Pronamide Improves Weed Control in New Grass Plantings Protected by Activated Charcoal

George W. Mueller-Warrant[1,4] Mark E. Mellbye[2] and Susan Aldrich-Markham[3]

ABSTRACT

New stands of grasses grown for seed in western Oregon USA are normally established with bands of activated charcoal applied over the rows at planting, followed by broadcast application of diuron to control weeds. This technique fails to control *Bromus* spp. and volunteer cereals and is erratic on Italian ryegrass (*Lolium multiflorum* Lam.). Compared to diuron alone, adding pronamide (propyzamide) with reduced rates of diuron controlled a wider spectrum of seedling grasses between the rows while maintaining a similar degree of crop safety in the carbon-protected zone. Stand density of tall fescue (*Festuca arundinacea* Schreb.) and perennial ryegrass (*Lolium perenne* L.) decreased linearly with increasing rates of diuron and pronamide in most tests, but rates usually existed which controlled the weeds between the rows while permitting crop establishment within the rows. Based on regression analysis of relationships between crop stand and herbicide rate in tall fescue and perennial ryegrass plantings, pronamide was about 6 times as active as diuron per kg of herbicide in these crops. Orchardgrass (cocksfoot, *Dactylis glomerata* L.) was relatively more pronamide tolerant than the other two crops. Crops which showed poor pronamide tolerance also showed poor diuron tolerance. Soil factors related to poor herbicide tolerance in activated charcoal plantings included poor physical structure at planting and poor drainage.

Additional index words: **propyzamide, diuron, ethofumesate, *Lolium perenne, Festuca arundinacea, Dactylis glomerata, Bromus carinatus,* carbon banding, grass seed production, stand establishment.**

INTRODUCTION

The ability to establish weed-free stands is an essential first step in the production of high quality, certified grass seed. Since its introduction nearly 20 years ago, the carbon-banding, broadcast-diuron (N'-(3,4-dichlorophenyl)-N,N-dimethylurea) system has become the most commonly used method to control weeds in new grass plantings in western Oregon (Lee, 1973). This system begins with tillage during the summer to destroy existing vegetation and create a seedbed. In early autumn (fall), grass seed is drilled at rates of 3 to 12 kg ha^{-1} in rows spaced 20 to 50 cm apart with activated charcoal sprayed over the rows in bands 2 to 4 cm wide. Prior to the first rain after planting, diuron is broadcast over the field at 2.2 to 2.7 kg ai ha^{-1}.

The standard rate of activated charcoal (340 kg ha^{-1} in the treated zone), provides about a two-fold safety margin for cool season grasses commonly grown in western Oregon when used with 3.4 kg ha^{-1} of diuron in autumn seedings on a Woodburn silt loam soil (fine-silty, mixed, mesic Aquultic Argixeroll) with a firm seedbed (Lee, 1973). The safety margin with some other soil types in western Oregon is lower, but still adequate to encourage large scale adoption of the system. Activated charcoal also protects seedling grasses from a variety of other herbicides, but with smaller safety margins (Lee, 1973).

Several limitations to this system were recognised at its onset. First, the amount of activated charcoal required to protect crop seedlings within the row is not absolute, but merely a ratio of charcoal rate to herbicide rate that varies with soil factors, herbicide, environmental conditions, and crop sensitivity (Burr, Lee and Appleby, 1972). Attempts to introduce carbon-banding, broadcast-diuron planting systems for grass seed production were less successful in eastern Oregon (W.O. Lee, 1987, USDA-ARS (retired), personal communication; Lee, 1978). In Minnesota, establishment of Kentucky bluegrass (*Poa pratensis* L.) and timothy (*Phleum pratensis* L.) with a carbon-banding, broadcast-diuron planting system was inconsistent, possibly because of differences in rainfall patterns between field tests (Bertges, 1976). A second major limitation to the system is diuron's poor control of several common weeds in western Oregon, including wild oats (*Avena fatua* L.), volunteer cereals, and *Bromus* species.

The selective herbicide ethofumesate [(±)-2-ethoxy-2,3-dihydro-3,3-dimethyl-5-benzofuranyl methanesulfonate] is registered in seedling stands of Italian ryegrass (*Lolium multiflorum* Lam.), perennial ryegrass (*L. perenne* L.) and tall fescue (*Festuca arundinacea* Schreb.) partly for the purpose of controlling many of the diuron-tolerant weeds that are present in carbon-banding, broadcast-diuron plantings (Lee, 1977; Lee, 1980). However, application of ethofumesate must be delayed until rain has dispersed the charcoal bands and moistened the soil (Lee, 1980). Ethofumesate label instructions allow Italian ryegrass to be

[1] USDA-ARS, Natl. Forage Seed Prod. Res. Cent., 3450 SW Campus Way, Corvallis, OR 97331-7102, USA.
[2] Oregon State Univ. Ext. Agent, Linn, Lane and Benton Co., Linn Co. Ext. Off., PO Box 765, Albany, OR 97321, USA.
[3] Oregon State Univ. Ext. Agent, Yamhill and Polk Co., Yamhill Co. Ext. Off., 2050 Lafayette Ave., McMinnville, OR 97128. Contribution of the USDA-ARS in cooperation with the Agric. Exp. Stn., Oregon State Univ. Tech. Paper No. 9259 of the latter. Received for publication 23 January 1991.
[4] Corresponding author.

treated either pre- or post-emergence, but perennial ryegrass and tall fescue can only be treated post-emergence, after reaching the two-leaf growth stage. Growth by weeds during the period prior to ethofumesate application makes them harder to kill and requires use of higher rates. The maximum rate of ethofumesate registered on seedling tall fescue, 1.1 kg ai ha^{-1}, is less than half that required to kill three-leaf California brome (*Bromus carinatus* H. & A.) (Mueller-Warrant, unpublished data). Ethofumesate is not available for use on orchardgrass (cocksfoot, *Dactylis glomerata* L.), as this crop can be killed by applications during the seeding year.

