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PRE AND POSTEMERGENCE CONTROL OF Poa annua IN TURF WITH ETHOFUMESATE

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PRE AND POSTEMERGENCE CONTROL OF *Poa annua* IN TURF WITH ETHOFUMESATE

By

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ABSTRACT

PRE AND POSTEMERGENCE CONTROL OF *Poa annua* IN TURF WITH ETHOFUMESATE

By

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Ethofumesate is an unique herbicide in that it has both pre and postemergence activity to selectively remove *P. annua* from desirable turfgrass. This research used various field studies to evaluate postemergence application timings on the reduction of *P. annua,* injury to desirable turfgrasses, and during renovation. Additional studies compared ethofumesate with other standard preemergence herbicides for *P. annua* control. Greenhouse studies were utilized to determine the effect of temperatures on ethofumesate efficacy. All combination of rates and timings tested were found to be effective at controlling *P. annua*. Multiple applications of ethofumesate showed safety on Kentucky bluegrass and creeping bentgrass and the more applications, the greater the reduction in *P. annua*. Preemergence herbicides provided good control in the fall with ethofumesate being the only exception. Studies indicated freezing temperatures prior to an ethofumesate application are more effective in *P. annua* reduction than when not subjected to freezing temperatures.

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RENOVATION USING ETHOFUMESATE

ABSTRACT

Most renovations on golf course fairways are done to eliminate *Poa annua* infested areas. One major objective of a renovation program is to prevent reinvasion of *P. annua*. Studies were conducted over three years to determine if the application of ethofumesate [2-ethoxy-2, 3-dihydro-3, 3-dimethyl-5-benzofuranyl methanesulfonate] at various rates and times could prevent the reinvasion of *P. annua*. All combination of rates and timings tested were found to be effective at controlling *P. annua*. In general, rates of 0.8 kg a.i. ha^{-1} or less applied either two or four weeks after emergence of the bentgrass provided acceptable turf quality with little injury. Turf density was good for most treatment combinations except the ethofumesate applications at seeding and the 1.7 kg a.i. ha^{-1} rate in 1991. In 1992 percent coverage was weak for most treatments over all seeding dates due to the early, cool fall temperatures resulting in poor growing conditions. Ethofumesate appears to be beneficial in preventing *P. annua* from reestablishing in a newly seeded bentgrass fairway.

INTRODUCTION

On most golf courses *Poa annua* (annual bluegrass) is considered an undesirable weed. Two subspecies of *P. annua* exist; one is an annual, *P. annua* var *annua* (L.) Timm, and the other is a perennial, *P. annua* var *reptans* (Hausskn.) Timm. The annual has an upright growth habit, no or few secondary tillers per culm, prolific seedhead production, little rooting on the culm/tiller, six nodes or less per culm/tiller and the seed has a dormancy period (Beard 1973; Gibeault 1974). The perennial has a creeping growth habit, numerous secondary tillers per culm, less seedhead production, several adventitious roots on a prostrate culm/tiller, greater than six nodes per culm/tiller and no seed dormancy (Beard 1973; Gibeault 1974). Many golf course superintendents and golfers have had to learn to live with *P. annua*. If a golf course has predominantly *P. annua,* the cultural management of the course will be designed to benefit the *P. annua*. Many drawbacks are associated with *P. annua* such as the need for high fertility, disease and insect susceptibility, and high moisture requirement. These drawbacks are causing turf managers to attempt to remove *P. annua*. Cultural and chemical techniques exist to selectively remove *P. annua* but progress can be slow (Kageyama and Widell 1989). Another option is to renovate the existing turf stand.

The renovation process typically results in the closure of the course for at least 3-4 weeks. The majority of renovations are primarily done to remove *P. annua* from the tees, fairways and/or greens. While the purpose of renovation is to remove existing *P. annua*, one would also like to prevent the reinvasion of *P. annua*.

In Michigan the recommendation has been to begin renovation in mid-August and have a well established stand of bentgrass prior to the fall germination of *P. annua*. This procedure can result in interference with play during the peak of the season, increased demands on personnel in the peak of the maintenance season, and *P. annua* may germinate all season long (Chapter 2) contrary to what was previously thought (Beard 1973). It would be highly desirable to delay renovation into the late summer, prevent some of the inconveniences, and prevent reestablishment of *P. annua* in the newly established bentgrass.

The purpose of this research was to develop a renovation procedure for fairways that would minimize the re-encroachment of *P. annua* into the newly established turf. Ethofumesate was chosen because of its selectivity for *P. annua* (Ball and Roberts 1974; Dernoeden and Turner 1988; Dickens 1981; Shearman 1986) and safety on creeping bentgrass (Dernoeden and Turner 1986; Johnson et al. 1989).

MATERIAL AND METHODS

Field studies were conducted for three years and evaluations were conducted from the initiation of the study through the following spring. The first study began in the fall of 1989 and two additional studies were begun in the fall of 1990 and 1991. The research site was located at the Hancock Turfgrass Research Center, East Lansing, Michigan. The site consisted of 70-80% *P. annua* since 1981 ensuring a large seed bank.

Prior to seeding, plots were sprayed with glyphosate [Isopropylamine salt of N-(phosphonomethyl) glycine] at 1.7 kg a.i. ha^{-1}. One week after the glyphosate application the area was verticut with a vertical mower (Ryan Ren-o-Thin1[1]) in three directions to remove much of the dead plant material and break up the soil surface. This dead plant material was removed from the plot area before seeding.

Three seeding times were used in each study. Seeding dates for 1989 were August 18, September 1, and September 15; August 16, August 31, and September 13 for 1990; and August 15, August 29, and September 12 for 1991. Penncross creeping bentgrass was seeded at 49 kg ha^{-1}. The area was fertilized at seeding with 49 kg N ha^{-1} as 12-12-12 and then 24 kg N ha^{-1}

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[1] Cushman Inc., 9036 Ryan, P.O. Box 82409, Lincoln, NE 68501

applied as urea every two weeks for a total of three applications. Plots were mowed three times weekly during the growing season and as needed during late fall and early spring, at a height of 1.3 cm. Mowing did not begin after seeding until seedlings were well established. Each seeding date was watered daily until seed germinated and then only as needed.

A split plot design was used with three replications. Main plots were seeding dates with ethofumesate treatments as subplots. Each subplot was 1.2 x 1.8 m and received ethofumesate treatments at various rates and weeks after emergence (WAE) of the bentgrass (Table 1.1). No additional pesticides were applied to the research area for the duration of the experiment. Treatments were applied with a four nozzle boom-CO_2 backpack sprayer delivering 514 L/ha at 0.28 Mpa.

Visual evaluations were used to determine the control of *P. annua* achieved with the ethofumesate applications and quality of the bentgrass. Control was determined by rating percent *P. annua* on a 0-100% scale. Quality ratings were taken on a 1-9 scale with a rating higher then 6.5 being acceptable for a golf course fairway. A rating of 1 was worst quality and 9 was best quality. Percent turf cover was evaluated on the last two studies. This was done to see if the application of ethofumesate inhibited germination

or rate of cover of the bentgrass. Cover ratings were on a 0-100% scale. A rating less than 97% would be considered unacceptable in a fairway situation.

RESULTS

1989-1990 Field Study

Turf treated with ethofumesate did not show evidence of injury over the early and late seeding dates (Table 1.2). The 0.8 kg a.i. ha^{-1} 4, 6, + 8 weeks after emergence (WAE) along with 0.8 kg a.i. ha^{-1} 4 WAE + 1.4 kg a.i. ha^{-1} 6 WAE treatments did cause some unacceptable quality on the 9/1 seeding date.

Most treatments provided significant control of *P. annua* on all seeding dates. The only exception was 0.8 kg a.i. ha^{-1} 4 WAE + 1.4 kg a.i. ha^{-1} 6 WAE on the first seeding date.

Quality, even though two treatments dropped slightly below unacceptable, recovered nicely during the spring (data not shown).

