# Control of California Brome (*Bromus carinatus*) with Pronamide in Orchardgrass (*Dactylis glomerata*) Grown for Seed

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## ABSTRACT

**California brome (*Bromus carinatus* H. & A.) has become a troublesome perennial weed in orchardgrass (cocksfoot, *Dactylis glomerata* L.) grown for seed in Oregon because of the absence of effective control measures for established California brome and the decreasing availability of seedling control treatments. Of the five herbicides used for seedling grass control in established orchardgrass as recently as 1987, only the one least effective on California brome, diuron, remains currently registered and available. Field studies were conducted from 1985 to 1989 to evaluate orchardgrass tolerance to and California brome control from promising alternative herbicides. Pronamide (propyzamide) controlled seedling and suppressed established California brome in most tests. Early winter application of pronamide more effectively controlled established California brome than late autumn (fall) or mid-winter timing. However, orchardgrass tolerance to pronamide was slightly better with late autumn than early winter application. Although pronamide visibly injured orchardgrass, seed yield was not affected by rates up to 0.67 kg ai ha$^{-1}$ under weed-free conditions, and was increased where dense infestations of California brome were controlled. Seed yield was reduced when 0.90 kg ha$^{-1}$ or more of pronamide was applied in early winter.**


***Additional index words*: cocksfoot, *Bromus carinatus*, grass seed production, weed control, pronamide, propyzamide, diuron.**

## INTRODUCTION

California brome (*Bromus carinatus* H. & A.) has become a troublesome perennial weed in grasses grown for seed in the Willamette Valley of Oregon, reducing crop yields and complicating the seed cleaning process (Mueller-Warrant and Mellbye, 1988). This native species is widely distributed in the Pacific northwest, is highly variable in morphology, and generally viewed as a short-lived perennial (Hitchcock, Cronquist and Ownbey, 1984). It is found more commonly on higher elevation, relatively well-drained soils such as those used for orchardgrass (*Dactylis glomerata* L.) and tall fescue (*Festuca arundinacea* Schreb.) seed production than on the lower, more poorly drained soils used for perennial ryegrass (*Lolium perenne* L.).

Traditionally, grass-seed growers have relied on combinations of open-field-burning and herbicides to control new weeds coming from seed each autumn in established stands of perennial grasses. Limits during the past decade to the number of hectares burned after harvest have contributed to increasing problems with weeds such as California brome; proposed additional restrictions on the use of open-field-burning and propane-flaming as management tools may further exacerbate the situation.

Ethofumesate ((±)-2-ethoxy-2,3-dihydro-3,3-dimethyl-5-benzofuranyl methanesulfonate) at rates between 1.1 and 2.2 kg ai ha$^{-1}$ has controlled seedling California brome, with the higher rate being needed to control those seedlings past the two-leaf growth stage when treated (Mueller-Warrant, unpublished data). Although ethofumesate is registered for this use in established tall fescue and perennial ryegrass (maximum rate 2.1 kg ha$^{-1}$ in both crops), it is not registered in orchardgrass because of potential serious crop injury (J. Randall King, 1988, Nor-Am Chem. Co., personal communication). Propham (1-methylethyl phenylcarbamate) and chlorpropham (1-methylethyl 3-chlorophenylcarbamate) have been registered for control of various seedling grasses, including *Bromus* spp., in established grasses grown for seed (Anon., 1980 and 1983). However, they were not re-registered as herbicides on any crops, and will no longer be available once current supplies have been exhausted (Ken DeLeo, 1989, PPG Industries, Inc., personal communication).

Grass-seed growers have reported failure to control California brome with diuron (N'-(3,4-dichlorophenyl)-N,N-dimethylurea), atrazine (6-chloro-N-ethyl-N'-(1-methylethyl)-1,3,5-triazine-2,4-diamine), and simazine (6-chloro-N,N'-diethyl-1,3,5-triazine-2,4-diamine), even at rates injuring established crops. Preliminary studies indicated that 0.56 kg ha$^{-1}$ of pronamide (propyzamide) (3,5-dichloro(N-1,1-dimethyl-2-propynyl)benzamide) might control this weed selectively in orchardgrass, but not in tall fescue (Mueller-Warrant, 1987). Indeed, the Oregon and Washington label for use of pronamide on rhubarb (*Rheum* spp.) lists orchardgrass as a weed that may be only partially

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controlled even at 2.2 kg $ha^{-1}$ (Anon., 1988). Although California brome is not listed on the pronamide label for weed control in fallow in the Pacific northwest, downy brome (*Bromus tectorum* L.) is listed as a weed that can be controlled at 0.28 to 0.56 kg $ha^{-1}$. Another case of selective removal of seedling weedy grasses from an established grass with pronamide is the registered use of 1.68 kg $ha^{-1}$ of pronamide on bermudagrass (*Cynodon dactylon* (L.) Pers.) grown for turf or seed (Anon., 1988). These points suggest the possibility that pronamide could be used to remove *Bromus* spp. selectively from orchardgrass at rates near 0.56 kg $ha^{-1}$.

