Oxyfluorfen Controls Seedling Grasses in Established Perennial Grasses Grown for Seed

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ABSTRACT

Traditional practices for seedling grass control in established perennial grasses grown for seed have involved post-harvest field burning followed by herbicide application to emerged weeds. Field burning has been curtailed by regulations and legislation; several of the herbicides used for the past 30 years in grass seed crops have failed to survive the current re-registration process. Herbicide screening trials were therefore conducted to identify alternatives to atrazine, simazine and chlorpropham for weed control in the absence of field burning. Oxyfluorfen was found to be a promising candidate, both applied by itself and when tank–mixed with other herbicides. Applied by itself, oxyfluorfen was most effective at seedling emergence, and control declined rapidly beyond the 2 to 3–leaf growth stage in most species. Volunteer perennial ryegrass (*Lolium perenne* L.) was the hardest to control of the ten species tested, whereas rat's–tail fescue (rattail fescue, *Vulpia myuros* K.C. Gmel.), cocksfoot (orchardgrass, *Dactylis glomerata* L.), and colonial bentgrass (*Agrostis tenuis* Sibth.) were the most susceptible. Crop tolerance to oxyfluorfen applied by itself was generally good, although fine fescue yield was reduced at higher rates. Tank–mixes with diuron, terbicil, metribuzin and pendimethalin provided good control of most weeds but increased crop injury.

Additional index words: **grass seed, grass seed production.**

INTRODUCTION

Weeds pose serious problems in grass seed production (Lee, 1966; Budd and Shildrick, 1968; Johnson, Scott, Dibb and Greenwood, 1982). Species that can be separated from the crop during seed conditioning reduce yield through competition and increase cleaning costs in proportion to their abundance in the field. Weed seeds that cannot be completely removed from the crop during seed conditioning may also influence price and ease of marketing, particularly if their presence is restricted by seed trade laws, regulations, and expectations. Dicot species are generally susceptible to growth–hormone herbicides such as 2,4–D[(2,4–dichlorophenoxy)acetic acid], dicamba (3,6–dichloro–2–methoxybenzoic acid), clopyralid (3,6–dichloro–2–pyridinecarboxylic acid), and picloram (4–amino–3,5,6–trichloro–2– pyridinecarboxylic acid); grass seed yield and quality are usually not affected if care is taken to apply the broadleaf–control herbicides after floral initiation but before inflorescence emergence (Lee, 1970; Canode, 1974; Darwent and Smith, 1982,1988; Mueller–Warrant, unpublished data). Grassy weeds, however, are much harder than dicots to control with herbicides without injuring the crop and reducing the seed yield (Johnson et al., 1982; Oswald, 1985; Waddington, 1988). Volunteer crop seedlings are generally the most common weeds in non–burned stands of established perennial grasses grown for seed, occurring at high densities in nearly all fields after harvest. In Oregon, standards for production of certified perennial ryegrass seed limit the proportion of later–generation plants to no more than 25% of the original planting (Oscar Gutbrod, Seed Certification Office, Oregon State University, 1989, personal communication). Fields violating these standards can be classified as last–year–eligible for certification, forcing them to be taken out of production. Early attempts to control weeds without field burning generally met with disappointing results because of the high densities of volunteer crop seedlings and poor herbicide selectivity (W.O. Lee, USDA–ARS, Corvallis, OR, 1975; D.O. Chilcote and W.C. Young III, Department of Crop and Soil Science, Oregon State University, 1980; personal communication).

Numerous other grass species may be found along with volunteer crop in grass fields grown for seed production. Indeed, many of these weeds pose even greater threats to the production of certified grass seed than do the volunteer seedlings, and their control has been the focus of much previous research. Ethofumesate [(±)–2–ethoxy–2,3–dihydro–3,3–dimethyl– 5–benzofuranyl methanesulfonate] is often used during the establishment of new grass stands for control of weeds such as annual blue grass (*Poa annua* L.), rat's–tail fescue, California brome (*Bromus carinatus* H. & A.), and volunteer wheat (*Triticum aestivum* L.) (Lee, 1977, 1980, 1981). Ethofumesate may also be used in established grass stands for control of the same species. Diuron [N^1–3,4–dichlorophenyl)–*N*,*N*–dimethylurea] has been widely used for weed control in new grass seedings and in established stands (Lee, 1966, 1973, 1981). Crop tolerance to diuron in new seedings is achieved by applying a band of activated charcoal over the row at planting time before the diuron is broadcast. Atrazine [6–chloro–N–ethyl–N^1–(methylethyl)–1,3,5–triazine–2,4–diamine], simazine, (6–chloro–*N*,N^1–diethyl–1,3,5–triazine–2,4– diamine), propham (1–methylethyl phenylcarbamate), and chlorpropham (1–methylethyl 3– chlorophenylcarbamate) have been widely used for seedling grass control in established stands of grass grown

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for seed. In 1987, however, one manufacturer voluntarily withdrew the registrations of atrazine and simazine on established grasses grown for seed. This was followed soon after by another manufacturer's decision not to try to re-register either propham or chlorpropham as herbicides for use on any crops in the United States. This sudden loss of four out of five of the broad-spectrum herbicides registered for control of grassy weeds in established perennial grasses understandably concerned the entire industry. These fears were further compounded by ongoing calls by political leaders for a drastic phase- down of field burning.

Volunteer crop seedlings and other grassy weeds germinate in a dense flush in non- burned fields at the onset of autumn rains, usually around mid-October (Mueller-Warrant, Young, and Mellbye, 1994). Because of the nearly universal use of field burning in grass seed production until the late 1980s, experience in controlling this dense flush has been quite limited (Chilcote, 1969; Chilcote, Youngberg, Stanwood and Kim, 1980; Young, Youngberg, and Chilcote, 1984). However, herbicides have long been used in turf for pre- emergence control of grassy weeds such as annual blue grass. Bensulide [*O,O*-bis(1-methylethyl)*S*-[2[(phenylsulfonyl)amino]ethyl] phosphorodithioate] and DCPA (dimethyl 2,3,5,6-tetrachloro-1,4-benzenedicarboxylate) were shown in the 1960s to safely suppress annual bluegrass in turf (Goss, 1964; Bingham, Schmidt and Curry, 1969). Bensulide is also registered in bentgrass (*Agrostis* spp.) and perennial bluegrasses (*Poa* spp.) grown for seed production, but has been considered too expensive for widespread use. The dinitroanilines pendimethalin [*N*-(1-ethylpropyl)-3,4-dimethyl-2,6-dinitrobenzenamine], benefin [*N*-butyl-*N*-ethyl-2,6-dinitro-4-(trifluoromethyl)benzenamine], and trifluralin [*N*-butyl-*N*ethyl-2,6-dinitro-4-(trifluoromethyl)benzenamine] have all been used in turf to control most seedling grasses and some dicots (Bhowmik and Bingham, 1990). Many other herbicides are used for seedling grass control in other crops, but often stunt or discolour established turfgrass. Examples include metolachlor [2-chloro-*N*-(2-ethyl-6-methylphenyl)-*N*-(2-methoxy- 1-methylethyl)acetamide] and oryzalin [4-(dipropylamino)-3,5-dinitrobenzenesulfonamide], which injured all six species of container-grown ornamental grasses tested in New York (Neal and Senesac, 1991). In the same tests, however, granular pendimethalin plus oxyfluorfen [2-chloro-1-(3- ethoxy-4-nitrophenoxy)-4-(trifluoromethyl)benzene] caused no injury to the grasses.

