient oryzalin released from Rout® after 21 simulated irrigation events (8). Alternative formulation methods targeted at rendering the active ingredient more soluble, especially with the oryzalin impregnated Biodac® carriers, might result in increased efficacy. Certainly more work can be undertaken with these carriers, as well as other carriers and herbicides, in an effort to solve the ongoing problem of non-target herbicide loss in the container nursery industry.

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