The objectives of these experiments were to evaluate the efficacy of herbicides historically used in orchardgrass seed production on seedling California brome, to evaluate the efficacy of experimental treatments, including pronamide, on seedling and established California brome, and to evaluate the tolerance of orchardgrass to pronamide at rates required to control established California brome.

## MATERIALS AND METHODS

### General techniques

During the period from autumn 1985 to summer 1989, eighteen different herbicides were tested alone and in various combinations at several application rates and dates in thirteen experiments for control of seedling and established California brome and for testing of established orchardgrass tolerance. In Tests 1 to 4 and 10, herbicides were applied with a compressed air, bicycle-type plot sprayer delivering 240 l $ha^{-1}$ at a pressure of 210 kPa through a series of 8002 flat-fan nozzles spaced 30 cm apart at a height adjusted to provide double-overlap coverage at the top of the grass canopy. In Tests 5 to 9 and 11 to 13, herbicides were applied through a hand-held boom, $CO_2$-pressurised, back-pack system calibrated to supply 190 l $ha^{-1}$ at 210 kPa through 8003 flat-fan nozzles spaced 51 cm apart. Herbicides were applied between early autumn and late winter each year, and orchardgrass was harvested the next summer. Pronamide was formulated as a 50% wettable powder. All tests are referred to by year of harvest, although each growing season began the previous autumn. All plots were 2.0 or 2.4 m wide by 6.0 m long.

Soil types were Woodburn silt loam (fine-silty, mixed, mesic Aquultic Argixeroll) in Tests 1, 2, 3, 7 and 10, Willamette silt loam (fine-silty, mixed, mesic Pachic Ultic Argixeroll) in Tests 4 and 5, Coburg silty clay loam (fine, mixed, mesic Pachic Ultic Argixeroll) in Tests 6 and 12, Conser silty clay loam (fine, mixed, mesic Typic Argiaquoll) in Test 8, Hazelair silty clay loam (very fine, mixed, mesic Aquultic Haploxeroll) in Tests 9 and 13, and Malabon silty clay loam (fine, mixed, mesic Pachic Ultic Argixeroll) in Test 11. Soil organic matter content was estimated from measured soil carbon content using the standard conversion factor.

All tests were conducted using randomised complete block designs with four replications. Data were subjected to analysis of variance, and means were separated with LSDs at the $P < 0.05$ level for weed control measurements and at the $P < 0.10$ level for orchardgrass seed yield. A higher risk of type I error in seed yield comparisons was accepted in order to reduce the chance of type II errors (failing to detect yield losses from herbicide injury or yield increases from reduced competitiveness of weeds where these really did occur). Data from common treatments were tested for treatment by location interactions before being pooled. Pooled data were subjected to regression analysis and means separation tests where appropriate.

### Seedling California brome control

Timing of the first herbicide treatments each autumn was determined by the onset of autumn rains, which initiated California brome seed germination. Seedling California brome control was rated by visual observation in comparison to untreated checks. Seedling control was evaluated in prepared seedbed conditions in Tests 1, 2 and 3 in 1986, 1987 and 1988, and in established orchardgrass stands in Tests 6 and 8 in 1988. Prepared seedbed tests were oversown with California brome seed before and after seedbed preparation to ensure severe infestations. Established orchardgrass stands were not oversown with California brome; naturally occurring infestations were relied on to supply the weed seedlings. Stands of these seedlings were sufficiently uniform and dense to reliably rate seedling weed control in established orchardgrass only in Tests 6 and 8 (data not shown for the other tests).