The herbicide oxyfluorfen is registered or under consideration for registration on minor crops as diverse as onion (*Allium cepa* L.) and muskmelon (*Cucumis melo* var *cantaloupensis naud* L.) for pre-emergence and early post-emergence control of many dicots and some grasses (Akey and Machado, 1985; Bellinder *et al.*, 1993). Oxyfluorfen blocks the synthesis of chlorophyll, leading to the build-up of photodynamic protoporphyrin IX. In the presence of light, this pigment generates large quantities of singlet oxygen, a free radical that peroxidizes lipids, degrading membranes and proteins, and rapidly destroying cellular integrity (Fadayomi and Warren, 1976; Kunert, Homrighausen, Bohme and Bogar, 1985; Lee, Matsumoto, and Ishizuka, 1992). Translocation of oxyfluorfen is extremely limited, although uptake is high (Fadayomi and Warren, 1977b). Oxyfluorfen adsorbs strongly to organic matter and only weakly to clay (Fadayomi and Warren, 1977a). It has very low water solubility (0.1 ppm), significant volatility under some conditions (Grabowski and Hopen, 1985), and does not leach. Higher application rates are required for pre-emergence control of weeds than for foliar destruction of young, already emerged seedlings. Oxyfluorfen was the only herbicide for which diclofop-resistant accessions of rigid ryegrass in Australia showed no cross-resistance (Heap and Knight, 1986). Given the extent to which herbicides will be relied upon to control seedling weeds in non-burned stands of grass, this absence of cross-resistance is encouraging.

Our objectives were to evaluate the efficacy and safety of potential replacements for atrazine, simazine, propham, and chlorpropham for weed control in grasses grown for seed. Efficacy against a wide range of species was tested in the absence of any crop to facilitate evaluation. A large number of treatments were tested in the first year, while emphasis in the second was shifted to focus on oxyfluorfen and oxyfluorfen-containing tank-mixes. Crop tolerance studies were expanded in the second year to include additional species and treatment combinations.

MATERIALS AND METHODS

Weed seeds were planted in rows in prepared seedbeds (soil had been ploughed, disked, and packed to firmness with a roller) in October 1987 and October 1988 in herbicide efficacy studies at the Hyslop Crop Science Field Laboratory near Corvallis, Oregon, USA, in Tests 1 and 2, respectively (Table 1). Crop and weed species screened included cv. Tetrone (or common in second year) Italian ryegrass (*Lolium multiflorum* Lam.), cv. Pennfine (or cv. Premier in second year) perennial ryegrass, annual bluegrass, roughstalk bluegrass (*Poa trivialis* L.), California brome, rat's-tail fescue, downy brome (*Bromus tectorum* L.), Highland colonial bentgrass, mixed chewings, creeping red, and hard fescue (*Festuca rubra* var *commutata* Gaud., *F. rubra* L., and *F. longifolia* Thuill.), tall fescue (*Festuca arundinacea* Schreb.) cv. Tempo and cocksfoot cv. Boone. A naturalised population of weeds was present in Test 3 at Hyslop as a result of previous herbicide screening trials, and the seedbed was left in a rough-ploughed condition to provide a more extreme test of herbicide efficacy. Control was visually rated relative to growth of each species in untreated checks in late winter or spring once maximum injury occurred. Growth stages of the seedling weeds at various herbicide application dates varied among species, with annual blue grass, roughstalk bluegrass, and perennial ryegrass being slightly less advanced (2 to 3 fewer leaves on the primary tiller, 1 to 2 fewer tillers per plant) than Italian ryegrass, rat's-tail fescue, downy brome, and California brome by time of mid-winter herbicide applications.

Tests 4-16 were crop tolerance studies taken to seed yield in all cases except Test 16. Residue management methods following the previous crop harvest were propane flaming in Tests 3-6, open field burning in Tests 7-13, and baling followed by flail chopping the stubble to a 7cm height in Tests 14-16. Tests 6 and 14-16 were conducted at Hyslop. Tests 4,5 and 7-13 were conducted in commercial seed production fields in western Oregon made available by co-operating growers who followed all normal seed production practices except herbicide application. Fertiliser was applied in autumn and spring, and fungicides were applied near anthesis as needed to control stem rust (caused by *Puccinia graminis* Pers. subsp *graminicola* Z. Urban). Control of volunteer crop seedlings was rated in all crop tolerance tests, but data are not shown for Tests 4-13 due to the low density and erratic distribution of weeds following field burning at those sites. Plots were harvested at physiological maturity in June or July of each year at a 15–cm cutting height by cutting and bagging 0.9m–wide strips centred in each plot using a self–propelled swather. Bagged material was air–dried, threshed, and cleaned to determine grass seed yield.

Herbicides were applied at various dates in autumn and winter in Tests 1–6 and 14–16 with a bicycle–wheel, pressurized–air plot sprayer supplying 243 L ha^{-1} at 276 kPa pressure. Herbicides were applied with a hand–held boom, CO_2–pressurised backpack sprayer supplying 187 L ha^{-1} at 207 kPa pressure in Tests 7–13. Treatments were arranged in randomised complete block designs with four replications in all cases except Test 3, which was a split plot design with three replications. Plot width was 2.4 m in Tests 1, 3–6, and 14–16, 1.8 m in Tests 2 and 7–14, and plot length was 3.7, 6.1, 2.4, 6.1, 11.0, 6.4, 5.6, 4.3, and 5.2 m in Tests 1, 2, 3, 4–5, 6, 7–13, 14, 15, and 16, respectively. Plot length in the crop tolerance studies refers to harvested distance after the ends were mowed off to separate adjoining plots. Analysis of variance was performed on all data, and means were separated at the P=0.05 level by a least significant difference (LSD) test. Data from some treatments were omitted from the analyses to minimise table size and improve readability

RESULTS AND DISCUSSION

Weed control efficacy

One of the initial objectives of Test 1 had been to evaluate post-emergence applications of low rates of propyzamide (pronamide)[3,5–dichloro (*N*–1,1–dimethyl–2–propynyl) benzamide] as potential replacements for atrazine. Included within the entire group of treatments were six rates of propyzamide applied at two dates alone and in tank–mixes with 112 g ha^{-1} oxyfluorfen. Although 0.17 kg ha^{-1} propyzamide,the second lowest rate tested, provided 100% control of all species by late winter when applied on 23 November 1987 at the 1 to 2–leaf growth stage, it had not had any visible effects on any species in an earlier rating made only three weeks after application (Table 2). In contrast, the tank–mix of 112 g ha^{-1} oxyfluorfen plus 0.17 kg ha^{-1} propyzamide provided 90 to 100% control of all species by mid–December. The first application of oxyfluorfen by itself was made on 11 December 1987 to seedling grasses in the 2 to 3–leaf growth stage. This application killed nearly all of the annual bluegrass, roughstalk bluegrass, and rat's–tail fescue, but gave only 68 to 84% control of ryegrasses and California brome. Oxyfluorfen applied to 4 to 7–leaf stage grasses on 29 Janaury gave much poorer control than the 2 to 3–leaf stage application on 11 December, achieving good control only for the most sensitive weed, rat's–tail fescue. Application of 224 g ha^{-1} oxyfluorfen to 2 to 6–tiller stage grasses on 24 February was even less effective than the lower rate 27 days earlier. Propyzamide was much less effective when applied on 29 January than when applied on 23 November. Addition of oxyfluorfen to the 29 January application of propyzamide improved control to 90% or better for all species except perennial ryegrass.