1990-1991 Field Study

Ethofumesate injury to the turf was not observed at any seeding date (Table 1.3). Even though there were significant differences in quality between several treatments, this quality would be judged acceptable under fairway conditions. Again as in the previous year, all treatments having lower quality recovered during the spring (data not shown).

P. annua populations were significantly reduced by most treatments over all seeding dates, the only exception being 0.4 kg a.i. ha^{-1} 2 WAE + 0.8 kg a.i. ha^{-1} 5 WAE on the first seeding date.

During this field study, the effect of ethofumesate on turfgrass establishment was evaluated. The 0.8 kg a.i. ha^{-1} at seeding + 30 DAT resulted in poor turfgrass cover on the mid- and late seeding dates, and 1.7 kg a.i. ha^{-1} 2 + 5 WAE had unacceptable cover on all seeding dates. Treatments 10 yielded unacceptable cover only on the latest seeding date

1991-1992 Field Study

Treatments on the first seeding date generally exhibited acceptable quality, however, treatments 5, 7, 9, 12, 13, 14, and 18 had unacceptable quality (Table 1.4). On the mid seeding date treatments 9 - 18 gave unacceptable quality. On the last seeding date quality was unacceptable in all plots, including the control plot.

Most treatments significantly controlled *Poa annua*. Two exceptions were treatments 16 and 17 at the early seeding date.

Turfgrass cover was generally acceptable on the early seeding date. Only treatments 9, 10, 12, 13, 14, and 18 gave unacceptable percent cover. On the mid-seeding date only the two treatments, with two applications of 0.8 kg a.i. ha^{-1} at four week intervals, resulted in acceptable turf cover. The last

seeding date had unacceptable percent cover for all treatments including the control.

An unexpected result from all studies was the highly significant effect of seeding date and ethofumesate treatment on the level of *P. annua* establishment (Table 1.5). The early seeding dates had a higher percentage of *P. annua* than the later seeding dates.

DISCUSSION

Most treatments applied at or below the label rate of 0.8 kg a.i. ha^{-1} at two or four WAE with various application intervals had acceptable quality. The only exception was that the late seeding date in 1992 did exhibit undesirable injury. With the combination of cold temperatures and herbicide applications, seedlings never really developed and poor quality resulted. With the exception of the 1991-1992 study even treatments above 0.8 kg a.i. ha^{-1} did not cause poor quality. Treatments applied at seeding in the last two studies had unacceptable quality only in the 1991-1992 study.

Ethofumesate in all studies provided excellent control of *P. annua*. The 0.8 kg a.i. ha^{-1} at 4 WAE followed by two additional applications at either two or four week intervals consistently resulted in excellent *P. annua* control. The 0.8 kg a.i. ha^{-1} at 4 and 8 WAE had more *P. annua* when compared to the 0.8 kg a.i. ha^{-1} with three applications. Treatments with 0.4 and 1.4 kg a.i. ha^{-1} applied to the first seeding dates of all studies had a higher percentage of *P. annua*.

Turfgrass cover was not evaluated until the 1991 study. In the 1991 study all of the treatments had acceptable turf cover with the exception of treatments applied at seeding. All treatments (except those applied at seeding)

applied in the 1992 study had acceptable coverage for the first seeding date but only treatments with two applications in the mid-seeding date had acceptable percent cover and the last seeding showed poor percent cover in all treatments. This poor percent cover in the 1992 study was a result of cold temperatures resulting in winter kill of the bentgrass seedlings and reduced establishment but not winter kill of *P. annua*. An example is the control treatment on the last seeding date of 1992 had 75% cover of which 52% was *P. annua* and therefore only 23% bentgrass.

The poor percent cover observed where treatments were applied at seeding in 1991 and in tilled and untilled treatment in 1992 is not totally expected. Ethofumesate has shown some preemergence activity (Adams 1989) therefore likely preventing the germination of creeping bentgrass especially where organic matter has been removed through tilling (Carlson and Branham 1991). There was a greater reduction in turf cover in 1992 where treatments were tilled versus untilled.

There are several possible reasons why the percentage of *P. annua* was lower for the later seeding dates: 1) maximum activity from ethofumesate comes when the herbicide is not watered in after application; 2) ethofumesate was not acting as a preemergence herbicide (Chapter 3); 3) applications of ethofumesate could be temperature dependent; or 4) *P. annua* germination

levels off or decreases during late summer and fall (Figure 2.1 and 2.2). As the later seeding dates were irrigated to initiate germination of the bentgrass the earlier seeding dates were receiving ethofumesate applications and also being watered due to the layout of the experimental area, leading to reduced ethofumesate activity in the early seeding dates. After the early seeding dates had received all their treatments *P. annua* germination may have continued with little preemergence control from ethofumesate. During later seeding dates conditions were less conducive for *P. annua* germination. With less germination and some control from the ethofumesate treatments, less *P. annua* was observed with the late seedings. The preemergence activity of ethofumesate can be better observed if a comparison of tilled versus untilled plots from the 1992 study is made. There was significantly less establishment of both *P. annua* and bentgrass in the tilled plots when compared to the untilled plots. Most renovation projects would not till but leave the dead, existing turf stand to provide better stability and moisture for the new, establishing seedlings. The tilled plots do not have a layer of organic matter to bind the ethofumesate but the untilled plots still have an organic matter layer present, binding ethofumesate and making the application less effective. On the early seeding dates temperatures were mild, but on the later seeding dates temperatures were colder possibly causing increased *P. annua* control (Chapter

3 and 4) from an ethofumesate application. As an example, in 1991 the average low/high temperature was 14/28 for the early seeding date and 7/20 on the late seeding date.

3 and 4) from an ethofumesate application. As an example, in 1991 the average low/high temperature was 14/28 for the early seeding date and 7/20 on the late seeding date.

Table 1.1. ETHOFUMESATE TREATMENTS FOR RENOVATION STUDIES RATES (kg ai ha^{-1}) AND TIMINGS

1989-1990 Study

1)	Control
2)	0.8- 4 WAE† + 0.8- 8 WAE
3)	0.8- 6 WAE + 0.8- 10 WAE
4)	0.8- 4 WAE + 0.8- 8 WAE + 0.8- 12 WAE
5)	0.8- 4 WAE + 0.8- 6 WAE + 0.8- 8 WAE
6)	0.6- 4 WAE + 0.6- 6 WAE + 0.6- 8 WAE
7)	0.8- 4 WAE + 1.4- 6 WAE
8)	0.4- 2 WAE + 0.8- 5 WAE

1990-1991 Study

1-8)	Same treatments as used in the previous study plus
9)	1.7- 2 WAE + 1.7- 5 WAE
10)	0.8- 2 WAE + 0.8- 5 WAE + 0.8- 8 WAE
11)	0.6- at Seeding + 30 DAT‡
12)	0.8- at Seeding + 30 DAT

1991-1992 Study

1-12)	Same treatments as used in the previous study plus
13)	0.6- at Seeding + 30 DAT (plots tilled)
14)	0.8- at Seeding + 30 DAT (plots tilled)
15)	0.6- at Seeding
16)	0.8- at Seeding
17)	1.1- at Seeding
18)	1.7- at Seeding

† - WAE - weeks after emergence of bentgrass

‡ - DAT - days after treatment

Table 1.2. 1989-90 STUDY OF ETHOFUMESATE ON TURF INJURY AND *Poa annua* CONTROL DURING FAIRWAY RENOVATION

ETHOFUMESATE RATES (kg ai ha^{-1}) AND TIMING	TURF QUALITY (1-9)†			PERCENT *P. annua*		
	11/13/89			5/14/90		
	Seeding Date					
	8/18	9/1	9/15	8/18	9/1	9/15
1) Control	8.0	8.5	8.3	27	38	30
2) 0.8- 4 WAE‡ + 0.8- 8 WAE	8.3	7.7	7.3	11	3	0
3) 0.8- 6 WAE + 0.8- 10 WAE	7.3	8.0	8.7	5	15	2
4) 0.8- 4 WAE + 0.8- 8 WAE + 0.8- 12 WAE	7.3	7.5	7.3	5	1	0
5) 0.8- 4 WAE + 0.8- 6 WAE + 0.8- 8 WAE	7.2	6.2	7.7	1	1	0
6) 0.6- 4 WAE + 0.6- 6 WAE + 0.6- 8 WAE	7.5	7.5	7.5	6	1	1
7) 0.8- 4 WAE + 1.4- 6 WAE	8.7	6.5	7.7	22	0	0
8) 0.4- 2 WAE + 0.8- 5 WAE	7.8	8.0	7.3	14	3	0
LSD (P= 0.05)	**1.2**	**1.2**	**1.2**	**7**	**7**	**7**