### Established California brome control

Established California brome control was evaluated in nine tests. Two of these were conducted in pure stands of the weed (Tests 2 and 4), and seven more in established orchardgrass seed production fields naturally infested with California brome (Tests 6 to 9 and 11 to 13). Weed infestations in two other orchardgrass stands (Tests 5 and 10) were too low for meaningful evaluations. Numbers of established California brome plants initially present varied substantially between individual plots within tests. Control ratings for established plants were therefore based on reduction in weed seed yield on a per plant basis where weed seed yield was determined (Tests 7 and 12), since this was less variable than yield on a per unit area basis or change in weed density. Control was based on before and after treatment plant counts (weed density) in all other cases. Tests 12 and 13 in 1989 were conducted near sites previously used for Tests 6 and 9 in 1988.

### Orchardgrass tolerance

Standard orchardgrass seed production management practices were followed at all sites in regards to fertilisation, broadleaf weed control, and disease control. Test plots

were not grazed. Straw was removed either by field burning, which provided complete removal, or by raking and baling, which generally left about 1000 kg ha$^{-1}$ of straw on the soil surface. Nitrogen fertiliser was applied in early spring at 140 kg ha$^{-1}$. Scald (*Rhyncosporium orthosporum* Caldwell.) on the inflorescence and upper leaves of orchardgrass was suppressed by application of 0.84 kg ha$^{-1}$ chlorothalonil (tetrachloroisophthalonitrile) during late boot stage. Seed yield was measured each summer by harvesting a 0.9 m wide by 4.8 m long strip through the centre of each plot using a self-propelled swather. Bagged material was air-dried, threshed, and cleaned to a pure seed basis using an air-screen seed cleaner. Instead of an untreated check, diuron was used as the recognised standard against which the experimental pronamide treatments were compared in tests harvested for yield, to avoid interference from seedling grasses other than California brome. Diuron was not applied to plots treated with pronamide. Tests 5 and 10 were conducted under relatively weed-free conditions where density of established California brome was near zero. Tests 6, 7 and 12 were conducted under weedier conditions where competition with uncontrolled California brome might reduce orchardgrass seed yield. Orchardgrass cultivar 'Boone' was used in Tests 5, 6 and 12, while cultivar 'Hallmark' was used in Tests 7 and 10.

## RESULTS AND DISCUSSION

### Seedling California brome control

Atrazine and simazine have been widely used for seedling grass control in orchardgrass grown for seed since their introduction around 1960. However, in 1987 the manufacturer withdrew the registrations of atrazine and simazine for use on perennial grasses grown for seed, citing toxicological concerns and acceptable daily intake limits. While loss of registration of these herbicides limits the practical application of research findings with them, research with atrazine and simazine is still of value in understanding the historical basis of problems with California brome.

The performance of atrazine and simazine for seedling California brome control displays strong response to herbicide rate (Fig. 1). Both triazine herbicides required rates beyond 3.0 kg ha$^{-1}$ to reliably control seedling California brome. However, such rates are considerably greater than the maximums that were allowed under the registrations withdrawn in 1987 (2.2 kg ha$^{-1}$ for both herbicides on orchardgrass). Since most of the atrazine and simazine data points in Fig. 1 came from tests conducted in newly prepared seedbed conditions, rather than in established grass stands where the soil surface is covered with unburned residue or soot from field burns, the graphs probably overestimate herbicide effectiveness in established stands. In any case, failure of the triazines to control seedling California brome at normal use rates of 1.1 to 2.2 kg ha$^{-1}$ does much to explain the past proliferation of this weed in orchardgrass and tall fescue seed production fields.

Diruon was even less effective than atrazine and simazine. At 2.7 kg ha$^{-1}$, diuron controlled less than 30% of seedling California brome in tests where it was applied pre-emergence (near the onset of autumn rains), and between 50 to 90% in tests where it was applied early post-emergence (data not shown). Differences between tests in susceptibility of seedling California brome to diuron may represent genetic differences in tolerance among ecotypes present at the various locations. However, in another test in a clean tilled seedbed, seedling California brome and downy brome were moderately more and greatly susceptible respectively to diuron applied early post-emergence rather than pre-emergence (Mueller-Warrant, unpublished data). This suggests that some differences between sites may have been caused by choice of application date for diuron rather than by genetic differences in tolerance. Even with the optimum application timing, i.e. early post-emergence, diuron at the maximum label rate failed to adequately suppress seedling California brome. Indeed, it is possible to establish nearly pure stands of California brome simply by seeding this species and applying diuron, without the need for techniques such as carbon-banding that are required by nearly all other grass species (Mueller-Warrant, unpublished data).