Diuron-tolerant bromes have proliferated in response to widespread use of diuron in perennial grasses grown for seed and in winter wheat (Mueller-Warrant, 1987). Weeds such as California brome threaten the economic viability of the carbon-banding, broadcast-diuron planting system, even with the availability of ethofumesate in some of the crops. In tests to control established California brome in orchardgrass, pronamide (propyzamide) (3,5-dichloro(N-1,1-dimethyl-2-propynyl)benzamide) was found to be effective at 0.45 to 0.67 kg ai ha^{-1}, except where open field burning had deposited large amounts of sooty carbon ash on the soil surface (Mueller-Warrant and Mellbye, 1988 and 1991). This suggested that pronamide might be readily adsorbed by activated charcoal and could be a suitable alternative or addition to diuron in carbon-banding plantings.

The objective of these studies was to evaluate whether the previously untested herbicide pronamide could substitute in part or full for diuron when broadcast over rows of seedling grasses protected by bands of activated charcoal. This potential was evaluated in tolerance of seedling crops and susceptibility of California brome and other weeds to pronamide, diuron, and mixtures of both herbicides.

MATERIALS AND METHODS

General techniques

Tests 1 to 8 were conducted at the Oregon State University Hyslop Research Farm, Crop Science Field Laboratory, near Corvallis, Oregon, in summer 1988, autumn 1988, and autumn 1989 (Tables 1 and 2). Tests 9 to 14 were conducted on four additional soil types in newly planted grower fields in western Oregon in autumn 1989. In the tests conducted at Hyslop, perennial ryegrass, tall fescue, and orchardgrass were planted at 9, 12 and 10 kg seed ha^{-1} in 30 cm wide rows at a depth of 1 cm using a small-plot planter modified to spray a suspension of activated charcoal in 2.5 cm wide bands over the rows. Charcoal was applied as an aqueous slurry at 460 l ha^{-1} at a pressure of 3 kPa through 8008 nozzles. Concentration of activated charcoal and ground speed of the planter were adjusted to supply 0, 170 and 340 kg ha^{-1} charcoal in the treated zone. In tests conducted in grower fields, commercial-scale modified grass drills were used to plant the crops and apply the charcoal. In all tests, herbicides were applied with a unicycle-type plot sprayer supplying 240 l ha^{-1} at a pressure of 210 kPa through a series of 8002 nozzles spaced 30 cm apart at a height providing double overlap coverage at the soil surface.

In all tests except the summer 1988 seedings, stand density was evaluated by counting the number of 2.5 cm-long segments of row in which crop seedlings were either present or absent out of a total of 192 segments, or 4.8 m of row per plot. Stand density was then expressed as the percent of segments containing crop seedlings. No distinction was made between the presence of single versus multiple crop seedlings within each 2.5 cm-long segment of row, only whether there were any present at all. Stand density measurements therefore correspond more closely to percent ground cover by the crop within the row than to absolute numbers of crop seedlings per unit area. These stand density counts were made approximately four to five months after planting, by which time seedlings had either succumbed to the herbicides or were growing vigorously, i.e. beginning to tiller and grow into adjacent unoccupied areas. This method of evaluating stand density was designed to be relatively free of any effects of seeding rate beyond the minimum seeding rate needed to supply approximately one viable seed per cm of row. California brome, wild oat, and Italian ryegrass control was evaluated by counting the number of surviving weeds between the rows in the centre 10.8 m^2 of each plot. Unless otherwise noted, experimental designs were randomised complete blocks with three or four replications. Data were subjected to analysis of variance and means were separated with Fisher's protected least significant difference test ($P < 0.05$).

Summer 1988 seedings, Hyslop, Tests 1 and 2

'Tempo' tall fescue was seeded in Test 1 and 'Comet' orchardgrass in Test 2 in early summer 1988 (Table 2). California brome seed was broadcast by hand in the centre 1 m^2 of each plot after planting the crop. The experiment was arranged in a split-plot design with four replications, using three charcoal rates as mainplots and eight herbicide treatments plus two untreated checks as subplots. Subplots were 2.4 m wide by 4.6 m long. The area was sprinkler irrigated ten times with 2.5 cm of water per irrigation to ensure vigorous seedling growth during the summer. Crop establishment was evaluated by hand harvesting a 0.3 m long section of row in each plot to measure fresh weight growth on 19 August for tall fescue and 24 August for orchardgrass. California brome control and tall fescue and orchardgrass ground cover were visually rated on 24 August, but only the weed control ratings are included. Analysis of variance was performed on all data and on a logarithmic transformation of seedling fresh weight growth. Means separation was performed on the transformed values prior to their conversion back to actual yields for tabular presentation as a percent of the untreated check within each charcoal rate.