† - Quality 1-9 scale; 1= worst quality, 9= best quality, <6.5 unacceptable for a golf course fairway
‡ - WAE - weeks after emergence of bentgrass

Table 1.3. 1990-91 STUDY OF ETHOFUMESATE ON TURF QUALITY, *Poa annua* CONTROL, AND COVERAGE DURING FAIRWAY RENOVATION

ETHOFUMESATE RATES (kg ai ha^{-1}) AND TIMING	TURF QUALITY (1-9)†			PERCENT *P. annua*			PERCENT COVER		
	11/30/90			5/7/91			5/7/91		
	Seeding Date								
	8/16	8/31	9/13	8/16	8/31	9/13	8/16	8/31	9/13
1) Control	8.3	9.0	9.0	55	43	48	100	100	100
2) 0.8- 4 WAE‡ + 0.8- 8 WAE	8.3	8.0	8.3	8	12	0	100	100	98
3) 0.8- 6 WAE + 0.8- 10 WAE	7.0	7.0	8.3	18	1	9	99	99	99
4) 0.8- 4 WAE + 0.8- 8 WAE + 0.8- 12 WAE	7.7	8.0	7.7	15	3	2	99	100	99
5) 0.8- 4 WAE + 0.8- 6 WAE + 0.8- 8 WAE	7.0	8.3	7.0	6	1	0	98	99	97
6) 0.6- 4 WAE + 0.6- 6 WAE + 0.6- 8 WAE	7.3	7.3	8.3	22	4	2	99	100	97
7) 0.8- 4 WAE + 1.4- 6 WAE	8.0	8.3	8.0	18	3	2	98	100	99
8) 0.4- 2 WAE + 0.8- 5 WAE	8.0	8.0	9.0	50	18	8	100	100	99
9) 1.7- 2 WAE + 1.7- 5 WAE	8.3	8.7	8.3	15	0	0	93	89	82
10) 0.8- 2 WAE + 0.8- 5 WAE + 0.8- 8 WAE	7.7	8.3	8.7	10	1	0	98	98	92
11) 0.6- at Seeding + 30 DAT§	8.3	9.0	9.0	6	3	3	99	97	97
12) 0.8- at Seeding + 30 DAT	9.0	9.0	9.0	3	1	0	98	93	92
LSD (P= 0.05)	**0.4**	**0.4**	**0.4**	**13**	**13**	**13**	**3**	**3**	**3**

† - Quality 1-9 scale; 1= worst quality, 9= best quality, <6.5 unacceptable for a golf course fairway
‡ - WAE - weeks after emergence of bentgrass
§ - DAT - days after treatment

Table 1.4. 1991-92 STUDY OF ETHOFUMESATE ON TURF QUALITY, *Poa annua* CONTROL, AND COVERAGE DURING FAIRWAY RENOVATION

ETHOFUMESATE RATES (kg ai ha^{-1}) AND TIMING	TURF QUALITY (1-9)†			PERCENT *P. annua*			PERCENT COVER		
	11/13/91			5/22/92			5/22/92		
	Seeding Date								
	8/15	8/29	9/12	8/15	8/29	9/12	8/15	8/29	9/12
1) Control	7.7	8.0	4.7	38	55	52	100	100	75
2) 0.8- 4 WAE‡ + 0.8- 8 WAE	7.7	7.7	3.3	7	1	0	100	97	35
3) 0.8- 6 WAE + 0.8- 10 WAE	7.7	8.0	4.3	4	3	0	100	99	45
4) 0.8- 4 WAE + 0.8- 8 WAE + 0.8- 12 WAE	8.0	7.0	3.3	1	0	0	100	78	25
5) 0.8- 4 WAE + 0.8- 6 WAE + 0.8- 8 WAE	6.3	7.7	4.7	1	0	0	99	82	18
6) 0.6- 4 WAE + 0.6- 6 WAE + 0.6- 8 WAE	7.7	8.0	3.7	6	1	0	100	92	33
7) 0.8- 4 WAE + 1.4- 6 WAE	6.3	6.7	3.7	8	0	1	99	75	38
8) 0.4- 2 WAE + 0.8- 5 WAE	8.0	6.7	2.0	15	1	0	97	83	30
9) 1.7- 2 WAE + 1.7- 5 WAE	3.7	1.7	1.3	2	0	0	68	10	3
10) 0.8- 2 WAE + 0.8- 5 WAE + 0.8- 8 WAE	7.3	4.7	1.3	1	0	0	83	55	7

Table 1.4. (cont'd).

ETHOFUMESATE RATES (kg ai ha^{-1}) AND TIMING	TURF QUALITY (1-9)			PERCENT *P. annua*			PERCENT COVER		
	11/13/91			5/22/92			5/22/92		
	Seeding Date								
	8/15	8/29	9/12	8/15	8/29	9/12	8/15	8/29	9/12
11) 0.6- at Seeding + 30 DAT§	8.0	1.0	1.0	10	0	0	100	2	10
12) 0.8- at Seeding + 30 DAT	4.7	1.0	1.0	3	0	0	82	1	10
13) 0.6- at Seeding + 30 DAT (plots tilled)	3.0	1.0	1.0	1	0	0	62	1	2
14) 0.8- at Seeding + 30 DAT (plots tilled)	1.3	1.0	1.0	0	0	0	14	2	4
15) 0.6- at Seeding	8.0	1.0	1.0	23	6	0	98	18	23
16) 0.8- at Seeding	7.7	1.0	1.0	47	0	1	100	3	17
17) 1.1- at Seeding	7.3	1.0	1.0	48	0	0	100	4	7
18) 1.7- at Seeding	5.0	1.0	1.0	15	0	0	75	3	12
LSD (P= 0.05)	**1.4**	**1.4**	**1.4**	**8**	**8**	**8**	**18**	**18**	**18**

† - Quality 1-9 scale; 1= worst quality, 9= best quality, <6.5 unacceptable for a golf course fairway
‡ - WAE - weeks after emergence of bentgrass
§ - DAT - days after treatment

Table 1.5. PERCENT *Poa annua* AVERAGED ACROSS-ALL ETHOFUMESATE TREATMENTS WITHIN EACH SEEDING DATE

	YEAR OF STUDY		
SEEDING DATE	**1989-90**	**1990-91**	**1991-92**
Early	9.1	14.2	10.7
Mid	3.4	3.9	0.7
Late	0.4	2.2	0.1
LSD (P= 0.05)	**0.3**	**4.4**	**2.7**

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Chapter 2

PREEMERGENCE CONTROL OF *Poa annua*

ABSTRACT

One chemical method for *P. annua* control would be the use of a preemergence herbicide. A two year study was initiated to evaluate the potential of preemergence herbicides for control of *P. annua*. *P. annua* control was determined by counting the number of seedlings within observation circles. The observation circles provided a means to evaluate the effectiveness of the preemergence herbicides for *P. annua* control. *P. annua* seedlings were counted every two to three weeks in the observation circles as a way to determine the control achieved. Most preemergence herbicides provided consistent control over both years. Products provided good control in the fall with ethofumesate being the only exception. Products giving good control in the fall had good control the following spring. All spring applications provided fair control for almost 8-10 weeks. Oxadiazon [2-tert-butyl-4-(2,4 dichloro-5-isopropoxyphenyl)-Δ^2 1,3,4-oxadiazolin-5-one], dithiopyr [3,5-pyridinedicarbothioic acid, 2-(difluoromethyl)-4-(2-methylpropyl)-6-(trifluoromethyl)-S, S-dimethyl ester], and prodiamine [N^3, N^3-Di-n-propyl-2, 4-dinitro-6-(trifluoromethyl)-m-phenylenediamine] provided the highest level of

control throughout the study with values ranging from 100 to 75% control. Preemergence herbicides appear to be successful in preventing *P. annua* from germination. This could be beneficial in preventing *P. annua* from entering a newly established or renovated fairway.