Chlorpropham and propham applied at 3.4 kg ha$^{-1}$ in mid-October controlled 80 to 90 percent of seedling California brome in most tests, failing only when seedlings were beyond the two-leaf stage when treated (data not shown). These two herbicides have been the treatments of choice for grass seed growers with California brome problems. However, both of these chemicals have disappeared in the ongoing herbicide re-registration process, leaving orchardgrass seed growers with no registered herbicides capable of controlling seedling California brome.

Pronamide controlled seedling California brome well at 0.42 to 0.67 kg ha$^{-1}$, with little evidence of rate response within this range (Fig. 1). In established orchardgrass stands, application of 0.34 kg ha$^{-1}$ pronamide in late autumn in the first portion of the split timing treatment failed at some sites to have adequately controlled seedling California brome by mid-winter. However, pronamide applied in a clean tilled seedbed has controlled seedling California brome at rates below 0.28 kg ha$^{-1}$ (Mueller-Warrant, unpublished data). Although the current research did not precisely identify the minimum rate of pronamide able to control seedling California brome in established orchardgrass, it did demonstrate effectiveness in the range tested of 0.42 to 0.67 kg ha$^{-1}$.

Twelve herbicides were dropped from further testing during the course of the investigations for a variety of reasons (Table 1). Six were dropped because they seriously injured orchardgrass, despite their ability to kill seedling, and suppress established, California brome. Four others were dropped because they did not adequately control seedling California brome, despite acceptable crop tolerance.

The remaining two were dropped because they will apparently not be registered for any uses in the United States. One of them, cinmethylin (*exo*-1-methyl-4-(1-methylethyl)-2-[2-methylphenyl) methoxy]-7-oxabicyclo[2.2.1]heptane), was an extremely promising herbicide for control of seedling grasses without injuring established plants, but in late 1988 the manufacturer abandoned efforts to register it on any crops (J.A. Bruhn, 1988, E.I. duPont de Nemours & Co., personal communication). The other, tridiphane (2-(3,5-dichloropheny)-2-(2,2,2-thrichloroethyl) oxirane), a synergist of photosynthesis-inhibiting herbicides, improved control of seedling California brome by those herbicides, but also reduced safety margins in orchardgrass.

**Established California brome control**

When viewed over all test sites and application dates, pronamide clearly showed a potential to control established California brome, but also great variability (Fig. 2). A general rate response did exist (regression slope coefficient significantly $> 0$ at the $P < 0.05$ level), but this explained only a small part of the total variation in control. Additional sources of this variation must be identified to increase reliability of proposed treatments if use of pronamide to control established California brome in orchardgrass is to be accepted by seed growers, and registered by the manufacturer.

**Table 1. Herbicides lacking adequate weed control efficacy, causing unacceptable orchardgrass injury, or for which manufacturers have abandoned registration efforts.**

| Herbicide | Crop tolerance | General seedling grass control efficacy | Herbicide registration development status (USA) on orchardgrass (OG) |
|---|---|---|---|
| Cinmethylin | good | good | discontinued on all crops |
| Tridiphane[1] | marginal | good | discontinued on all crops |
| Ethofumesate | marginal | good | OG registration withdrawn |
| Glufosinate | poor | good | future OG registration unlikely |
| Sethoxydim | poor | good | future OG registration unlikely |
| Fluazifop-P | poor | good | future OG registration unlikely |
| Terbacil | marginal | good | possible future OG registration |
| Dalapon | poor | good | future OG registration unlikely |
| Dicamba | good | poor | OG currently registered |
| Metribuzin | good | fair to poor | OG currently registered |
| Diclofop | good | fair to poor | future OG registration unlikely |
| Monocarbamide dihydrogensulfate | good | fair to poor | OG currently registered |

[1] Ratings are for tank-mixes of tridiphane plus terbacil, metribuzin, and diuron. Tridiphane applied alone possesses good crop safety but poor weed control efficacy.

Application timing had a significant impact on how well pronamide controlled established California brome (Table 2). Early winter timing was the most effective; the differences between this timing and late autumn or mid-winter alternative timing were more pronounced in 1988 than in 1989. Control improved with rate of early winter applied pronamide up to 0.67 kg ha$^{-1}$ in 1988, when averaged over all four sites (Table 2). When averaged over all three sites in 1989, rate response was unambiguous only up to 0.56 kg ha$^{-1}$. Split late autumn/mid-winter application of a total of 0.67 kg ha$^{-1}$ in 1988 was less effective than applying the entire amount in late autumn, but was more effective than applying it all in mid-winter. These differences for split application did not exist in 1989. Split application was most clearly inferior in Tests 6 and 8, where late autumn application of the full rate provided nearly total control (Table 3, but data not shown for split application).