Table 1. Soil descriptions and drainage characteristics based on official county soil surveys.

Soil type	Description	Soil horizon depth cm	Permeability cm h^{-1}	Highest seasonal water-table[1] cm
Woodburn silt loam	fine-silty, mixed, mesic Aquultic Argixeroll	0 to 48 48 to 137 137 to 173	1.5 to 5 1.5 to 5 0.15 to 0.5	+51 to +76
Coburg silty clay loam	fine, mixed, mesic Pachic Ultic Argixeroll	0 to 46 46 to 135 135 to 165	1.5 to 5 0.5 to 1.5 5.0 to 15	+37 to +63
Willamette silt loam	fine-silty, mixed, mesic Pachic Ultic Argixeroll	0 to 61 61 to 135 135 to 152	1.5 to 5 1.5 to 5 1.5 to 5	> +152
Dayton silt loam	fine, montmorillonitic mesic Typic Albaqualf	0 to 37 37 to 102 102 to 193	1.5 to 5 < 0.15 0.5 to 5	-12 to +37
Bashaw silty clay	very-fine, montmorillonitic mesic Typic Pelloxerert	0 to 36 36 to 122 122 to 152	< 0.15 < 0.15 < 0.15	-25 to +12

[1] Positive values represent the distance from highest water-table up to the soil surface, while negative values represent seasonal water-tables rising above the soil surface.

Table 2. Test site planting and treatment dates, soil types, soil pH, and organic matter content.

Test no.[1]	Year	Planting date	Herbicide treatment date	Soil type	Soil pH by depth (cm)		Organic matter by depth (cm)	
					0-5	5-15	0-5	5-15
					pH		%	
1,2	1988	15 June	16 June	Woodburn silt loam	5.9	5.6	2.5	2.7
3,4,5	1988	11 Oct	12 Oct	Woodburn silt loam	6.2	6.2	2.0	2.2
6,7,8	1989	1 Nov	2 Nov	Woodburn silt loam	6.7	6.7	2.3	2.7
9	1989	5 Oct	6 Oct	Coburg silty clay loam	5.7	5.3	4.1	4.3
10	1989	5 Oct	6 Oct	Willamette silt loam	6.6	5.1	3.8	3.6
11	1989	12 Oct	13 Oct	Willamette silt loam	6.0	6.0	5.7	5.5
12	1989	13 Oct	18 Oct	Woodburn silt loam	5.3	5.5	2.8	3.8
13	1989	29 Sept	3 Oct	Dayton silt loam	6.3	5.6	2.9	3.1
14	1989	30 Sept	4 Oct	Bashaw silty clay	6.3	5.6	4.0	4.4

[1] Tests 1-8 were conducted in adjacent areas at Hyslop in summer 1988, autumn 1988, and autumn 1989. Tests 9-14 were conducted in six separate commercial production fields throughout western Oregon in autumn 1989.

Autumn 1988 seedings, Hyslop, Tests 3 to 5

Tests 3, 4 and 5 were seeded in autumn 1988 near the same area used in Tests 1 and 2 (Table 2). Plot size was 2.4 m wide by 6.0 m long, with eight rows per plot. 'Premier' perennial ryegrass was planted in Test 3, 'Tempo' tall fescue in Test 4, and 'Boone' orchardgrass in Test 5. California brome seed was broadcast by hand in the centre of each plot after planting. Five treatments received herbicides but no charcoal, and nineteen treatments, including a no-herbicide check, received charcoal at a rate of 340 kg ha^{-1} in 2.5 cm wide bands over the rows. Treatments were arranged in a randomised complete block design with four replications. Herbicides were applied on 12 October 1988.

Autumn 1989 seedings, Hyslop, Tests 6 to 8

Plot size was 2.4 m wide by 6.0 m long, with five rows per plot. Three replications were used in the autumn 1989 seedings. Test 6, 7 and 8 were conducted adjacent to the same area used in the previous tests (Table 2). 'Laddy' perennial ryegrass, 'Tempo' tall fescue, and 'Boone' orchardgrass were planted 1 November 1989 in Tests 6, 7 and 8, respectively, in soil heavily infested with Italian ryegrass and rattail fescue (*Vulpia myuros* (L.) K.C. Gmel). Charcoal rate was 340 kg ha^{-1} in the 2.5 cm wide bands. Diuron and pronamide were applied pre-emergence on 2 November, and ethofumesate was applied post-emergence on 6 December at the two-leaf stage of tall fescue and perennial ryegrass.

Autumn 1989 seedings, grower sites, Tests 9 to 14

Tests 9, 10, 11, 12, 13 and 14 were conducted on grower fields using commercial equipment for planting grass seed and applying charcoal. Charcoal rates were calibrated by the growers to be approximately 340 kg ha^{-1}. Diuron and pronamide were applied within 5 days after planting and prior to any significant rainfall (Table 2). Ethofumesate was applied after crop emergence on 20 November for Tests 9, 13 and 14 and on 21 November for Tests 10, 11 and 12.