Diuron and terbacil [5–chloro–3–(1,1–dimethylethyl)–6–methyl–2,4–(1*H*,3*H*)– pyrimidinedione] were included as standard treatments because they were the only broad– spectrum herbicides still registered for use on some of the grass seed crops, although neither was registered on all of the crops. Diuron was most effective when applied at the 1 to 2–leaf stage (Table 2). It failed to control seedling California brome, but performed well on the other species. Diuron applied after the 2 to 3–leaf stage declined dramatically in efficacy on all species except rat's–tail fescue, even when tank–mixed with oxyfluorfen. Terbacil provided much better control when applied at the 2 to 3–leaf stage than at the 4 to 7–leaf stage (29 Jan.), but tank–mixing it with 224 g ha^{-1} oxyfluorfen on 24 February improved control back to approximately what had been achieved at the first application date, and better than that for California brome. Simazine was nearly as effective at the 1 to 2–leaf stage as when applied pre–emergence. Atrazine applied at the 2 to 3–leaf stage was less effective than the earlier applications of simazine on perennial ryegrass and roughstalk bluegrass. Metolachlor, another potential replacement for the cancelled herbicides, controlled weeds well both pre– emergence and when applied at the 1 to 2–leaf stage.

In autumn and winter of 1988, the effect of timing of oxyfluorfen application was studied in greater detail than it had been in the previous year (Table 3). The first significant autumn rains in 1988 occurred on 6 November, ending an unusually warm, dry spell that had begun in August (Fig. 1). Oxyfluorfen application on 7 November was made between showers to cool, wet soil, but before any signs of seed germination were visible. Applied under these conditions, 140 g h^{-1} oxyfluorfen achieved 99 to 100% control of all species except California brome, for which the control was 93%. Applications made 11 days later still provided good, but clearly less than total control of all species except perennial ryegrass. Control of perennial ryegrass declined more rapidly with delay in application date (and increase in grass growth stage) than occurred for any other species tested. By 19 December (at the 3 to 4–leaf stage), control of perennial ryegrass had dropped to little better than 50%, a condition that continued for other applications made over the next month.

Species whose control was excellent through 2 December (at the 2 to 3–leaf stage) but dropped dramatically by 19 December (at the 3 to 4–leaf stage) included annual bluegrass, California brome, downy brome, and fine fescue. Control of Italian ryegrass, rat's–tail fescue, and cocksfoot dropped off by 3 January (at the 4 to 5–leaf stage). Tall fescue showed a slower increase in tolerance with age than most of the other species, but was reasonably tolerant by 3 Janaury (at the 4 to 5–leaf stage).

Table 1. Test site location, seedbed conditions, cropping history, cultivar and soil type.

Test No.	Location	Seedbed conditions and crop cultivar	Soil type[2]
1	Corvallis, OR	Firm seedbed, weeds planted in rows	Woodburn silt loam
2	Corvallis, OR	Firm seedbed, weeds planted in rows	Woodburn silt loam
3	Corvallis, OR	Rough ploughed, naturalised weed stand	Woodburn silt loam
4	Gervais, OR	Established Loretta perennial ryegrass	Willamette silt loam
5	Gervais, OR	Established Abbey Kentucky bluegrass	Willamette silt loam
6	Corvallis, OR	Established fine fescue[1]	Willamette silt loam
7	Albany, OR	Established Derby perennial ryegrass	Dayton silt loam
8	Tangent, OR	Established Rebel tall fescue	Dayton silt loam
9	Peoria, OR	Established Newport Kentucky bluegrass	Woodburn silt loam
10	Peoria, OR	Established Potomac cocksfoot	Woodburn silt loam
11	Sublimity, OR	Established Koket chewings fescue	Jory silty clay loam
12	Sublimity, OR	Established Lifalla chewings fescue	Jory silty clay loam
13	Albany, OR	Established Penncross creeping bentgrass	Cloquato silt loam
14	Corvallis, OR	Established Hallmark cocksfoot	Woodburn silt loam
15	Corvallis, OR	Established Fawn tall fescue	Willamette silt loam
16	Corvallis, OR	Established Delray perennial ryegrass	Willamette silt loam

[1] *Fine fescue cultivar strips were Agram, Victory, and Cascade chewings fescue, Pennlawn creeping red fescue, and Tournemant, Spartan, Scaldis, Reliant, and Biljart hard fescue.*

[2] *Woodburn silt loam is a fine–silty, mixed, mesic Aquultic Argixeroll; Willamette silt loam is a fine– silty, mixed, mesic Pachic Ultic Argixeroll; Dayton silt loam is a fine, montmorilionitic mesic Typic Albaqualf; Jory silty clay loam is a clayey, mixed, mesic Xeric Haplohumult; Cloquato silt loam is a coarse–silty, mixed, mesic Cumulic Ultic Haploxeroll.*

Table 2. Effect of timing and rate of application of oxyfluorfen and other herbicides on control of seedling grasses in the 1987–88 growing season, Test 1.

Herbicide treatment: Oxyfluorfen application rate g ha^{-1}	Date applied	Seedling grass growth stage	Weed species: Italian ryegrass	Perennial ryegrass	Annual bluegrass	Rough Stalk bluegrass	California brome	Rat's–tail fescue
			% control[2]					
112	11 Dec.	2 to 3–leaf	68 b[1]	73 b	97 ab	98 abc	84 cd	99 a
112	29 Jan.	4 to 7–leaf	28 c	46 c	70 c	70 f	72 d	95 a
224	24 Feb.	2 to 6–tiller	26 c	15 d	10 e	10 hi	54 ef	64 c
O+propyzamide[3]	23 Nov.	1 to 2–leaf	100 a	100 a	100 a	100 a	100 a	100 a
O+propyzamide	29 Jan.	4 to 7–leaf	36 c	21 d	58 d	40 g	56 ef	40 d
112+propyzamide	23 Nov.	1 to 2–leaf	100 a	100 a	100 a	100 a	100 a	100 a
112+propyzamide	29 Jan.	4 to 7–leaf	93 a	75 b	90 b	90 abcd	91 abc	94 a
O+propyz.early rating[4]	23 Nov.	1 to 2–leaf	0 d	0 e	0 f	0 i	0 i	0 e
112+propyz.early rating	23 Nov.	1 to 2–leaf	99 a	90 a	100 a	100 a	99 a	100 a
O+diuron[3]	6 Nov.	pre–emerge	98 a	93 a	97 ab	100 a	0 i	100 a
O+diuron	17 Nov.	1–leaf	100 a	96 a	98 ab	100 a	15 h	100 a
O+diuron	23 Nov.	1 to 2–leaf	100 a	98 a	98 ab	100 a	39 g	100 a
O+diuron	11 Dec.	2 to 3–leaf	99 a	89 a	93 ab	99 ab	19 h	100 a
O+diuron	29 Jan.	4 to 7–leaf	70 b	44 c	76 c	76 ef	11 hi	89 ab
224+diuron	24 Feb.	2 to 6–tiller	11 d	23 d	70 c	20 h	58 e	90 ab
O+terbacil[3]	11 Dec.	2 to 3–leaf	100 a	75 b	98 ab	98 abc	85 bcd	96 a
O+terbacil	29 Jan.	4 to 7–leaf	56 b	49 c	89 b	88 cd	35 g	81 b
224+terbacil@2Xrate	24 Feb.	2 to 6–tiller	96 a	70 b	100 a	100 a	100 a	100 a
O+simazine[3]	6 Nov.	pre–emerge	100 a	100 a	98 ab	100 a	39 g	100 a
O+simazine	23 Nov.	1 to 2–leaf	98 a	92 a	90 b	99 ab	56 ef	100 a
O+atrazine[3]	11 Dec.	2 to 3–leaf	98 a	75 b	94 ab	85 de	44 fg	91 ab
O+metolachlor[3]	6 Nov.	pre–emerge	100 a	100 a	99 ab	96 abc	98 ab	100 a
O+metolachlor	23 Nov.	1 to 2–leaf	99 a	100 a	95 ab	89 bcd	98 ab	100 a