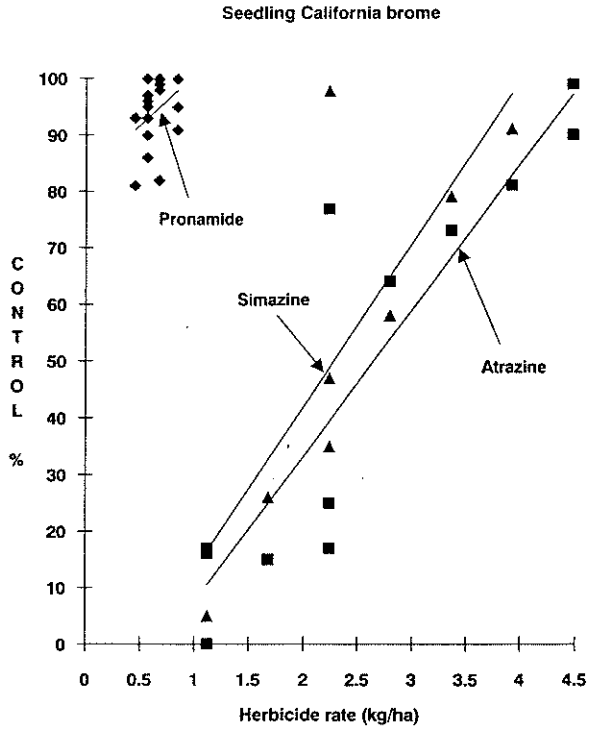



**Figure 1.**
Control of seedling California brome in western Oregon with various rates of atrazine (closed squares), simazine (closed triangles), and pronamide (closed diamonds). Data were pooled from six experiments conducted during 1986-1988. Regression equations for each herbicide were:

Control = -18.4 + 25.8 X Atrazine rate, $R^2 = 0.82$, t = 6.65 with 10 dF;
Control = -15.7 + 28.8 X Simazine rate, $R^2 = 0.62$, t = 3.11 with 6 dF;
Control = 82.8 + 18.1 X Pronamide rate, $R^2 = 0.14$, t = 1.68 with 17 dF.

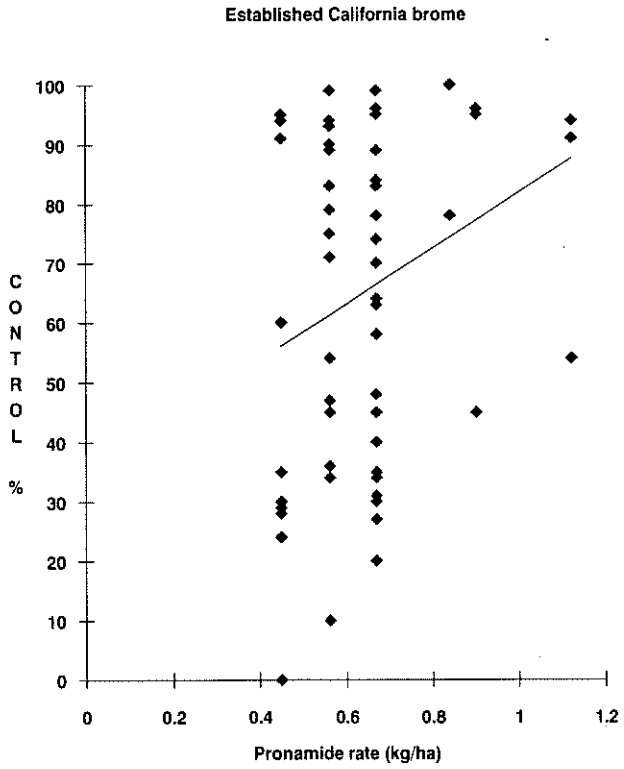



**Figure 2.**
Control of established California brome in western Oregon with various rates of pronamide applied in late autumn, early winter, and mid-winter. Data were pooled from nine experiments conducted during 1987-1989. Regression equation was:

Control = 34.9 + 47.0 X Pronamide rate, R2= 0.07, t = 2.15 with 59 dF.