Regression analysis, all seedings

Effects of diuron and pronamide rates on crop establishment were further analysed through multiple regression procedures to better judge the relative behaviour of these herbicides when applied over bands of activated charcoal. Regression results were interpreted as meaningful only in those cases where increasing rates of herbicides reduced crop stands and one or both of the regression coefficients differed significantly from zero at a confidence level of at least $P < 0.10$. Regressions were only conducted for crop stand density data from Tests 3-14. Plots treated with herbicides but not receiving activated charcoal were not included in the regression models. Weed control data were not analysed with regression because of differences between sites in species present and because 100% control was frequently achieved at the lowest rate tested.

RESULTS AND DISCUSSION

Summer 1988 seedings, Hyslop, Tests 1 and 2

Seedling tall fescue and orchardgrass were severely injured by diuron and pronamide in the absence of activated charcoal (Table 3). Without charcoal, orchardgrass was more seriously damaged than tall fescue by 1.1 kg ha^{-1} diuron, whereas both species produced about 40% growth at the 0.28 kg ha^{-1} (lowest) rate of pronamide. The 170 kg ha^{-1} (half-normal) rate of charcoal adequately protected tall fescue from 1.1 kg ha^{-1} diuron plus 0.28 kg ha^{-1} pronamide, but failed at higher rates of either herbicide alone or in combination. At the 340 kg ha^{-1} (full) rate of charcoal, tall fescue was not injured by any herbicide treatments.

The half-normal rate of charcoal protected orchardgrass more completely than tall fescue from pronamide. Orchardgrass growth with the half-normal rate of charcoal was not significantly reduced by any rate of pronamide applied alone, although it was reduced by 1.1 kg ha^{-1} diuron plus 0.56 kg ha^{-1} pronamide and by 2.2 kg ha^{-1} diuron applied alone. The full rate of charcoal protected orchardgrass from all herbicide treatments and orchardgrass growth in the herbicide-treated plots at the full rate of charcoal exceeded that in the untreated, weedy check by an average of 14%. California brome control was excellent at the 0.28 kg ha^{-1} (lowest) rate of pronamide, with or without diuron. As expected, diuron applied alone was relatively ineffective against California brome, and control reached only 62% at 2.2 kg ha^{-1}.

Autumn 1988 seedings, Hyslop, Tests 3 to 5

The half-normal rate of charcoal was omitted from this and all subsequent experiments to simplify planting and treatment application. Instead, an expanded range of herbicide rates was tested, resulting in ratios of charcoal to herbicide rates similar to those used in Tests 1 and 2. Herbicides severely damaged crops in the absence of charcoal. Without charcoal, tall fescue, orchardgrass, and perennial ryegrass developed only 35% stands at 1.1 kg ha^{-1}; there were almost no survivors at the higher rate (Table 4). Tall fescue and perennial ryegrass failed to survive 0.28 kg ha^{-1} pronamide without charcoal, whereas orchardgrass produced a 22% stand at that rate, but almost none at higher rates.

Activated charcoal protected all three crops from 0.28 kg ha^{-1} pronamide (Table 4). Stands of all three crops decreased with increasing rates of herbicides, but their relative sensitivities to pronamide and diuron varied. Tall fescue was the most sensitive to pronamide, orchardgrass the least. Increasing diuron rates reduced stands in all three crops to nearly identical degrees; coefficients for stand loss versus diuron rate were 5.6, 6.7 and 7.3 percent stand loss

Table 3. Effects of diuron, pronamide, and activated charcoal on tall fescue and orchardgrass seedling growth and California brome control in Tests 1 and 2, 15 June 1988 seedings.

Herbicide		Tall fescue seedling growth, 19 August 1988 harvest[1]			Orchardgrass seedling growth 24 August 1988 harvest[1]			California brome control avg. both tests and all charcoal rates
		Activated charcoal rate applied within bands, kg ha^{-1}			Activated charcoal rate applied within bands, kg ha^{-1}			
Diuron	Pronamide	0	170	340	0	170	340	
kg ha^{-1}					%			
0	0	100 a[2]	100 ab	100 a	100 a	100 ab	100 a	0 d
0	0.28	40 bc	81 abc	88 a	44 b	118 a	116 a	100 a
0	0.56	0.3 de	72 abc	98 a	4 cd	63 abc	100 a	100 a
0	0.84	0 e	46 c	89 a	5 cd	122 a	115 a	100 a
1.1	0	68 ab	127 a	127 a	10 c	119 a	116 a	21 c
1.1	0.28	3 d	101 ab	113 a	3 cd	53 abc	124 a	100 a
1.1	0.56	1 de	42 c	115 a	3 cd	46 bc	91 a	100 a
1.1	0.84	0 e	58 bc	96 a	0.5 d	87 abc	118 a	100 a
2.2	0	19 c	56 bc	78 a	0 d	40 c	134 a	62 b

[1] Data were transformed using ln (1 + growth [fresh weight] in g per 0.093 m^2) for analysis of variance and separation of means, and converted back to g m^{-2} and expressed as percent of untreated checks within a charcoal rate. Herbicide treatment by charcoal rate interaction was significant for tall fescue and orchardgrass seedling growth, but not for California brome control.