INTRODUCTION

Controlling *P. annua* is a difficult task. If acceptable control cannot be achieved with postemergence strategies, complete renovation of *P. annua* infested tees, fairways, and greens is an option (Chapter 1). However even with complete renovation, the problem is not solved. During the years an area has been infested with *P. annua*, prolific production of viable *P. annua* seed occurs (Lush 1988b; Grime 1981).

With postemergence control of *P. annua* possible and even in the case of complete renovation, there is still a large seed bank remaining in the soil (Grime 1981). Each *P. annua* inflorescence can produce between 2 to 3 viable seeds (Lush 1988a). On a golf course green this could lead to production of 150,000 - 675,000 seeds m^{-2} y^{-1} (Lush 1988a) with 30,000 seeds m^{-2} persisting till next season or for later years (Lush 1988b). Of the total seeds produced there is a potential of 100,000 - 265,000 seeds germinating (Lush 1988a) with little or no dormancy needed for the seed (Warwick and Briggs 1978). Koshy(1969) has stated the versatility of seed formation for *P. annua* contributes to its conspicuous success as a weed. In addition to a postemergence control program or following renovation, a preemergence

strategy should play an important role in preventing *P. annua* from reestablishing.

The variability that exists within *P. annua* (Koshy 1969; Wu, Till-Bottraud and Torres 1987; McNeilly 1984; Naylor and Abdalla 1982) could pose a challenge in the use of a preemergence control plan for *P. annua*. Germination of *P. annua* will vary from one golf course to the next (Wu, Till-Bottraud and Torres 1987) and even from one part of a course to another (Lush 1989). In addition to the variability due to location, germination will vary depending on the requirements needed to initiate germination. *P. annua* germination is most successful at temperatures between 10 and 15°C (Beard 1980; Standifer 1988; Eggens and Ormrod 1982; Naylor and Abdalla 1982), but will germinate over a large temperature range. Most germination will occur between 2 to 40°C and decline above and below this range (Koch 1968). Success in germination is also dependent upon sufficient light (Naylor and Abdalla 1982) and promoted by adequate nitrate (Williams 1983).

With the success of *P. annua* and the variability within the species, the use of a preemergence herbicide to control *P. annua* germination could be challenging. Development of a control strategy using a preemergence herbicide could be beneficial in preventing *P. annua* from establishing. The objective of this research was to attempt to determine which herbicides provide

good preemergence *P. annua* control at fairway height. Some research has been done on preemergence control of *P. annua* (Juska and Hanson 1962; Engel 1976) but is limited and has not looked at preemergence control on fairway height cut and the potential to develop a *P. annua* management strategy. Other objectives were to determine the longevity of the preemergence applications and the need for multiple applications. Evaluation of preemergence control of *P. annua* becomes difficult in a densely populated turf stand. Counting the number of seedlings within observation circles was a way to overcome this problem.

MATERIAL AND METHODS

Two field studies were conducted during the fall of 1990 through the spring of 1991 and one study in the fall of 1991 through the spring of 1992 to evaluate ethofumesate and other preemergence herbicides for preemergence *P. annua* control. The research site consisted of a predominately *P. annua* turf at the Hancock Turfgrass Research Center, East Lansing, Michigan. The area was fertilized with 46-0-0 totaling 146 kg N ha^{-1} in 1990, 98 kg N ha^{-1} in 1991 and 76 kg N ha^{-1} in 1992. Pesticides applied were fenarimol [α-(2-chlorophenyl)-α-(4-chlorophenyl)-5-pyrimidinemethanol] at 5 kg ha^{-1} and a combination product of 2,4-D [dimethylamine salt of 2,4-dichlorophenoxyacetic acid]; mecoprop [dimethylamine salt of 2-(2-methyl-4-chlorophenoxy) propionic acid]; and dicamba [dimethylamine salt of dicamba (3,6-dichloro-o-anisic acid)] at 21 L ha^{-1} in 1990, two applications of triadimefon [1-(4-chlorophenoxy)-3, 3-dimethyl-1-(1H-1, 2, 4-triazol-1-yl)-2-butanone] at 6 kg ha^{-1} and an application of chlorothalonil [tetrachloroisophthalonitrile] at 18 kg ha^{-1} in 1991, and sethoxydim [2-[1-(ethoxyimino)butyl]-5-[2-(ethylthio)propyl]-3-hydroxy-2-cyclohexen-1-one] at 25 kg ha^{-1} were made in 1992. The plots were mowed three times weekly

during the growing season and as needed during late fall and early spring, at a height of 1.3 cm. The area was irrigated as needed.

The 1990 and 1991 general preemergence studies used a randomized complete block design with three replications. Individual plots measured 1.2 m x 3.0 m. The ethofumesate [2-ethoxy-2, 3-dihydro-3, 3-dimethyl-5-benzofuranyl methanesulfonate] study in 1990 used a factorial design to evaluate ethofumesate control in the fall and spring. Factor one was a fall application and factor two was a spring application. Each factor had five rates of ethofumesate 0.0, 0.6, 1.1, 1.7, and 2.2 kg a.i. ha^{-1}. Plot size was 1.2 m x 1.8 m. The plots in the 1990 and 1991 studies were split in half with one half receiving both fall and spring applications. This allowed evaluation of preemergence control of the spring and fall application.

For both studies liquid treatments were applied with a four nozzle boom-CO_2 backpack sprayer delivering 514 L ha^{-1} at 0.28 MPa for the fall applications and 538 L ha^{-1} at 0.28 MPa for the spring applications. Granular treatments were weighed and applied with a shaker bottle. All treatments were applied on 9/6/90 for the ethofumesate study. The general preemergence studies were initiated on 9/11/90 and 9/11/91. Spring applications were applied on 4/12/91 and 3/31/92. All treatments were watered in with approximately 0.6 cm of water.

Observation circles measuring 11.4 cm^2 were sprayed with glyphosate [N-(phosphonomethyl) glycine] in each plot area. The observation circles provided a means to maintain a microclimate (temperature, moisture, organic matter, cover, etc.) similar to an established fairway turf. Counting the seedlings within the circles provided an estimate of *P. annua* control.

Seedlings were counted every two to three weeks in three of the six observation circles in 1990-91 and four of eight circles in 1991-92. The circles were then sprayed again with glyphosate. On the next evaluation the remaining circles were used for evaluation and then sprayed with glyphosate. This procedure of alternating between half of the observation circles continued throughout the study. The average seedlings per treatment were determined and data are reported as percent control. Experimental design was a randomized complete block with three replications; all data were subjected to an analysis of variance.

RESULTS

1990-1991 Field Studies

Ethofumesate treatments applied in the fall gave little to no control of *P. annua* (Table 2.1), and the study was discontinued after the fall data was collected.

The general preemergence study gave excellent control of *P. annua* (Table 2.2). The two evaluations taken in October showed more than 90% control with a preemergence herbicide. The last evaluation taken on 11/5 (data not shown) indicated that germination of *P. annua* had ceased.

Control from the fall application was still evident in the evaluation taken at the time of the spring application. Both rates of pendimethalin [N-(1-ethylpropyl)-3,4-dimethyl-2,6-dinitrobenzamine], dithiopyr (EC), benefin [N-butyl-N-ethyl-α,α,α-trifluoro-2,6-dinitro-p-toluidine], and DCPA [dimethyl tetrachloroterephthalate]; and the low rate of dithiopyr (G) had less than 75% control. All other treatments provided greater than 75% control of *P. annua*. By the 6/17 evaluation all fall applied treatments provided 0% control.