[1] *Within columns, means followed by the same letter do not differ at the P<0.05 probability level.*

[2] *Control relative to untreated checks was visually rated between 22 Feb. and 17 Mar. 1988, except for treatments applied on 24 Feb. 1988, which were rated on 12 May 1988.*

[3] *Standard application rates for other herbicides applied alone or tank–mixed with oxyfluorfen: 0.17 kg ha^{-1} propyzamide, 1.8 kg ha^{-1} diuron, 0.56 kg ha^{-1} terbacil, 2.2 kg ha^{-1} simazine, 2.2 kg ha^{-1} atrazine, and 1.7 kg ha^{-1} metolachlor.*

[4] *A preliminary, early rating of control was made three weeks after 23 Nov. 1987 application of oxyfluorfen + propyzamide and propyzamide alone.*

Terbacil was much more effective applied to 2–leaf grass on 29 November than when it had been applied pre–emergence on 28 October to dry soil (Table 3). Addition of oxyfluorfen to terbacil on 29 November raised the level of control to 99% for perennial ryegrass and 100% for all other species. Results with metribuzin followed similar patterns to those for terbacil: pre–emergence application was unsatisfactory on nearly all species, whereas 29 November (2–leaf stage application) was excellent. Indeed, 29 November application of a metribuzin plus oxyfluorfen tank–mix achieved 100% control of all species. In contrast to results with terbacil and metribuzin, pendimethalin applied pre–emergence on 28 October achieved 100% control of all species, especially perennial ryegrass, fine fescue, and downy brome. Addition of oxyfluorfen to the 29 November pendimethalin application improved control back up to the 95 to 100% range for all species except perennial ryegrass.

Table 3. Effect of timing and rate of application of oxyfluorfen and other herbicides on control of seedling grasses in the 1988–89 growing season, Test 2.

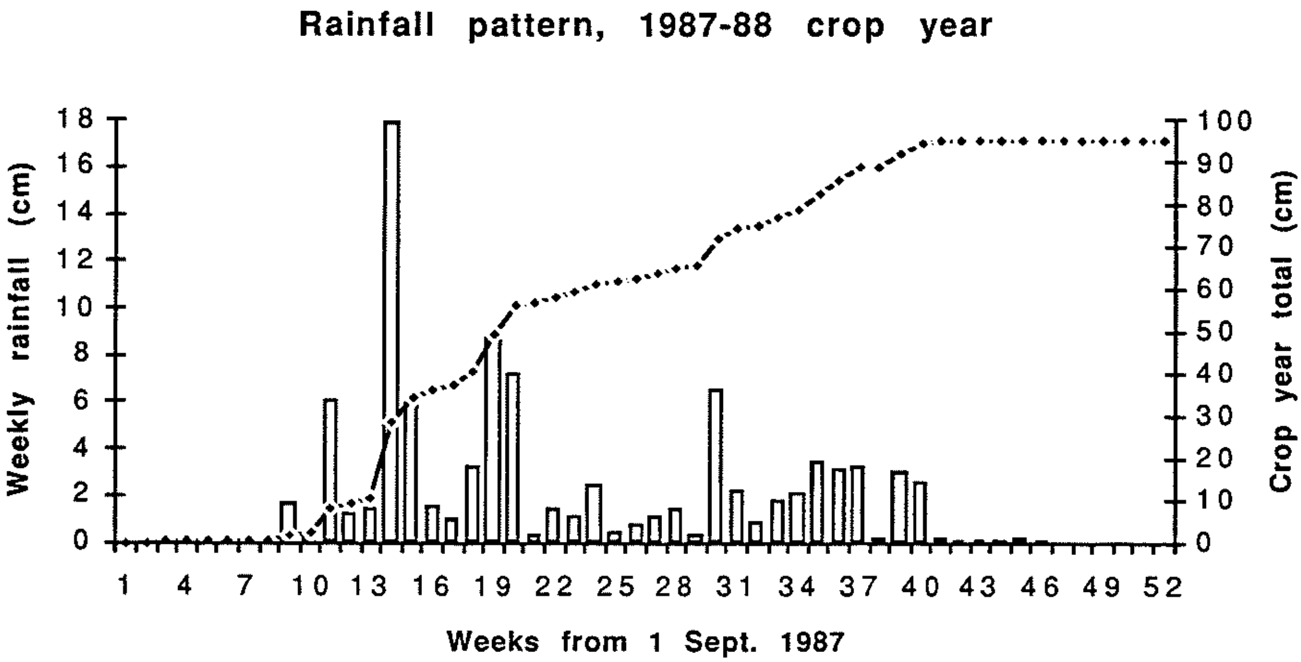
Herbicide treatment[1]		Seedling grass growth stage	Weed Species									
Oxyfluorfen rate g ha^{-1}	Date applied		Italian rye–grass	Peren–nial rye–grass	Annual blue–grass	Califor–nia brome	Downy brome	Rat's tail fescue	Fine fescue	Tall fescue	Cocks–foot	Colonial bent–grass
			% control[2]									
140	7 Nov.	pre–emerge	100 a[3]	99 a	99 ab	93 ab	99 a	100 a	100 a	99 ab	100 a	100 a
140	18 Nov.	1 to 2–leaf	97 a	83 bc	98 ab	96 ab	96 a	100 a	96 ab	93 abc	100 a	100 a
140	29 Nov.	2–leaf	98 a	77 ab	97 ab	98 ab	99 a	100 a	87 abc	83 bcd	100 a	100 a
140	2 Dec.	2 to 3–leaf	98 a	70 cd	98 ab	94 ab	90 a	100 a	87 abc	90 abc	99 a	100 a
157	19 Dec.	3 to 4–leaf	89 ab	55 ef	77 de	52 ef	45 cd	95 abc	58 def	80 cd	97 a	99 a
314	19 Dec.	3 to 4–leaf	96 a	57 e	82 cde	73 cd	50 bcd	97 ab	82 abc	78 cde	94 a	100 a
140	3 Jan.	4 to 5–leaf	67 c	37 g	55 g	62 de	30 ef	79 de	68 cde	43 g	72 bc	100 a
280	3 Jan.	4 to 5–leaf	89 ab	52 ef	82 cde	55 ef	47 cd	83 cd	72 cd	72 de	93 a	100 a
140	19 Jan.	5–leaf	83 b	55 ef	69 ef	45 fg	40 de	77 de	75 cd	70 def	90 ab	99 a
280	19 Jan.	5–leaf	82 b	57 e	58 fg	73 cd	62 b	85 bcd	77 bcd	67 def	82 ab	99 a
O+terbacil	28 Oct.	pre–emerge	62 c	38 g	86 bcd	35 g	20 f	67 e	43 f	62 ef	84 ab	70 c
O+terbacil	29 Nov.	2–leaf	100 a	93 ab	100 a	92 ab	100 a	100 a	100 a	100 a	100 a	100 a
140+terbacil	29 Nov.	2–leaf	100 a	99 a	100 a	100 a	100 a	100 a	100 a	100 a	100 a	100 a
O+metribuzin	28 Oct.	pre–emerge	59 c	45 fg	72 e	42 fg	22 f	52 f	60 def	55 fg	60 c	83 b
O+metribuzin	29 Nov.	2–leaf	100 a	99 a	100 a	91 ab	100 a	100 a	100 a	100 a	100 a	100 a
140+metribuzin	29 Nov.	2–leaf	100 a	100 a	100 a	100 a	100 a	100 a	100 a	100 a	100 a	100 a
O+pendimethalin	28 Oct.	pre–emerge	100 a	100 a	100 a	100 a	100 a	100 a	100 a	100 a	100 a	100 a
O+pendimethalin	29 Nov.	2–leaf	82 b	57 a	94 abc	82 bc	57 bc	97 ab	50 ef	71 def	73 bc	97 a
140+pendimethalin	29 Nov	2–leaf	100 a	81 cd	99 ab	97 ab	99 a	100 a	95 ab	98 ab	100 a	100 a