[2] Means followed by the same letter within a column do not differ at $P < 0.05$.

per kg diuron for tall fescue, orchardgrass, and perennial ryegrass respectively (Table 4). Tall fescue stands were clearly reduced when more than 0.56 kg ha^{-1} pronamide was applied alone, or when more than 0.28 kg ha^{-1} was applied with either 1.1 or 2.2 kg ha^{-1} diuron. Orchardgrass stands were only slightly reduced by 0.84 kg ha^{-1} pronamide at any diuron rate. Indeed, reasonably good orchardgrass stands developed even with the highest rate of pronamide, i.e. 1.7 kg ha^{-1}. Perennial ryegrass stands were usually reduced by the same rates of pronamide that injured tall fescue, but less severely. The regression coefficient for stand loss from pronamide was 25% greater in tall fescue than in perennial ryegrass (Table 4).

The lowest rate of pronamide completely controlled California brome. In contrast, the 4.5 kg ha^{-1} (highest) rate of diuron suppressed this weed only slightly. Control of California brome by diuron was even poorer than the partial suppression seen in Tests 1 and 2 conducted during the summer, possibly because the damaging effects of photosynthesis-inhibiting herbicides are enhanced at higher light intensities (Stanger and Appleby, 1972). Pronamide applied alone failed to control many broadleaf weeds, and the most weed-free stands of tall fescue, orchardgrass, and perennial ryegrass were those that developed in plots treated with pronamide plus diuron.

Autumn 1989 seedings, Hyslop, Tests 6 to 8

Tests in the 1989-90 growing season were conducted with a reduced set of treatments on an expanded range of test sites (Table 2). Use of herbicides without charcoal was discontinued as irrelevant. Because of the severity of broadleaf weed problems that had developed in pronamide-alone treatments, all rates of pronamide were applied in conjunction with low to moderate rates of diuron. Even the low rate of diuron (1.1 kg ha^{-1}) had adequately controlled most broadleaf weeds in Tests 1 to 5 (data not shown). Rates of pronamide and diuron applied to each crop were selected to more narrowly bracket the maximum safe rates found in the previous tests. Standard treatments for comparison included a full rate of diuron applied alone and the same rate followed by post-emergence application of 1.1 kg ha^{-1} ethofumesate for tall fescue and perennial ryegrass. These changes in rates were intended to increase the likelihood that the majority of the treatments would fall in the most useful region of the entire pronamide by diuron response surface, those combinations where crop establishment was good, but clearly approaching maximum tolerated doses given use of the standard rate of activated

Table 4. Effects of diuron, pronamide, and activated charcoal on perennial ryegrass, tall fescue, and orchardgrass stands and California brome control in Tests 3, 4 and 5, 11 Oct. 1988 seedings.

Herbicide rate		Activated charcoal rate	Perennial ryegrass stand Test 3	Tall fescue stand Test 4	Orchard-grass stand Test 5	California brome control avg. for all three tests
Diuron	Pronamide					
kg ha^{-1}			%			
0	0	340	94	90	95	0
0	0.28	340	94	85	89	100
0	0.56	340	86	80	89	100
0	0.84	340	75	56	78	100
0	1.1	340	72	41	75	100
0.0	1.7	340	44	24	65	100
1.1	0	340	96	85	93	6
1.1	0.28	340	91	73	90	100
1.1	0.56	340	88	59	87	100
1.1	0.84	340	76	60	82	100
1.1	1.1	340	52	40	67	100
1.1	1.7	340	60	19	67	100
2.2	0	340	92	78	76	21
2.2	0.28	340	87	74	78	100
2.2	0.56	340	78	57	71	100
2.2	0.84	340	52	45	72	100
2.2	1.1	340	44	34	67	100
2.2	1.7	340	27	14	51	100
4.4	0	340	68	68	62	17
0	0.28	0	2	3	22	100
0	0.56	0	1	1	5	100
0	0.84	0	5	1	2	100
1.1	0	0	35	34	36	0
2.2	0	0	2	8	6	0
LSD ($P < 0.05$)		-	16	15	12	7
Regression analysis for crop stands in charcoal treated plots only						
Intercept			104.8	93.1	96.5	-
Diuron coefficient			-7.3***[1]	-5.6***	-6.7***	-
Pronamide coefficient			-32.5***	-40.8***	-16.1***	-
R^2			0.864	0.969	0.866	-
Pronamide:diuron activity ratio			4.5	7.3	2.4	-
Estimated herbicide rate to reduce stand to 75% of untreated check for:						
Diuron, kg ha^{-1}			4.66	4.53	3.80	-
Pronamide, kg ha^{-1}			1.05	0.62	1.58	-

[1] Significant at $P < 0.001$.

charcoal.

Protection of perennial ryegrass, tall fescue, and orchardgrass from pronamide and diuron by activated charcoal at Hyslop was similar to previous results. In Tests 6, 7 and 8, perennial ryegrass, tall fescue, and orchardgrass stands from all combinations of diuron and pronamide equalled or exceeded those of the untreated, weedy checks (Tables 5 and 6). Orchardgrass stands for all treatments exceeded those in untreated checks except for the

combination of the 1.1 kg ha^{-1} (lowest) rate of diuron, plus the 0.56 kg ha^{-1} (lowest) rate of pronamide. This treatment reduced Italian ryegrass density between the rows by 96.6%, which may not have been quite enough under these extremely weedy conditions. The more successful treatments provided nearly 100% control (Table 7). The observed differences in Italian ryegrass control among various rates of pronamide and diuron (from 92.2 to 100% control) would have agronomic significance primarily in crops with limited seedling vigour during the winter (e.g. orchardgrass) or where establishment of other species might cause a new planting to be rejected for seed certification.