Spring treatments were applied on 4/12/91 when germination of P. annua had already occurred. Treatments gave excellent control (Table 2.3) on the 5/30 evaluation with the low rates of dithiopyr (G) and benefin, and

bensulide [S-(0,0-diisopropyl phosphorodithioate) ester of N-(2-mercaptoethyl) benzenesulfonaminde] having less than 75% control (Table 2.3). On the 6/17 evaluation, almost ten weeks after application only bensulide, the low rates of oxadiazon and prodiamine; and the high rate of dithiopyr (G) had better than 75% control. The 7/1 evaluation showed all treatments provided less than 75% control.

The spring treatments were applied on 4/12 and controlled *P. annua* germination for approximately 12 weeks. The first evaluation after the spring application taken on 5/10 showed no germination in any of the treatments including the control plots. Research has shown that when soil is dry and temperatures are high, emergence of *P. annua* may be delayed and when temperatures are low, emergence is delayed or reduced (Wells 1974). This may explain the rating on 5/10 with no germination, since prior to the evaluation the environmental conditions were cool and dry and not conducive to *P. annua* germination.

1991-1992 Field Studies

Fall treatments provided greater than 75% control of *P. annua* germination on the 10/22 evaluation date with the exception of both rates of ethofumesate and the low rate of benefin(Table 2.4). All treatments on the

11/8 evaluation had better than 75% control except the low rate of ethofumesate.

The first spring evaluation on 4/23 showed that the low rates of oxadiazon and pendimethalin; both rates of benefin, bensulide and ethofumesate; the high rate of dithiopyr (EC); and benefin + trifluralin [N-butyl-N-ethyl-α,α,α-trifluoro-2,6-dinitro-p-toluidine + α,α,α-trifluoro-2,6-dinitro-N,N-dipropyl-p-toluidine] had less than 75% control. The 5/13 evaluation showed that benefin + trifluralin; the low rates of oxadiazon [2-tert-butyl-4-(2,4 dichloro-5-isopropoxyphenyl)-Δ^2 1,3,4-oxadiazolin-5-one], dithiopyr(EC), prodiamine, bensulide; the high rate of DCPA [Dimethyl tetrachloroterephthalate]; and both rates of benefin and ethofumesate gave less than 75% control. On 6/1 the low rate of prodiamine; the high rates of dithiopyr (G) and bensulide; and both rates of pendimethalin and DCPA gave better than 75% control. The final evaluation taken on 6/22 showed no treatments giving better than 75% control.

Spring applications were applied on 3/31/92 and unlike the previous year *P. annua* had not yet germinated. Spring applied treatments gave excellent control until 6/22 with most treatments giving greater than 75% control of *P. annua* compared to the check plot (Table 2.5). On the 6/22 evaluation treatments began to show reduced control. The only treatments

giving better than 75% control were the high rates of oxadiazon, pendimethalin, and prodiamine.

DISCUSSION

As cited in the literature, *P. annua* produces prolific amounts of seed and the viability of that seed is high; the need to prevent germination is very important. These results show the potential preemergence herbicides could play in the overall control strategy of *P. annua*. Preemergence herbicides can prevent *P. annua* seed from reestablishing.

Preemergence herbicides gave significant control except ethofumesate. Ethofumesate has been shown to have both post and preemergence properties for *P. annua* control (Adams 1989). In a preemergence study done at Michigan State University in 1987 (Carlson and Branham 1991), ethofumesate gave excellent preemergence control of *P. annua*. The 1987 study was conducted on bare soil with all rates of ethofumesate providing good control of *P. annua*. Why was ethofumesate effective in the bare soil study but gave little to no control in these preemergence studies? In the bare soil study, there was little organic matter on the soil surface. Thus, the organic matter inherently present with turf, approximately 0.6-1.3 cm of thatch in these studies, may bind ethofumesate making it ineffective as a preemergence control.

Most herbicides provided consistent control over both years. Preemergence herbicides provided good control in the fall with ethofumesate

being the only exception. In the evaluations, oxadiazon, pendimethalin, dithiopyr (G), prodiamine, and DCPA provided good control. Benefin, dithiopyr (EC), and bensulide had fair control with ethofumesate and benefin + trifluralin having poor control. In 1992 control was observed approximately one month longer than 1991 and was probably the result of the unseasonably cool fall in 1991 giving little reduction of the herbicide activity.

Spring herbicide applications provided control for about 8-10 weeks before they began to have reduction in preemergence control. Benefin, dithiopyr (EC) bensulide, DCPA, and ethofumesate provide the weakest control.

These conclusions drawn from both years may not be totally representative of what is occurring. The observation circles were small in size and few in number making variability high. In addition the circles were lacking plant cover so were not totally representative of a turf stand. This may account for some of the variability with a product over both years.

The next logical step in controlling *P. annua* is to determine the optimum timing to apply the preemergence herbicide for the most effective results. Germination of *P. annua* occurs much earlier in the spring than expected. The average number of seedlings in the control plots was plotted against time for both 1991 and 1992. The results show that *P. annua*

germinates early and all season long (Figure 2.1 and 2.2). There are several times at which no germination occurred and this is probably related to conditions not conducive to germination. Previous investigators (Beard *et al.*1978) thought that *P. annua* germinated in the spring and fall and stopped during the summer. These results suggest that two or more preemergence applications may be needed to achieve season long control. A fall application is beneficial for fall germination and gives some control the following spring. With the early germination of P. annua it is important to get a spring application out as early in the spring as possible. With these studies giving approximately eight good weeks of control before germination started, an additional one or two applications would be needed to prevent germination and give season long control.

Table 2.1. 1990 FALL ETHOFUMESATE APPLICATION FOR CONTROL OF *Poa annua*

ETHOFUMESATE†	PERCENT CONTROL‡		
kg a.i. ha^{-1}	**9/29/90**	**10/22/90**	**11/5/90**
2.2	13	17	3
1.7	7	13	0
1.1	11	9	14
0.6	9	30	5
0.0	0	0	0
LSD (P= 0.05)	**NS**	**16**	**NS**

† - Treated 9/11/90

Table 2.2. 1990 FALL PREEMERGENCE APPLICATION FOR CONTROL OF *Poa annua*

	FORMULATION	RATE (kg a.i. ha-[1])†	PERCENT CONTROL 10/6/90	10/22/90	4/16/91
1) Oxadiazon	2 G	2.2	94	100	79
2) Oxadiazon	2 G	4.5	100	100	98
3) Pendimethalin	60 WDG	2.2	100	94	24
4) Pendimethalin	60 WDG	3.4	100	100	68
5) Dithiopyr	0.25 G	0.3	98	89	67
6) Dithiopyr	0.25 G	0.4	98	97	86
7) Dithiopyr	1 EC	0.4	100	99	56
8) Dithiopyr	1 EC	0.6	100	100	62
9) Benefin	2.5 G	2.2	93	83	34
10) Benefin	2.5 G	3.4	100	100	60
11) Prodiamine	65 WDG	0.6	100	100	82
12) Prodiamine	65 WDG	0.8	100	100	85
13) Bensulide	4 EC	14.0	100	100	73
14) DCPA	75 WP	11.8	100	100	61
15) DCPA	75 WP	16.8	100	100	56
	LSD (P=0.05)		**10**	**22**	**35**

† - Treated 9/6/90

Table 2.3. 1991 SPRING PREEMERGENCE APPLICATION FOR CONTROL OF *Poa annua*

	FORMULATION	RATE (kg a.i. ha^{-1})†	PERCENT CONTROL		
			5/30/91	**6/17/91**	**7/1/91**
1) Oxadiazon	2 G	2.2	90	77	20
2) Oxadiazon	2 G	4.5	94	67	57
3) Pendimethalin	60 WDG	2.2	88	40	21
4) Pendimethalin	60 WDG	3.4	100	57	14
5) Dithiopyr	0.25 G	0.3	67	55	29
6) Dithiopyr	0.25 G	0.4	100	90	58
7) Dithiopyr	1 EC	0.4	100	50	58
8) Dithiopyr	1 EC	0.6	100	33	13
9) Benefin	2.5 G	2.2	67	28	22
10) Benefin	2.5 G	3.4	80	35	30
11) Prodiamine	65 WDG	0.6	100	82	55
12) Prodiamine	65 WDG	0.8	94	50	40
13) Bensulide	4 EC	14.0	37	76	64
14) DCPA	75 WP	11.8	95	58	50
15) DCPA	75 WP	16.8	81	61	45
	LSD (P=0.05)		**38**	**41**	**NS**