[1] *Standard application rates for other herbicides applied alone or tank–mixed with oxyfluorfen were 0.56 kg ha^{-1} terbacil, 0.56 kg ha^{-1} metribuzin, and 2.2 kg ha^{-1} pendimethalin.*

[2] *Control relative to untreated checks was visually rated on 28 Feb – 1 Mar 1989.*

[3] *Within columns, means followed by the same letter do not differ at the P<0.05 probability level.*

Similar effects of application dates for terbacil, metribuzin, and pendimethalin occurred in a natural infestation of weeds (Table 4). Terbacil and metribuzin were more effective applied on 7 December than on 28 October for most species present, but the difference in control between the two dates was greater for metribuzin than for terbacil.



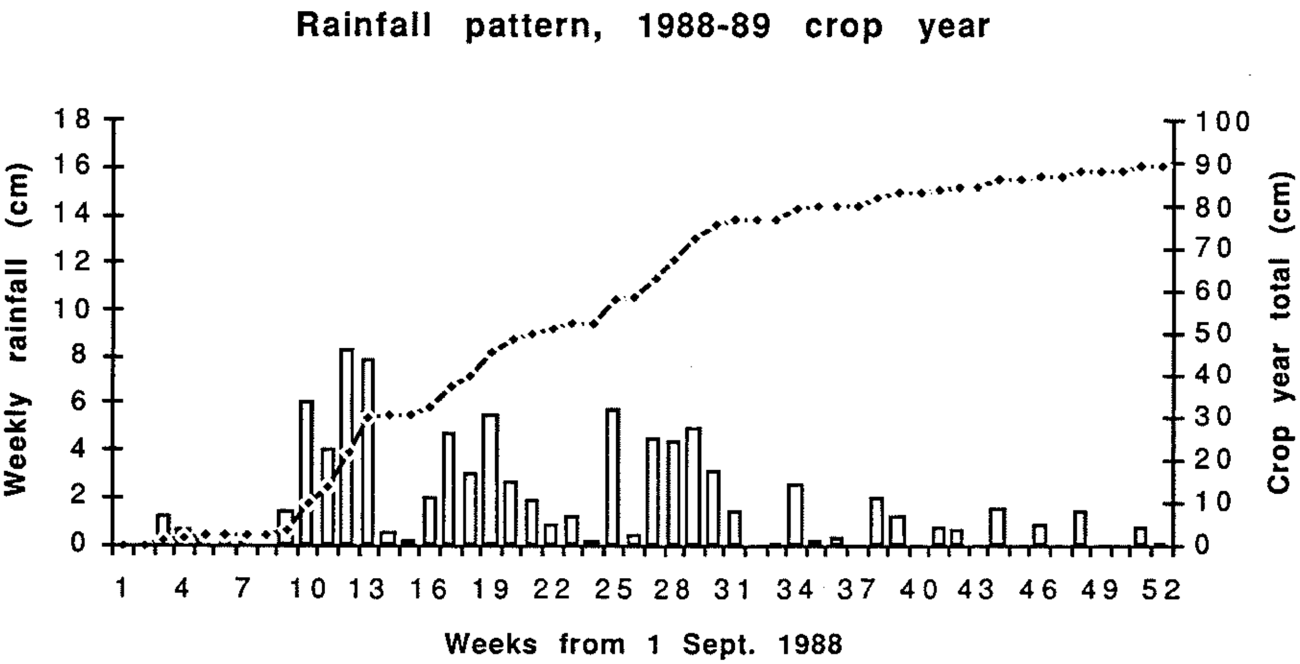


Figure 1. **Weekly and cumulative rainfall occurrence patterns, 1987–88 and 1988– 89 growing seasons at Corvallis, Oregon.**

Table 4. Effect of pre–emergence and post–emergence applications of herbicides on control of natural infestations of downy brome, Italian ryegrass, and rat's–tail fescue in the 1988–89 growing season, Test 3

Herbicide treatment					
Pre–emergence (28 Oct. 1988)	Post–emergence[1] (7 Dec. 1988)	Downy brome	Italian ryegrass	Rat's tail fescue	All grass weeds[2]
kg ha^{-1}		% control[3]			
none	none	0 c[4]	0 d	0 c	0 f
0.84 terbacil	none	93 a	70 bc	0 c	58 bc
0.84 metribuzin	none	27 b	62 c	13 c	35 e
3.4 pendimethalin	none	28 b	90 ab	97 a	57 cd
none	0.84 terbacil	87 a	95 ab	75 ab	89 a
none	0.84 metribuzin	90 a	100 a	60 b	73 b
none	3.4 pendimethalin	0 c	83 abc	88 ab	42 de
none	0.14 oxyfluorfen	90 b	99 a	99 a	94 b
0.84 terbacil	0.14 oxyfluorfen	100 a	100 a	100 a	100 a
0.84 metribuzin	0.14 oxyfluorfen	100 a	99 a	100 a	100 a
3.4 pendimethalin	0.14 oxyfluorfen	100 a	100 a	100 a	100 a
none	0.14 oxyfluorfen+0.84 terbacil	100 a	100 a	100 a	100 a
none	0.14 oxyfluorfen+0.84 metribuzin	100 a	100 a	100 a	100 a
none	0.14 oxyfluorfen+3.4 pendimethalin	99 a	100 a	100 a	99 a
none	156 monocarbamide dihydrogensulfate	40 b	33 c	17 b	38 d
0.84 terbacil	156 monocarbamide dihydrogensulfate	88 a	87 ab	22 b	72 b
0.84 metribuzin	156 monocarbamide dihydrogensulfate	53 b	65 b	37 b	53 cd
3.4 pendimethalin	156 monocarbamide dihydrogensulfate	82 a	99 a	98 a	78 b
none	156 monocarbamide dihydrogensulfate +0.84 terbacil	94 a	100 a	90 a	96 a
none	156 monocarbamide dihydrogensulfate +0.84 metribuzin	93 a	100 a	30 b	78 b
none	156 monocarbamide dihydrogensulfate +3.4 pendimethalin	33 b	83 ab	100 a	57 c