Autumn 1989 seedings, grower sites, Test 9 to 14

Activated charcoal adequately protected perennial ryegrass in three out of four tests conducted in grower fields (Table 5). Pronamide caused serious stand reductions in Test 9, a site with Coburg silty clay loam soil, which is moderately well drained at the surface, but which has a depth-to-water-table of only 38 to 63 cm (Table 1). Soils at the other sites planted to perennial ryegrass (Tests 10, 11, and 12) were better drained Willamette and Woodburn silt loams. Whether differences between sites were caused by soil factors, charcoal application technique, or carryover herbicide residues from previous crops is unclear.

Table 5. Effects of pronamide and diuron on perennial ryegrass stands in Tests 6, 9, 10, 11, and 12, autumn 1989 seedings protected by activated charcoal.

Herbicide rate		Perennial ryegrass stands Feb. 1990				
Diuron	Pronamide	Test 6	Test 9	Test 10	Test 11	Test 12
— — — kg ha^{-1} — — —		— — — — — — — — — — % — — — — — — — — — —				
0	0	88	88	96	72	72
1.1	0.42	94	54	91	81	73
1.1	0.56	91	50	87	94	82
1.1	0.70	90	31	81	85	77
1.7	0.42	90	43	88	65	70
1.7	0.56	90	43	82	85	84
1.7	0.70	89	27	80	84	80
3.4	0	90	66	88	76	73
3.4[1]	0[1]	91	68	84	71	64
LSD (P < 0.05)		6	12	9	29	21
Regression analysis for crop stands in charcoal treated plots only						
Intercept		89.6	81.6	97.7	71.8	70.5
Diuron coefficient[2]		+0.1NS	-4.8NS	-2.6*	+0.1NS	+0.5NS
Pronamide coefficient[2]		+1.3NS	-46.0+	-17.0**	+19.3NS	+12.2NS
R^2		0.054	0.557	0.863	0.359	0.430
Pronamide:diuron activity ratio		-	9.7	6.4	-	-
Estimated herbicide rate to reduce stand to 75% of untreated check for:						
Diuron, kg ha^{-1}		>3.4	3.37	9.70	>3.4	>3.4
Pronamide, kg ha^{-1}		> 0.70	0.35	1.51	>0.70	>0.70

[1] Treatment included ethofumesate applied at 1.1 kg ha^{-1} on 6 Dec. in Test 6, on 20 Nov in Test 9, and on 21 Nov. in Tests 10, 11 and 12.

[2] Significance at the P < 0.1, 0.05 and 0.01 levels denoted by +, *and **.

Pronamide did not control California brome as effectively as it had in previous tests (Tables 3, 4 and 7). In Test 9, 0.70 kg ha^{-1} pronamide controlled only 75% of California brome. The standard diuron plus ethofumesate treatment controlled 93% of California brome; diuron alone controlled none of it. Control of California brome from pronamide in Test 9 was probably poorer than in Tests 1 to 5 because of differences in germination patterns. Soils were drier at planting in both summer and autumn 1988 compared with autumn 1989, and initial rainfall (or irrigation) leading to weed seed germination was much more intense in 1988 than in 1989 (data not shown). Since California brome was naturalised in the field in Test 9, some of the weed seeds germinated at several cm below the soil surface from moisture already present in the soil at planting and herbicide application. These early germinating weed seedlings emerged before rainfall leached pronamide down into the root zone. Since many weeds increase in herbicide toler-

Table 6. Effects of pronamide and diuron on tall fescue and orchardgrass stands in Tests 7, 8, 13 and 14, autumn 1989 seedings protected by activated charcoal.

Herbicide rate		Tall fescue stands			Orchardgrass stand
Diuron	Pronamide	Test 7	Test 13	Test 14	Test 8
kg ha^{-1}			%		
0	0	72	70	86	63
1.1	0.56	-	-	-	58
1.1	0.70	-	-	-	72
1.1	0.84	-	-	-	81
1.7	0.28	67	40	28	-
1.7	0.42	72	43	22	-
1.7	0.56	74	37	15	87
1.7	0.70	-	-	-	79
1.7	0.84	-	-	-	85
2.2	0.28	78	51	32	-
2.2	0.42	72	31	17	-
2.2	0.56	69	27	9	-
3.4	0	-	-	-	74
4.5	0	66	33	23	-
4.5[1]	0[1]	71	27	24	-
LSD (P < 0.05)		13	15	10	19
Regression analysis for crop stands in charcoal treated plots only					
Intercept		72.6	70.3	83.2	58.9
Diuron coefficient[2]		-1.3NS	-8.1NS	-13.6***	+5.0NS
Pronamide coefficient[2]		+3.7NS	-39.5*	-84.7***	+16.3NS
R^2		0.208	0.862	0.970	0.438
Pronamide:diuron activity ratio		-	4.9	6.2	-
Estimated herbicide rate to reduce stand to 75% of untreated check for:					
Diuron, kg ha^{-1}		>4.5	2.24	1.36	>3.4
Pronamide, kg ha^{-1}		>0.56	0.46	0.22	>0.84

[1] Treatment included ethofumesate applied at 1.1 kg ha^{-1} on 6 Dec. in Test 7, and on 20 Nov in Tests 13 and 14.
[2] Significance at the P < 0.05, 0.01, and 0.001 levels denoted by *, **, and ***.

ance as they grow, this early germination relative to timing of rainfall may explain the poorer control of California brome in Test 9.