† - Treated 4/12/91

Table 2.4. 1991 FALL PREEMERGENCE APPLICATION FOR CONTROL OF *Poa annua*

	FORMULATION	RATE (kg a.i. ha^{-1})†	PERCENT CONTROL					
			10/22/91	**11/8/91**	**4/23/91**	**5/13/91**	**6/1/91**	**6/22/91**
1) Oxadiazon	2 G	2.2	100	100	66	25	33	0
2) Oxadiazon	2 G	4.5	100	100	79	89	50	25
3) Pendimethalin	60 WDG	2.2	100	100	55	75	100	0
4) Pendimethalin	60 WDG	3.4	100	100	94	100	100	5
5) Dithiopyr	0.25 G	0.3	100	100	78	92	33	0
6) Dithiopyr	0.25 G	0.4	100	100	98	100	66	1
7) Dithiopyr	0.25 G	0.6	100	100	100	92	100	0
8) Dithiopyr	1 EC	0.4	100	100	97	36	62	0
9) Dithiopyr	1 EC	0.6	100	100	67	89	67	0
10) Benefin	2.5 G	2.2	67	100	11	8	31	4
11) Benefin	2.5 G	3.4	100	94	50	56	40	0
12) Prodiamine	65 WDG	0.6	100	100	100	58	100	31
13) Prodiamine	65 WDG	0.8	100	100	88	81	67	23
14) Bensulide	4 EC	14.0	100	100	52	58	83	8
15) Bensulide	4 EC	11.2	100	100	59	83	62	0
16) DCPA	75 WP	11.8	100	100	88	83	79	0
17) DCPA	75 WP	16.8	100	100	88	33	90	5
18) Ethofumesate	1.5 EC	0.8	33	94	29	67	14	35
19) Ethofumesate	1.5 EC	1.7	33	50	35	22	21	1
20) Benefin + Trifluralin	2 G	1.7	100	67	22	25	0	17
	LSD (P=0.05)		**47**	**28**	**46**	**56**	**54**	**NS**

† - Treated 9/11/91

Table 2.5. 1992 SPRING PREEMERGENCE APPLICATION FOR CONTROL OF *Poa annua*

	FORMULATION	RATE (kg a.i. ha^{-1})†	PERCENT CONTROL					
			4/23/92	5/13/92	6/1/92	6/22/92	7/15/92	8/5/92
1) Oxadiazon	2 G	2.2	100	100	67	57	12	52
2) Oxadiazon	2 G	4.5	100	100	100	91	52	68
3) Pendimethalin	60 WDG	2.2	100	100	100	0	41	6
4) Pendimethalin	60 WDG	3.4	100	100	100	77	66	78
5) Dithiopyr	0.25 G	0.3	100	92	100	0	15	0
6) Dithiopyr	0.25 G	0.4	100	100	100	60	42	82
7) Dithiopyr	0.25 G	0.6	100	100	100	40	38	58
8) Dithiopyr	1 EC	0.4	100	100	83	21	22	2
9) Dithiopyr	1 EC	0.6	100	100	100	8	25	19
10) Benefin	2.5 G	2.2	72	67	50	28	15	42
11) Benefin	2.5 G	3.4	94	100	100	7	34	31
12) Prodiamine	65 WDG	0.6	95	100	100	51	84	86
13) Prodiamine	65 WDG	0.8	100	100	100	80	50	73
14) Bensulide	4 EC	14.0	100	100	89	33	17	23
15) Bensulide	4 EC	11.2	90	83	100	13	18	24
16) DCPA	75 WP	11.8	97	100	100	26	20	18
17) DCPA	75 WP	16.8	97	100	93	52	17	35
18) Ethofumesate	1.5 EC	0.8	100	67	63	31	38	24
19) Ethofumesate	1.5 EC	1.7	94	100	96	29	56	34
20) Benefin + Trifluralin	2 G	1.7	88	100	96	28	13	19
	LSD (P=0.05)		**19**	**26**	**37**	**40**	**44**	**35**

† - Treated 3/31/92

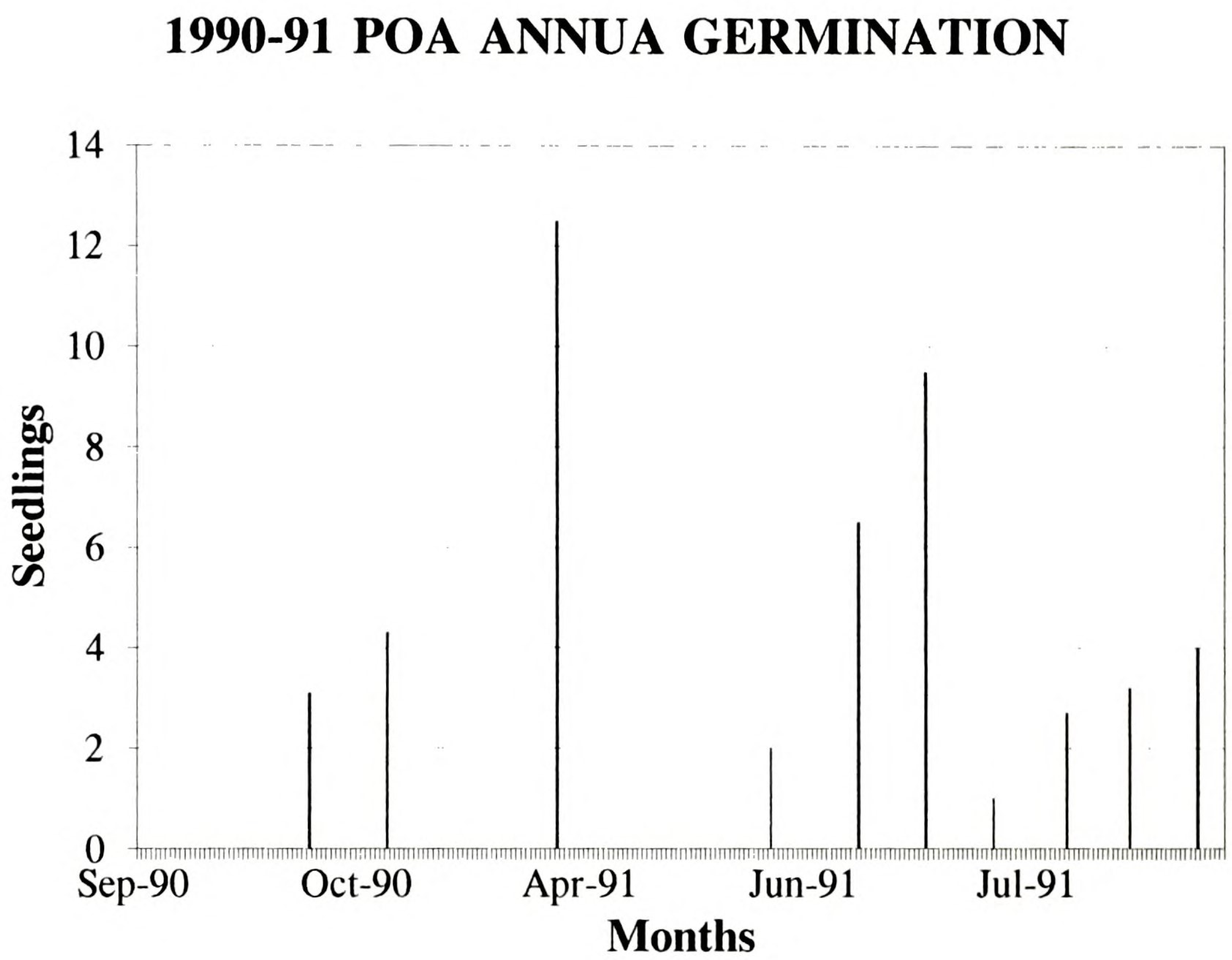

Figure 2.1. 1990-1991 Poa annua germination in response to soil temperature.