[1] *Within groups of seven treatments in a column, means followed by the same letter do not differ at the P<0.05 probability level.*

[2] *Average control rating for all grass weeds. Dominant species were downy brome and Italian ryegrass, with lower densities of rat's–tail fescue, California brome, and bentgrass.*

[3] *Control relative to untreated checks was visually rated on 19 May 1989.*

A trend toward greater efficacy of pre–emergence rather than post–emergence pendimethalin also existed in this test. Inclusion of 140 g ha^{-1} of oxyfluorfen on 7 December in sequence or tank–mixed with pre–emergence or post–emergence terbacil, metribuzin, and pendimethalin raised control of all grasses to 99 to 100%. Indeed oxyfluorfen applied by itself at 140 g ha^{-1} achieved 99% control of Italian ryegrass and rat's–tail fescue, and 90% control of downy brome. Monocarbamide dihydrogen sulfate applied on 7 December 1988 added little weed control beyond that given by metribuzin, terbacil, and pendimethalin themselves. Cool, wet weather in early December may have enhanced the performance of oxyfluorfen and impaired the performance of monocarbamide dihydrogen sulfate, but such weather is common in western Oregon in late autumn.

Crop tolerance

Oxyfluorfen applied by itself in the 1987–88 growing season had no effect on seed yield of perennial ryegrass and Kentucky bluegrass at rates of up to 224 g ha^{-1}, but did reduce fine fescue yield at 224 and 448 g ha^{-1} (Table 5). Yield loss in fine fescue involved a reduction in the numbers of reproductive tillers per plant rather than problems with seed set or fill (data not shown). Oxyfluorfen did not affect total dry matter production in any species, and the effects on harvest index paralleled those on seed yield (data not shown). However, application of oxyfluorfen did discolour the leaves of all three crops during winter, a condition which appeared in 7 to 14 days and disappeared in another 21 to 42 days. Given the severity of the initial leaf injury, the absence of effects on yield in perennial ryegrass and tall fescue is perhaps more suprising than the presence of some adverse effects in fine fescue.

A broader range of rates was tested in the 1988–89 growing season on a total of six species. Tolerance to oxyfluorfen in fine fescue was tested in two fields because of the sensitivity seen in that species in the first year. Included in the second–year treatments were one experimental treatment (propyzamide) and several standard herbicides, all of which were applied both alone and in tank–mixes with oxyfluorfen (Table 6). None of the herbicide treatments affected perennial ryegrass, tall fescue, or cocksfoot seed yield, including the highest oxyfluorfen rate (560 g ha^{-1}) tested on those crops. Fine fescue seed yield decreased as oxyfluorfen rate was increased in the range from 70 to 560 g ha^{-1} in Test 11. In this test, fine fescue yield at 420 g ha^{-1} was lower than the yield for the traditional standard treatment, simazine applied by itself. In Test 12, fine fescue yield at 280 and 560 g ha^{-1} was lower than the yield of the experimental treatment 0.21 kg ha^{-1} propyzamide plus 140 g ha^{-1} oxyfluorfen. Seed yield response patterns in Kentucky bluegrass and creeping bentgrass were somewhat unusual, with yields apparently both increasing and decreasing as oxyfluorfen rates were incremented. For example, the highest bentgrass yield occurred at 280 g ha^{-1} oxyfluorfen, whereas the lowest yields occurred at both 140 and 1120 g ha^{-1}. Maximum Kentucky bluegrass yield occurred at 70 g ha^{-1} oxyfluorfen, exceeding the yields at 140 and 560 g ha^{-1}, but not those at 0, 280, and 420 g ha^{-1}. Weed seedling densities were relatively low in Tests 7–13, and benefits from controlling weeds probably do not account for the oxyfluorfen rate responses in creeping bentgrass and Kentucky bluegrass. Growth regulatory effects of herbicide treatments may have influenced bentgrass and bluegrass seed yields by reducing lodging or by modestly delaying maturity, possibly decreasing harvest losses due to seed shatter, but this requires confirmation.

In addition to these seven tests which evaluated the effects of oxyfluorfen rate on seed yield of six species grown under propane–flame or field burned conditions, other tests conducted in non–burned fields of cocksfoot, tall fescue, and perennial ryegrass compared the effects of a factorial combination of eight soil residual herbicide treatments and four or five herbicide application timing and tank–mix patterns. In cocksfoot, post–emergence application of monocarbamide dihydrogen sulfate increased seed yield compared with post–emergence applications of oxyfluorfen, soil residual herbicides, or tank–mixes of oxyfluorfen plus the soil residual herbicides (Table 7). However, the same groups of treatments that reduced

Table 5. Seed yield of perennial grasses treated with oxyfluorfen on 7 January in the 1987–88 growing season.

Herbicide treatment / Oxyfluorfen rate (g ha^{-1})	Perennial ryegrass Test 4 - 6 July[2]	Kentucky bluegrass Test 5 - 30 June[2]	Fine fescue Test 6 - 1 July[2]
	Seed Yield (kg ha^{-1})		
0	1176 a[1]	960 a	1254 ab
56	1169 a	1072 a	1285 a
112	1167 a	931 a	1198 ab
224	1362 a	1128 a	1113 b
448	NA[3]	NA	951 c

[1] *Within columns, means followed by the same letter do not differ at the P<0.05 probability level.*
[2] *Harvest date*
[3] *Treatment not applied*

Table 6. Seed yield of perennial grasses treated with oxyfluorfen in the 1988–89 growing season.

Herbicide treatment[1,2] / Oxyfluorfen rate (g ha^{-1})	Perennial ryegrass Test 7 5 July[3]	Tall fescue Test 8 26 June[3]	Kentucky bluegrass Test 9 22 June[3]	Cocksfoot Test 10 22 June[3]	Fine fescue Test 11 27 June[3]	Fine fescue Test 12 27 June[3]	Creeping bentgrass Test 13 15 Aug[3]
	Seed Yield (kg ha^{-1})						
0	2238 a[4]	510 a	1169 ab	1094 a	815 abc	1471 ab	1068 ab
70	2149 a	487 a	1224 a	1194 a	931 ab	1431 ab	1091 ab
140	2154 a	408 a	974 b	1127 a	878 abc	1493 ab	971 b
280	2237 a	458 a	1139 ab	1232 a	865 abc	1327 b	1186 a
420	2143 a	466 a	1114 ab	1119 a	808 bc	NA	NA
560	2070 a	400 a	978 b	1163 a	743 c	1362 b	1082 ab
1120	NA[5]	NA	NA	NA	NA	NA	940 b
140+diuron	2195 a	436 a	1060 ab	1224 a	NA	NA	984 b
diuron	2065 a	521 a	1092 ab	1252 a	NA	NA	1113 ab
140+simazine	NA	NA	NA	NA	845 abc	1439 ab	NA
simazine	NA	NA	NA	NA	967 a	1455 ab	NA
140+propyzamide	NA	NA	NA	NA	NA	1649 a	NA
propyzamide	NA	NA	NA	NA	NA	1500 ab	NA