Pronamide controlled California brome well in Test 11, where 0.42 kg ha^{-1} was nearly as effective as the two higher rates (Table 7). Diuron had no effect on California brome. Pronamide partially controlled wild oats in Test 10, and the combination of 1.7 kg ha^{-1} diuron plus 0.70 kg ha^{-1} pronamide controlled 93% of the wild oats, nearly as good as the standard diuron plus ethofumesate treatment (Table 7). Pronamide controlled volunteer perennial ryegrass well in Test 12, and control from 0.42 kg ha^{-1} pronamide plus 1.1 or 1.7 kg ha^{-1} diuron exceeded that from the full rate (3.4 kg ha^{-1}) of diuron alone (Table 7).

Tall fescue establishment in Tests 13 and 14 was unsatisfactory for all herbicide treatments (Table 6). The untreated checks were extremely weedy, although they did contain adequate numbers of tall fescue seedlings. The most successful treatment was 2.2 kg ha^{-1} diuron plus 0.28 kg ha^{-1} pronamide, but this resulted in only 51 and 32% stands in Tests 13 and 14, respectively (Table 6). Diuron at 4.5 kg ha^{-1} alone and with ethofumesate also failed to allow establishment of adequate crop stands (Table 6). Both sites were poorly drained soils with water tables reaching and occasionally rising above the soil surface (Tables 1 and 2). The growers had poor crop establishment and poor weed

Table 7. Effects of pronamide and diuron on weed control between the rows in Tests 6, 7, 8, 9, 10, 11, and 12, autumn 1989 seedings protected by activated charcoal.

Herbicide rate		Italian ryegrass control 5 Apr			Perennial ryegrass control 7 May	California brome control 26 Feb	California brome control 7 May	Wild oat control 22 Feb
Diuron	Pronamide	Test 6	Test 7	Test 8	Test 12	Test 9	Test 11	Test 10
— kg ha^{-1} —		— — — —	— — —	— — —	%	— — —	— — —	— — —
0	0	0	0	0	0	0	0	0
1.1	0.42	98	-	-	95	52	94	51
1.1	0.56	99	-	97	96	72	94	52
1.1	0.70	100	-	100	98	75	98	76
1.1	0.84	-	-	100	-	-	-	-
1.7	0.28	-	92	-	-	-	-	-
1.7	0.42	98	99	-	94	64	97	62
1.7	0.56	100	99	98	98	65	95	87
1.7	0.70	100	-	100	99	68	97	93
1.7	0.84	-	-	100	-	-	-	-
2.2	0.28	-	99	-	-	-	-	-
2.2	0.42	-	99	-	-	-	-	-
2.2	0.56	-	100	-	-	-	-	-
3.4	0	99	-	95	79	0	0	37
3.4[1]	0[1]	98	-	-	85	93	98	97
4.5	0	-	100	-	-	-	-	-
4.5[1]	0[1]	-	100	-	-	-	-	-
LSD ($P < 0.05$)		1.4	4.4	1.8	3.5	27	4.3	59

[1] Treatment included ethofumesate applied at 1.1 kg ha^{-1} on 20 Nov, 21 Nov, or 6 Dec 1989.

control in the surrounding portions of their fields at both of these sites.

In April 1990, the entire field surrounding Test 13 was sprayed with a broadcast application of glyphosate (N-(phosphonomethyl)glycine) and replanted, while the field surrounding Test 14 received a directed application of glyphosate between the rows to remove perennial ryegrass that had survived the grower's application of a relatively low rate of diuron at planting. Failure of the grower's standard carbon-banding, broadcast-diuron programme at these sites may have been caused by uncontrollable soil factors, problems with their charcoal application technique, or carryover herbicide residues from previous crops.

Regression analysis, all seedings

Magnitude of the effects that diuron and pronamide rates had on crop establishment varied greatly between tests and species (Tables 4, 5 and 6). Negative coefficients for herbicides in the regressions imply that higher rates reduced crop stands, whereas positive coefficients imply they improved stands, presumably through indirect effects involving reduced weed competition with the crop as higher herbicide rates more fully controlled weeds. Five of the tests (all in 1989) had either positive coefficients for effects of herbicides on crop stands, or coefficients that did not differ significantly from zero. Lack of crop damage at the rates tested or counteracting benefits from improved weed control presumably occurred in these five cases. In seven other tests, one or both of the herbicide coefficients were significantly less than zero, indicating that some of the herbicide rates were high enough to be causing crop damage. Regression results are not reported from Tests 1 and 2, where injury occurred only at the half-normal rate of charcoal, but they were similar to those from the other tests conducted at the full charcoal rate.