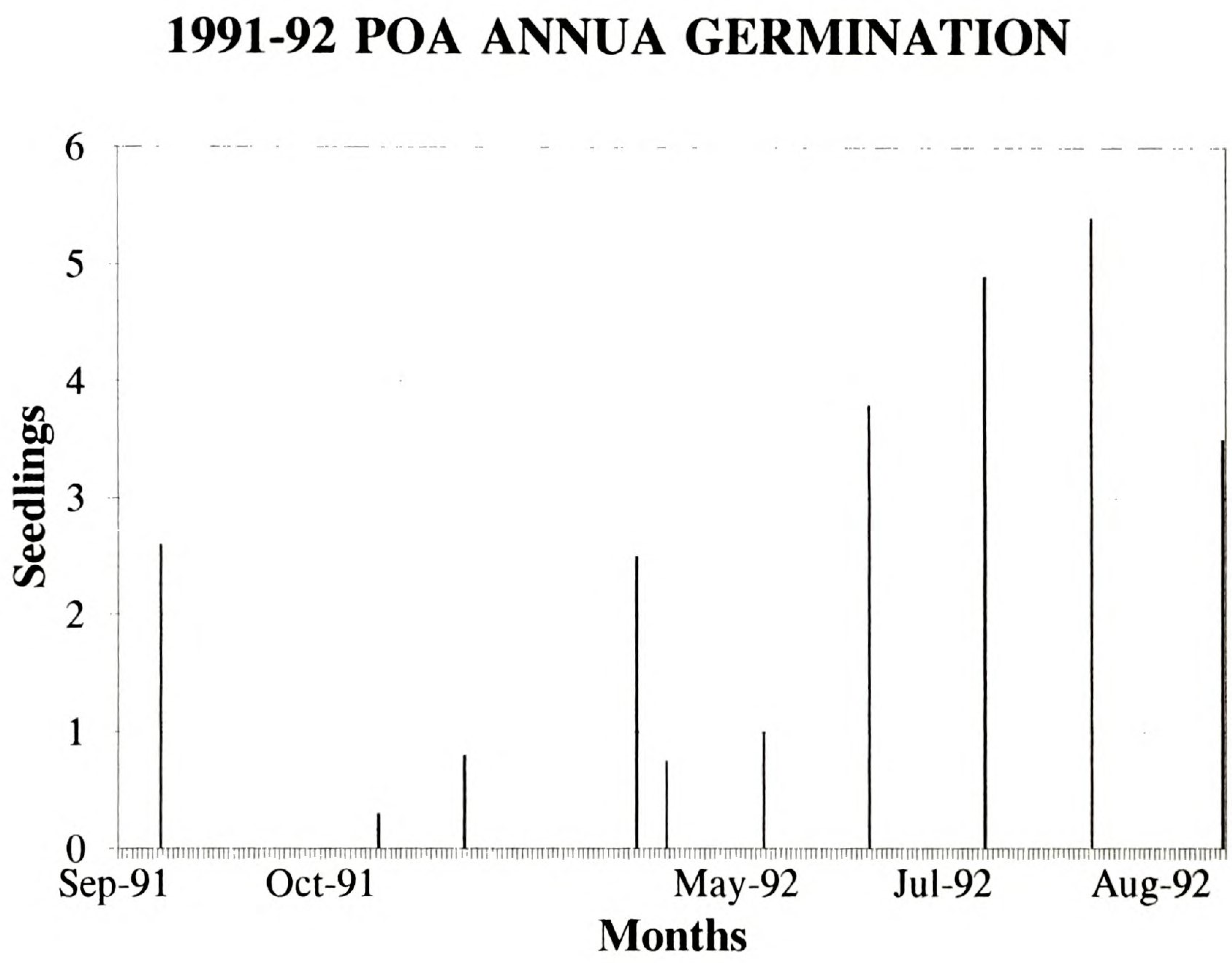

Figure 2.2. 1991-1992 Poa annua germination in response to soil temperature.

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Chapter 3

SAFETY AND EFFICACY OF MULTIPLE APPLICATIONS OF ETHOFUMESATE ON TURFGRASSES

ABSTRACT

Ethofumesate [2-ethoxy-2, 3-dihydro-3, 3-dimethyl-5-benzofuranyl methanesulfonate] is a unique herbicide which requires multiple applications to achieve acceptable control. Various multiple application studies were done evaluating safety on Kentucky bluegrass and creeping bentgrass. Two studies were also conducted to determine the control of *P. annua* achieved with multiple applications. Ethofumesate showed safety on Kentucky bluegrass at rough height but some injury at fairway height. Ethofumesate showed exceptional safety on creeping bentgrass varieties. The greater the number of applications of ethofumesate made the greater the reduction in *P. annua*.

INTRODUCTION

Control of *P. annua* has long been a highly sought goal by golf course superintendents. Many old and new golf courses not following proper management practices have had a problem with the invasion of *P. annua*. The concerns over *P. annua* are fivefold: 1) interferes with the rolling golf ball, 2) affects course appearance, 3) requires increased amounts of water, 4) requires more nitrogen than bentgrass, and 5) increased susceptibility to disease and insect injury. The desire for control is probably related both to environmental and economical factors, i.e., over-watering and fertilizer and pesticide applications.

Several methods have been used to reduce *P. annua* but are labor intensive and/or slow in response. One approach has combined two cultural practices; collecting clippings and managing to encourage the desired turfgrass. The other has been the use of plant growth regulators to control the *P. annua* growth giving the desired turf an advantage or suppressing seedhead production (Kageyama and Widell 1989), hence less seed produced.

Another approach to controlling *P. annua* is through the use of the selective herbicide ethofumesate (Ball and Roberts 1974, Dernoeden and Turner 1988, Dickens 1981, Shearman 1986). Ethofumesate selectively

controls *P. annua* and is safe over a wide range of turf species (Dernoeden and Turner 1986, Johnson et al. 1989). Multiple applications of ethofumesate are needed to obtain an acceptable level of efficacy (Coats and Krans 1986, Shearman 1986). The number of applications may be reduced by waiting until later in the growing season (Chapter 4).

There were two objectives of this research. One was to determine the safety of multiple applications of ethofumesate on desirable turfgrasses. The other was to evaluate the effects of multiple ethofumesate applications on *P. annua* control.

MATERIAL AND METHODS

1990-1991 Field Studies

Two field studies were conducted in the fall of 1990 and through the spring of 1991. One study examined safety on Kentucky bluegrass. The second study evaluated *P. annua* reduction and safety on creeping bentgrass.

The Kentucky bluegrass study was located at the Hancock Turfgrass Research Center, East Lansing, Michigan. This site received 146 kg N ha^{-1} as 46-0-0 during the study. Pesticides other than ethofumesate were not applied during this study. The plot area was mowed weekly at a height of 7.6 cm.

The creeping bentgrass study was located at the Detroit Golf Club, Detroit, Michigan. The study was located on a fairway and maintained at typical high maintenance level. The fairway consisted of approximately 40% *P. annua* and 60% creeping bentgrass.

A randomized complete block design with three replications was used for both studies. The Kentucky bluegrass study had two or three applications of ethofumesate at 0.8 or 1.7 kg a.i. ha^{-1}. The creeping bentgrass study had rates of 0.8 or 1.7 kg a.i. ha^{-1} with various treatment combinations. Individual plots in both studies measured 1.2 m x 1.8 m.