[1] *Standard application rates for other herbicides applied alone or tank–mixed with oxyfluorfen: 1.8 kg ha^{-1} diuron, 1.8 kg ha^{-1} simazine, and 0.21 kg ha^{-1} propyzamide.*
[2] *Herbicides were applied on 17 Nov., 18 Nov., 29 Nov., 1 Dec., 1 Dec., and 28 Nov. in Tests 7, 8, 9, 10, 11, and 12, respectively.*
[3] *Harvest date*
[4] *Within columns, means followed by the same letter do not differ at the P<0.05 probability level.*
[5] *Treatment not applied*

Table 7. Cocksfoot seed yield and volunteer control from pre–emergence and post–emergence applications of herbicides in the 1988–89 growing season, Test 14

Herbicide treatment factor main effects[1] (kg ha^{-1})	Seed yield 23 June (kg ha^{-1})	Volunteer seedlings 10 Mar (%)
Check treatments and soil residual herbicide means		
no–herbicide check	423 b[3]	0 e
0.14 oxyfluorfen–only check	456 b	97 ab
213 monocarbamide dihydrogensulfate–only check	493 ab	71 d
2.0 diuron	553 a	95 ab
3.4 diuron	528 ab	97 ab
0.49 terbacil	409 b	82 c
0.84 terbacil	301 c	90 b
0.49 metribuzin	485 ab	76 d
0.84 metribuzin	456 c	81 c
2.0 pendimethalin	482 ab	98 ab
3.4 pendimethalin	483 ab	99 a
Herbicide application timing/tank–mix pattern means		
residual herbicides pre–emergence (18 Oct. 1988)	468 ab	75 c
residual herbicides post–emergence (9 Dec. 1988)	433 b	96 a
residual herbicides pre–emergence/0.14 oxyfluorfen post–emergence	429 b	97 a
residual herbicides + 0.14 oxyfluorfen post–emergence	428 b	100 a
residual herbicides pre–emergence/213 monocarbamide dihydrogensulfate post–emergence	543 a	82 b

1 *Treatment design was a factorial combination of eight soil residual herbicide treatments in five application timing and tank–mix patterns, plus three additional check treatments beyond the factorial set (no herbicide check, oxyfluorfen–only check, and monocarbamide dihydrogensulfate–only check). These three check treatments have been pooled into the application timing/tank–mix patterns means for seed yield but not for volunteer control.*

2 *Volunteer control was visually rated relative to untreated checks on 10 March 1989.*

3 *Within columns, means followed by the same letter do not differ at the P<0.05 probability level*

yields slightly were also the ones that were most effective in controlling volunteer cocksfoot seedlings. In tall fescue, pre–emergence applications of the soil residual herbicides were higher yielding than post–emergence applications of oxyfluorfen following pre–emergence soil residual herbicides, or post–emergence applications of tank–mixes of oxyfluorfen plus soil residual herbicides (Table 8). As in the case with cocksfoot, these oxyfluorfen–containing treatments were also the ones that were the best at controlling volunteer crop seedlings.

A third–year perennial ryegrass stand received the same treatments as were used in the cocksfoot test (Table 9). However, most of the treatments caused unacceptable stand loss in perennial ryegrass, and the test was not harvested for seed yield. Diuron at 2.0 and 3.4 kg ha^{-1} virtually destroyed the stand. Application of oxyfluorfen by itself caused over 50% crop injury in a late–season rating. A post–emergence tank–mix of oxyfluorfen plus soil residual herbicides caused an average injury of 68%. Post–emergence oxyfluorfen improved average control from soil residual herbicides from 82% without it to 96 to 100% with it, depending on application timing. Tank–mixes of oxyfluorfen with soil residual herbicides appeared to be slightly more effective than sequential applications, although the difference was not statistically significant. Pendimethalin was the only soil residual herbicide that did not cause unacceptable crop injury. Even the lower rate of pendimethalin, 2.0 kg ha^{-1}, provided an average of 99% control of volunteer perennial ryegrass. The soil residual herbicides tested were generally more effective when applied post–emergence rather than pre–emergence, although this was not true for pendimethalin. Reasons for differences in herbicide tolerance between the perennial ryegrass stands in Tests 4, 7, and 16 are not obvious. However, the perennial ryegrass plants in Test 16 were slow to begin their autumn regrowth, and whatever factors slowed their growth prior to herbicide application probably also contributed to their poor tolerance of the herbicides.

Table 8. Tall fescue seed yield and volunteer control from pre–emergence and post– emergence applications of herbicides in the 1988–89 growing seasaon, Test 15.

Herbicide treatment factor main effects[1] (kg ha^{-1})	Seed yield 16 June (kg ha^{-1})	Volunteer seedling control[2] 3 Apr. (%)
Check treatments and soil residual herbicide means		
no–herbicide check	1479 a[3]	0 f
0.14 oxyfluorfen–only check	1178 c	85 bc
213 monocarbamide dihydrogensulfate–only check	1404 ab	35 e
2.0 and 3.4 diuron avg.	1343 b	92 b
0.49 and 0.84 terbacil avg.	1454 ab	71 d
0.49 and 0.84 metribuzin avg.	1404 ab	79 c
2.0 and 3.4 pendimethalin avg.	1490 a	99 a
Herbicide application timing/tank–mix pattern means		
residual herbicides pre–emergence (18 Oct. 1988)	1506 a	71 b
residual herbicides pre–emergence/0.14 oxyfluorfen post–emergence	1346 b	99 a
residual herbicides + 0.14 oxyfluorfen post–emergence	1350 b	99 a
residual herbicides pre–emergence/213 monocarbamide dihydrogensulfate post–emergence	1397 ab	73 b

1 *Treatment design was a factorial combination of eight soil residual herbicide treatments in four application timing and tank–mix patterns, plus three additional check treatments beyond the factorial set (no herbicide check, oxyfluorfen–only check, and monocarbamide dihydrogensulfate–only check). These three check treatments have been pooled into the application timing/tank–mix patterns means for seed yield but not for volunteer control.*

2 *Volunteer control was visually rated relative to untreated checks.*

3 *Within columns, means followed by the same letter do not differ at the $P<0.05$ probability level.*

Table 9. Perennial ryegrass crop injury and volunteer control from pre–emergence and post–emergence applications of herbicides in the 1988–89 growing season, Teest 16.