**Table 2. Influence of pronamide rate and application timing on control of established California brome in western Oregon. Data were averaged over four experiments in 1988 and three experiments in 1989.**

| Pronamide rate | Pronamide application timing[1] | | | | | |
|---|---|---|---|---|---|---|
| | 1988 | | | 1989 | | |
| | Late autumn | Early winter | Mid-winter | Late autumn | Early winter | Mid-winter |
| kg ha$^{-1}$ | % control | | | | | |
| 0.45 | - | 44 c[3] | - | 39 d | 50 cd | - |
| 0.56 | - | 60 b | - | 62 bc | 71 ab | - |
| 0.67 | 59 b | 81 a | 24 d | 64 bc | 70 ab | 63 bc |
| 0.67 split[2] | - | - | 45 c | - | - | 59 bc |
| 0.90 | - | - | - | - | 79 a | - |
| 1.12 | - | - | - | - | 80 a | - |

[1] Late autumn applications were 20 Nov. 1987 and 23 Nov. 1988, early winter applications were 21 Dec. 1987 and 20 Dec. 1988, and mid-winter applications were 22 Jan. 1988 and 21 Jan. 1989, for 1988 and 1989 harvest years, respectively.
[2] Denotes split application of 0.34 kg ha$^{-1}$ in late autumn plus 0.34 kg ha$^{-1}$ in mid-winter.
[3] Means followed by the same letter within a year did not differ at $P < 0.05$.

**Table 3. Crop residue removal practice, stand age, soil organic matter content, and control of established California brome with late autumn and early winter application of pronamide in orchardgrass grown for seed in western Oregon, 1988-1989.**

| Year[1] | Test site | Crop stand age (yr) | Previous crop residue removal practice | Soil organic matter content by depth (mm) | | California brome control by application timing and pronamide rate (kg ha$^{-1}$) | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Late autumn | | Early winter | |
| | | | | 0-6 | 0-50 | (0.67) | (0.45) | (0.56) | (0.67) |
| | | | | % | | | | | |
| 1988 | 6 | 6 | field-burn | 4.7 | 4.0 | 75 b[2] | 60 c | 79 b | 98 a |
| | 7 | 5 | field-burn | - | 3.9 | 58 ab | 29 b | 71 a | 89 a |
| | 8 | 4 | field-burn | - | 4.8 | 64 b | 60 b | 79 ab | 95 a |
| | 9 | 15 | field-burn | 8.3 | 4.9 | 40 a | 28 ab | 10 b | 45 a |
| 1989 | 11 | 7 | field-burn | - | 4.6 | 34 a | 35 a | 39 a | 31 a |
| | 12 | 7 | bale-only | (near site 6) | | 95 a | 91 a | 95 a | 96 a |
| | 13 | 16 | bale-only | (near site 9) | | 63 ab | 24 b | 81 a | 83 a |

[1] Denotes seed crop harvest year. Pronamide was applied during the preceding late autumn and early winter. Late autumn: 20 Nov. 1987 and 23 Nov. 1988. Early winter: 21 Dec. 1987 and 20 Dec. 1988. Pre-treatment, post-harvest crop residues were removed by baling or field-burning in late summer of 1987 and 1988.
[2] Means followed by the same letter within a row did not differ at $P < 0.05$.

Reasons for differences in established California brome control among the three application timings were not directly identified in this study. However, it is known that soil temperatures above a minimum of about 10°C are needed to promote microbial decomposition of pronamide (Yih, Swithenbank and McRae, 1970). Early winter application timing corresponded to conditions of minimum soil temperatures both at treatment and for the first month afterwards (data not shown). Pronamide effectiveness with mid-winter application may have been limited by the relatively short time available between application and the arrival of warmer weather in early spring. Limitations to pronamide's performance with late autumn application were of a different nature; visible control peaked in early spring, with partial recovery occurring in the final two months before harvest.

To more fully understand the rate response for early winter applied pronamide, it is necessary to examine data and conditions in individual tests (Table 3). Consistent rate responses occurred in four out of seven tests. Established California brome control was better at 0.67 than at 0.45 kg $ha^{-1}$ in Tests 6, 7, 8 and 13 (Table 3). In these tests, the intermediate rate, 0.56 kg $ha^{-1}$, generally gave intermediate results, but control at 0.56 kg $ha^{-1}$ was clearly poorer than at the highest rate only in Test 6.