For tall fescue and perennial ryegrass, the absolute magnitude of the effects of pronamide on crop establishment ranged from 17 to 85% stand loss per kg, while the effects of diuron ranged from 3 to 14% stand loss per kg. However, these effects were correlated with each other in any test, and the ratio of the coefficients for pronamide and diuron was relatively more stable than the coefficients themselves. These ratios of the activity of pronamide to diuron ranged from 9.7 in Test 9 to 4.5 in Test 3, but the

degree of uncertainty associated with them varied among the tests (Tables 4, 5, and 6). If these estimates of the pronamide to diuron activity ratio are inversely weighted by significance levels of the coefficients involved in generating them, average estimates for this ratio of 5.8 and 6.5 are obtained for perennial ryegrass and tall fescue, or an average of 6.1 for both species. This ratio can be viewed as implying that each 1 kg of pronamide was equivalent to about 9 kg of diuron when they were substituted for each other in activated charcoal plantings. Orchardgrass was relatively more tolerant to pronamide than tall fescue and perennial ryegrass, and the pronamide to diuron activity ratio for orchardgrass was 2.4 in Test 5 (Table 4).

Growers always face tradeoffs between stand uniformity and level of weed control, and do not hesitate to accept somewhat thinner crop stands if accompanied by improved weed control. The regression equations were solved for diuron and pronamide rates estimated to give stands 75% as good as those in the untreated checks. This 25% reduction in stand was arbitrarily selected as an estimate of maximum tolerable injury, recognising that actual patterns in the spatial distribution of stand gaps will play a key role in determining how large a stand reduction can be tolerated. Because of the ability of individual grass plants to tiller and expand into adjacent unused space, stand reductions of 25% measured at four to five months after planting in these tests were undetectable by summer (data not shown). While first harvest year crop yield is affected in a complex manner by seeding rate, stand reduction from herbicides, weed competition, and weed control, a thorough analysis of these interactions falls outside the scope of this study, and remains to be accomplished.

Except for Tests 13 and 14, rates of diuron (or its equivalent in pronamide) estimated from the regressions to give 75% of check stands were greater than 2.7 kg ha^{-1}, the maximum rate listed on the diuron label (Tables 4, 5 and 6). In those tests where no noticeable crop injury occurred (Tests 6, 7, 8, 11 and 12) stands of 75% of check or better developed at the highest herbicide rates tested. These results imply that substantial safety margins relative to the recommended diuron rate or its equivalent in pronamide existed in most of the tests.

CONCLUSIONS

Pronamide can be substituted for a portion of the diuron applied in activated charcoal plantings of tall fescue, perennial ryegrass, and orchardgrass, improving the control of diuron-tolerant grasses. Seedling California brome was generally controlled by 0.28 to 0.42 kg ha^{-1} pronamide applied at planting, but weed seed germination patterns apparently affected the degree of control. Application of pronamide to new plantings of tall fescue and perennial ryegrass should be accompanied by reducing the diuron rate to about 6 times the pronamide rate, or 1.7 kg ha^{-1} diuron for 0.28 kg ha^{-1} pronamide. Total dose of diuron plus diuron-equivalent of pronamide that can be tolerated by charcoal plantings generally exceeds the 2.7 kg ha^{-1} recommended on the diuron label. A better estimate of the quantity of diuron or diuron-equivalent of pronamide that can be tolerated in new grass seedings should be made. The maximum tolerated herbicide rate will depend not only on charcoal rate, but also on crop species herbicide sensitivity and soil factors needing further characterisation. Its estimation over a wide range of test conditions will require use of an expanded set of treatments sampling a larger region of the pronamide by diuron response surface. Weed control efficacy also needs to be evaluated for the large number of species commonly encountered in western Oregon.

REFERENCES

1. Bertges, W.J. Jr. 1976. Establishment of forage species for seed production with herbicide-protectant combinations. Ph.D. thesis. University of Minnesota, St Paul, USA.

2. Burr, R.J., Lee, W.O. and Appleby, A.P. 1972. Factors affecting the use of activated carbon to improve herbicide selectivity. *Weed Science* 20: 180-183.

3. Lee, W.O. 1973. Clean grass seed crops established with activated carbon bands and herbicides. *Weed Science* 21: 537-541.

4. Lee, W.O. 1977. Winter annual grass control in Italian ryegrass with ethofumesate. *Weed Science* 25: 252-255.

5. Lee, W.O. 1978. Volunteer Kentucky bluegrass (*Poa pratensis*) control in Kentucky bluegrass seed fields. *Weed Science* 26: 675-678.

6 Lee, W.O. 1980. Control of volunteer wheat (*Triticum aestivum*) in fall-planted perennial ryegrass (*Lolium perenne*) with ethofumesate. *Weed Science* 28: 292-294.

7. Mueller-Warrant, G.W. 1987. Herbicide tolerance of California brome currently invading orchardgrass and tall fescue raised for seed. *Western Society of Weed Science Research Progress Report*, p. 357-358.

8. Mueller-Warrant, G.W. and Mellbye, M.E. 1988. Use of Kerb to control California brome in orchardgrass. Seed Production Research at Oregon State University, USDA-ARS Cooperating, p. 4-5.

9. Mueller-Warrant, G.W. and Mellbye, M.E. 1991. Control of California brome (*Bromus carinatus*) with pronamide in orchardgrass (*Dactylis glomerata*)

grown for seed. *Journal of Applied Seed Production* 9:27-35.

10. Stanger, C.E. and Appleby, A.P. 1972. A proposed mechanism for diuron-induced phytotoxicity. *Weed Science* 20: 357-363.