Herbicide treatment factor main effects[1] (kg ha^{-1})	Crop injury[2] 26 May (%)	Volunteer seedling control[2] 3 Mar. (%)
Check treatments and soil residual herbicide means		
no–herbicide check	5 g[3]	0 a
0.14 oxyfluorfen–only check	56 d	88 b
213 monocarbamide dihydrogensulfate–only check	15 g	55 d
2.0 diuron	79 b	97 a
3.4 diuron	88 a	99 a
0.49 terbacil	54 d	80 c
0.84 terbacil	66 c	89 b
0.49 metribuzin	55 d	81 c
0.84 metribuzin	66 c	90 b
2.0 pendimethalin	33 f	99 a
3.4 pendimethalin	42 e	100 a
Herbicide application timing/tank–mix pattern means		
residual herbicides pre–emergence (18 Oct. 1988)	41 b	82 b
residual herbicides post–emergence (7–8 Dec. 1988)	60 a	97 a
residual herbicides pre–emergence/0.14 oxyfluorfen post–emergence	62 a	96 a
residual herbicides + 0.14 oxyfluorfen post–emergence	68 a	100 a
residual herbicides pre–emergence/213 monocarbamide dihydrogensulfate post–emergence	37 b	85 b

1 *Treatment design was a factorial combination of eight soil residual herbicide treatments in five application timing and tank–mix patterns, plus three additional check treatments beyond the factorial set (no herbicide check, oxyfluorfen–only check, and monocarbamide dihydrogensulfate–only check). These three check treatments have been pooled into the application timing/tank–mix patterns means for crop injury but not for volunteer control.*

2 *Crop injury and volunteer control were visually rated relative to untreated checks.*

3 *Within columns, means followed by the same letter do not differ at the $P<0.05$ probability level.*

SUMMARY

Oxyfluorfen controlled seedling grasses in non–burned stands of established perennial grasses grown for seed. Weed species varied in their susceptibility to oxyfluorfen, with volunteer perennial ryegrass being the hardest to control. Optimum application timing was early post–emergence when oxyfluorfen was applied by itself, while tank–mixing it with other herbicides widened the satsifactory application window. Because oxyfluorfen seldom achieved total weed control by itself, it will probably need to be used in tank–mixes or sequential applications with other herbicides. Although the potential for crop injury exists, oxyfluorfen–containing treatments appear to be as safe to use as other herbicides registered on grasses grown for seed, when applied early post–emergence either by itself, or in tank–mixes with diuron, terbacil, and metribuzin.

REFERENCES

1. Akey, W.C., and Souza Machado. 1985. Response of onion *(Allium cepa)* to oxyfluorfen during early seedling development. *Canadian Journal of Plant Science* 65:357–362.

2. Belinder, R. R., Binning, L.K., Yourstone, K.S., Bonanno, A.R., Gorski, S.F., Majek, A.B., Neary, P.E., Baron, J.J., Holmdal, J. and Wallace, R.W. 1993. Oxyfluorfen under clear polyethylene film controlled weeds in transplanted cucurbits. *Weed Technology* 7:585–593.

3. Bhowmik, P.C. and Bingham, S.W. 1990. Pre–emergence activity of dinitroaniline herbicides used for weed control in cool–season turfgrasses. *Weed Technology* 4:387–393.

4. Bingham, S.W., Schmidt, R.E. and Curry, C.K. 1969. Annual bluegrass control in overseeded bermuda grass putting green turf. *Agronomy Journal* 61:908–911.

5. Budd, E.G. and Shildrick, J.P. 1968. Preliminary reports of studies on *Poa trivialis* (rough–stalked meadow grass) in seed crops. *Proceedings of the British Weed Control Conference* 9:520–526.

6. Canode, C.L. 1974. Tolerance of five cool–season perennial grasses to selected herbicides. *Agronomy Journal* 66:683–686.

7. Chilcote, D.O. 1969. Burning fields boosts grass seed yield. *Crops Soils* 21:18.

8. Chilcote, D.O., Youngberg, H.W., Standwood, P.C. and Kim, S. 1980. Post– harvest residue burning effects on perennial grass development and seed yield. In: Seed Production (ed. P.D. Hebblethwaite), 91–103, Butterworths, London.

9. Darwent, A.L. and Smith, J.H. 1982. Effects of 2,4–D and dicamba time of application on timothy seed production. *Canadian Journal of Plant Science* 62:1011–1017.

10. Darwent, A.L. and Smith, J.H. 1988. Effects of 2,4–D and dicamba time of application on bromegrass seed production. *Canadian Journal of Plant Science* 68:811–815.

11. Fadayomi, O. and Warren, G.F. 1976. The light requirement for herbicidal activity of diphenyl ethers. *Weed Science* 24:598–600.

12. Fadayomi, O. and Warren, G.F. 1977a Adsorption, desorption, and leaching of nitrofen and oxyfluorfen. *Weed Science* 25:97–100.

13. Fadayomi, O. and Warren, G.F. 1977b Uptake and translocation of nitrofen and oxyfluorfen. *Weed Science* 25:111–114.

14. Goss, R.L. 1964. Pre–emergence control of annual bluegrass (*Poa annua* L.). *Agronomy Journal* 56:479–481.

15. Grabowski, J.M. and Hopen, H.J. 1985. Phytotoxic effects of oxyfluorfen vaporization. *Weed Science* 33:306–309.

16. Heap, I., and Knight, R. 1986. The occurrence of herbicide cross–resistance in a population of annual ryegrass, *Lolium rigidum,* resistant to diclofop–methyl. *Australian Journal of Agricultural Research* 37:149–156.

17. Johnson, J., Scott, J.L., Dibb, C. and Greenwood, M.A. 1982. The effect of controlling volunteer cereals, *Poa trivialis* and ryegrass seedlings on the seed yield of perennial ryegrass. *Proceedings of the British Crop Protection Conference – Weeds*:407–414.

18. Kunert, K.J., Homrighausen, C., Bohme, H. and Boger, P. 1985. Oxyfluorfen and lipid peroxidation: Protein damage as a phytotoxic consequence. *Weed Science* 33:766–770.

19. Lee, J.J., Matsumoto, H. and Ishizuka, K. 1992. Light involvement in oxyfluorfen–induced protoporphyrin IX accumulation in several species of intact plants. *Pesticides, Biochemical, Physiology* 44:119–125.

20. Lee, W.O. 1966. Effect of annual applications of diuron on seed yields of perennial grasses in Oregon. *U.S. Department of Agriculture Technical Bulletin No. 1358,* 23p.

21. Lee, W.O. 1970. Effect of picloram on production and quality of seed in several grasses. *Weed Science* 18:171–173.

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

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

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

25. Lee, W.O. 1981. Control of annual bluegrass *(Poa annua)* in fall–planted perennial ryegrass *(Lolium perenne)* seed fields. *Weed Science* 29:444–447.

26. Mueller–Warrant, G.W., Young, W.C.III and Mellbye, M.E. 1994. Influence of residue removal method and herbicides on perennial ryegrass seed production: I. Weed control. *Agronomy Journal* 86:677–684.

27. Neal, J.C., and Senesac, A.F. 1991. Pre–emergent herbicide safety in container– grown ornamental grasses. *Horticultural Science* 26: 157–159.

28. Oswald, A.K. 1985. Effects of three herbicides used to control volunteer ryegrass on tillering and seed yield of two second year perennial ryegrass crops. *Weed Research* 25:373–379.

29. Waddington, J. 1988. Effect of herbicides for the control of weedy grasses on seed production of bromegrass, crested wheatgrass and timothy. *Canadian Journal of Plant Science* 68:817–821.

30. Young, W.C. III, Youngberg, H.W. and Chilcote, D.O. 1984. Post–harvest residue management effects on seed yield in perennial grass seed production. I. The long–term effect from non–burning techniques of grass seed residue removal. *Journal of Applied Seed Production* 2:36–40.