Established California brome control was non-responsive to rate of early winter applied pronamide in three cases (Tests 9, 11 and 12, Table 3). In Test 12, all three rates of pronamide controlled California brome equally well (91-96% control). This test was conducted adjacent to the area used for Test 6 the previous year, and the management shift away from field-burning to use of bale-only crop residue removal may explain California brome's increased sensitivity to pronamide in 1989 compared to 1988.

Negative effects from a prolonged history of field-burning almost certainly explain the results in Test 9, where the highest rate of pronamide, 0.67 kg ha-1, controlled less than half the established California brome (Table 3). This orchardgrass stand was 15 years old, and had been field-burned annually since 1973. The surface 6 mm of soil was black, with a soil organic matter content of 8.3%, almost twice the value found in the same zone at Test 6 or the entire surface 50 mm zone in all tests (Table 2).

When this same area was managed without field-burning for a single summer and pronamide applied again in Test 13, control improved substantially. The lowest rate, 0.45 kg $ha^{-1}$, was still ineffective, but control was good at 0.56 and 0.67 kg $ha^{-1}$, averaging 82% (Table 3). Two higher rates were also tested, 0.90 and 1.12 kg $ha^{-1}$, both giving about 95% control (data shown only in Fig. 1). Control was poor at all rates of pronamide in the only field-burned site used in 1989, Test 11. Soil organic matter in the shallow surface layer was not measured in this test, but the upper soil profile was blackened by soot from field-burning in the summer of 1988, and the site had a seven year history of continuous post-harvest field-burning.

**Orchardgrass tolerance**

Orchardgrass tolerance of pronamide at 0.45 to 0.67 kg $ha^{-1}$ was good. Orchardgrass seed yield under essentially weed-free conditions in Tests 5 and 10 was not affected by application of up to 0.67 kg $ha^{-1}$ pronamide (Table 4). In Tests 6, 7 and 12, seed yield of pronamide treatments generally increased in response to reduced competition from California brome compared to the standard diuron-treated check plots (Table 4).

In Test 6, orchardgrass seed yield increased relative to the diuron-treated check for all pronamide treatments except the lowest rate applied in early winter (Table 4). As this lowest-yielding treatment controlled California brome less successfully than 0.67 kg $ha^{-1}$ applied in late autumn and 0.56 to 0.67 kg $ha^{-1}$ applied in early winter (Table 3), this test clearly demonstrated the benefits of controlling California brome. Highest yield occurred when 0.67 kg $ha^{-1}$ pronamide was applied in late autumn, not only exceeding the diuron-treated check and the lowest rate of pronamide applied in early winter, but also exceeding the split-application treatment. Similar benefits from controlling California brome were also seen in Test 7, where yields were increased by late autumn and early winter applications of pronamide, except for 0.45 kg $ha^{-1}$ applied in early winter, which gave the poorest control of California brome. The three- to four-fold lower density of California brome at the site of Test 7 compared to the site used for Tests 6 and 12 may explain the smaller magnitude of the orchardgrass seed yield response to control of California brome in Test 7 compared with Tests 6 and 12.

Dramatic increases in yield over the diuron-treated check occurred in Test 12, as California brome was controlled. All pronamide treatments increased yield except early winter applications of 0.9 and 1.12 kg $ha^{-1}$, which clearly injured the orchardgrass, and the single mid-winter application, which gave poorest control of California brome (Table 4). Within the group of seven most favourable treatments, all of which gave excellent control of California brome, further insights into the tolerance of orchardgrass to pronamide can be gained. With late autumn application timing, yield decreased slightly as pronamide rate increased from 0.56 to 0.67 kg $ha^{-1}$, indicating the highest rate may have exceeded an optimum for late autumn application in this test. An optimum could have existed here because rates of late autumn-applied pronamide below 0.67 kg $ha^{-1}$ were fully adequate to control California brome, and the additional dose might only be increasing orchardgrass injury without the possibility of any further reduction in competition from California brome. Split application performed well in this test, not only providing yield benefits by controlling California brome, but actually controlling California brome fully as well as any other treatment. The 96 percent control of California brome from the split application treatment in

**Table 4. Effect of herbicide treatment on orchardgrass seed yield, 1988-1989.**

| Herbicide treatment | | Test number and pre-treatment weed density (established California brome plants $m^{-2}$) | | | | |
|---|---|---|---|---|---|---|
| **Timing[1]** | **Rate** | **Test 10 (0.01)** | **Test 5 (0.06)** | **Test 7 (0.66)** | **Test 6 (2.14)** | **Test 12 (2.90)** |
| | kg $ha^{-1}$ | seed yield, kg $ha^{-1}$ | | | | |
| **Late autumn** | | | | | | |
| Diuron standard[2] | 2.7 | 956 a3 | 1195 a | 1504 b | 986 d | 652 e |
| Pronamide | 0.45 | - | - | - | - | 1213 abc |
| Pronamide | 0.56 | - | - | - | - | 1281 ab |
| Pronamide | 0.67 | 940 a | 1204 a | 1863 a | 1491 a | 1053 bc |
| **Early winter** | | | | | | |
| Pronamide | 0.45 | 871 a | 1231 a | 1539 b | 1167 cd | 998 cd |
| Pronamide | 0.56 | - | 1259 a | 1837 a | 1343 abc | 1131 abc |
| Pronamide | 0.67 | 973 a | 1286 a | 1825 a | 1421 ab | 1146 abc |
| Pronamide | 0.90 | - | - | - | - | 699 e |
| Pronamide | 1.12 | - | - | - | - | 550 e |
| **Mid-winter** | | | | | | |
| Pronamide | 0.67 | 904 a | 1184 a | 1635 ab | 1353 abc | 777 de |
| Late autumn/mid-winter split | | | | | | |
| Pronamide | 0.34 + 0.34 | 918 a | 1140 a | 1865 a | 1216 bc | 1341 a |

[1] Late autumn applications were 20 Nov. 1987 (Tests 5-7), 25 Nov. 1987 (Test 10), 23 Nov. 1988 (Test 12 pronamide), and 10 Nov. 1988 (Test 12 diuron); early winter applications were 21 Dec. 1987 (Tests 5-7), 18 Dec. 1987 (Test 10), and 20 Dec. 1988 (Test 12); and mid-winter applications were 22 Jan. 1988 (Tests 5-7), 2 Feb. 1988 (Test 10), and 21 Jan. 1989 (Test 12), for the 1988 (Tests 5-7 and 10) and 1989 (Test 12) harvest years.

[2] Instead of an untreated check, diuron was used as a standard treatment for yield comparisons. This avoided the problem of seedling orchardgrass competition with the crop in check plots that might have biased comparisons in favour of pronamide.

[3] Means followed by the same letter within a column did not differ at $P < 0.10$

Test 12 stands in sharp contrast to the 48, 59 and 37 percent control seen from it in Tests 6, 7 and 8 (data shown only pooled over sites in Table 2). Excellent performance of the split application was probably related to the general success of late autumn applications in Test 12.

In early spring visual evaluations, the early winter timing of pronamide injured orchardgrass more seriously than the late autumn timing (data not shown). Perhaps the greater injury from the later application was merely the result of viewing the damage after less time for recovery had elapsed. However, it may also be an indication of an interaction between timing of pronamide application and subsequent weather. Low soil temperatures are known to slow the rate of breakdown of pronamide (Yih *et al.*, 1970), and various herbicides, including pronamide, decrease the cold tolerance of orchardgrass (Freyman, Moyer and Schaalje, 1982). The possibility exists that unusually cold weather in combination with use of pronamide could reduce orchardgrass yield at rates needed to control established California brome in less severe winters. However, the absence of more favourable alternatives has generated intense interest in the possibility of registering pronamide on orchardgrass grown for seed

## CONCLUSIONS

Pronamide applied at 0.42 to 0.67 kg $ha^{-1}$ controlled seedling California brome much more effectively than the only treatment registered in orchardgrass, 2.7 kg $ha^{-1}$ diuron.

Established California brome was effectively controlled by 0.56 to 0.67 kg $ha^{-1}$ of pronamide applied in late autumn or early winter, except in stands with long histories of field-burning and fresh layers of soot from recent burns. Suppression of California brome by the application of 0.45 kg $ha^{-1}$ pronamide was generally less complete than that from higher rates, and therefore resulted in less dramatic yield increases. Early winter application timing was the most effective on established California brome, but may pose slightly greater risks to orchardgrass. The safety margin in orchardgrass was less than a full 2X for the 0.56 kg $ha^{-1}$ rate of pronamide needed to control established California brome in most tests, and yield reductions can be expected in areas where spray patterns improperly overlap. Partly because of the lack of the traditional 2X safety margin, registration of pronamide for use on orchardgrass may require third party labelling by orchardgrass seed growers and waiving of the manufacturer's liability for crop damage.

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