For both studies treatments were applied with a four nozzle boom-CO_2 backpack sprayer delivering 514 L ha^{-1} at 0.28 MPa. All evaluations were visual. Injury to desirable turf was rated on a 1-9 injury scale with 9 showing no injury and 1 being completely dead. *P. annua* control was rated from 0-100% with 0% being no *P. annua* present and 100% having *P. annua* present in the entire plot. Percent cover was evaluated on the bentgrass study from 0-100% with 0% having no turf present and 100% having complete turf cover, with anything less than 97% considered unacceptable in a fairway situation.

1991-1992 Field Studies

Three field studies were conducted during the fall of 1991 and through the spring of 1992. Two studies examined safety, on bentgrass varieties mowed at greens height and Kentucky bluegrass mowed at fairway height. An additional study was done to evaluate multiple ethofumesate applications on *P. annua* reduction.

The study on Kentucky bluegrass was located at Forest Akers Golf Course, East Lansing, Michigan. This study was maintained under high maintenance practices typical of a golf course.

The bentgrass variety study was at the Hancock Turfgrass Research Center, East Lansing, Michigan. This safety study on bentgrass was fertilized with 20-0-10 at 98 kg N ha^{-1} and 25-0-25 at 73 kg N ha^{-1} in 1991; and 25-0-25

at 24 kg N ha^{-1}, 46-0-0 at 49 kg N ha^{-1}, and 8-4-24 at 24 kg N ha^{-1} in 1992. In 1991 pesticides applied were metalaxyl [N-(2,6-dimethylphenyl)-N-(methoxyacetyl) alanine methyl ester] at 1.0 kg ha^{-1}; fenarimol [α-(2-chlorophenyl)-α-(4-chlorophenyl)-5-pyrimidinemethanol] at 0.5 kg ha^{-1}; chlorpyrifos [0,0-diethyl 0-(3,5,6-trichloro-2-pyridinyl) phosphorothioate] at 1.1 kg ha^{-1}; chlorothalonil [tetrachloroisophthalonitrile] at 9.5 kg ha^{-1}; and a combination product of 2,4-D [dimethylamine salt of 2,4-dichlorophenoxyacetic acid]; mecoprop [dimethylamine salt of 2-(2-methyl-4-chlorophenoxy) propionic acid]; and dicamba [dimethylamine salt of dicamba (3,6-dichloro-o-anisic acid)] at 1.6 L ha^{-1}. In 1992 pesticides applied were mancozeb [zinc ion and manganese ethylene bisdithiocarbamate] at 25 L ha^{-1} and propiconazole [1-[[2-(2-, 4-dichlorophenyl)-4-propyl-1, 3-dioxolan-2y] methyl]- 1 H-1, 2, 4-triazole] at 3.2 L ha^{-1}. The plots were mowed at a height of 0.4 cm five days a week during the growing season and as needed during late fall and early spring. The area was irrigated daily.

The multiple application study was located at Walnut Hills Country Club, East Lansing, Michigan. This study was maintained under high fairway maintenance conditions typical of a golf course.

A randomized complete block with three replications was used for the Kentucky bluegrass and multiple application studies. The Kentucky bluegrass

study had two or three applications receiving 0.8 or 1.7 kg a.i. ha^{-1}. The multiple application study used 0.8 kg a.i. ha^{-1} with various treatment combinations. Individual plots measured 1.2 m x 1.8 m. The safety study on bentgrass varieties was a split plot design with three replications. With variety as the main plot and ethofumesate rate as the subplots. Rates of ethofumesate were 0.0, 0.6, or 0.8 kg a.i. ha^{-1}. Individual plots measured 1.2 m x 1.2 m.

The three studies had treatments applied with a four nozzle boom CO_2 backpack sprayer delivering 538 L ha^{-1} at 0.28 MPa. Ratings for injury, *P. annua* control, and percent cover were all evaluated the same way as the 1990-1991 studies.

RESULTS

1990-1991 Field Studies

The safety study on Kentucky bluegrass gave no observable injury during fall or spring evaluations (data not shown).

Ethofumesate applied at 0.8 kg a.i. ha^{-1} and 1.7 kg a.i. ha^{-1} gave significant control of *P. annua* on the creeping bentgrass study (Table 3.1). All treatments with multiple 0.8 kg a.i. ha^{-1} applications; treatments 2, 3, 4, and 5; gave acceptable ground cover on all rating dates. Acceptable ground cover was achieved with one application of ethofumesate at 1.7 kg a.i. ha^{-1} plus various multiple 0.8 kg a.i. ha^{-1} applications consisting of treatments 6, 9, 10, and 13 with only two exceptions.

Treatments 8, 12, 14, 15, 16, 17, 18, 19, 20, and 21 gave significant control of *P. annua*, the percent ground cover ratings indicated unacceptable fairway turf. On the final coverage rating, unacceptable coverage was still observed with treatments 12, 16, 17, 18, 20, and 21.

The April applications in this study gave unexpected results. The percent of *P. annua* in the April treatments was less when compared to the equivalent Sept, Oct, and/or Nov combination treatments.

Injury was severe on treatments 8, 12, 14, 15, 16, 17, 18, 19, 20, and 21, which were applied at twice the label rate of 0.8 kg a.i. ha^{-1} (Table 3.1). The early spring injury rating taken on 3/21 was evaluated before greenup and some injury was visible on all treatments. By mid-April injury was not visible on any plots receiving two or more applications at 0.8 kg a.i. ha^{-1}.

1991-1992 Field Studies

The study on Kentucky bluegrass at fairway height gave some injury (Table 3.2). Injury was only unacceptable at the 1.7 kg a.i. ha^{-1} rate. All injured turf recovered by mid-May.

Percent cover in this study for most treatments on all rating dates dropped below an acceptable level, with the exception of the 0.8 + 0.8 kg a.i. ha^{-1} treatment. This poor coverage was a result of reduction to the *P. annua* population.

Bentgrass varieties at greens height treated with ethofumesate showed exceptional safety over all creeping bentgrass varieties (Table 3.3). The only exceptions were BR 1518, Tracenta, Bardot, Egmont, and Allure which are not creeping bentgrass varieties and showed serious injury at the 0.8 kg a.i. ha^{-1} rate.

The multiple application study gave some interesting and expected results. For simplicity, treatments are displayed in groups of one, two, three,

or four applications. The single application showed the most promising results. Injury was acceptable with single applications except October 15 but injury recovered during early spring. *P. annua* reduction was significant for the November 1 and 15 applications. A single application did not adversely affect percent ground cover. Treatments applied later in the season usually gave a greater reduction in *P. annua* compared to the control plot or earlier applied treatments.

Multiple applications showed expected results with two or three applications providing good *P. annua* reduction. The injury observed with the Oct 15 plus Nov 1 or Nov 15 treatments was not acceptable but recovered by late April. All treatments with three applications gave unacceptable injury in early April but by the end of April only the Sept 15 + Oct 1 + Nov 1 and Oct 1 + Oct 15 + Nov 15 had not recovered to an acceptable level. Two and three applications did affect ground cover when evaluations were taken in early April but by mid-May coverage was acceptable with the exception of the Sept 15 + Oct 1 + Nov 1 and Sept 15 + Oct 15 + Nov 1 treatments. Four and five applications provided excellent *P. annua* reduction but the injured turf never recovered to an acceptable level for a golf course fairway situation.

DISCUSSION

Ethofumesate on Kentucky bluegrass at the label rate of 0.8 kg a.i. ha^{-1} was safe at both 7.6 and 1.3 cm mowing heights. Even though there was some injury at the 1.3 cm height this turf did recover. Some of the injury effect could possibly be explained by the relationship of Kentucky bluegrass and *P. annua*. Both Kentucky bluegrass and *P. annua* are in the same genus *Poa*. With such a close botanical relationship susceptibility to injury from an ethofumesate application between these two species is possible.

Ethofumesate also showed exceptional safety on creeping bentgrasses at green heights. At the present time ethofumesate is not labeled for use on golf greens. This gives some indication for the potential use of ethofumesate on golf course greens.

Three conclusions can be drawn from the multiple application studies. First, the later ethofumesate is applied after freezing temperatures have occurred the better *P. annua* reduction achieved. The Walnut Hills study showed the benefit of waiting later in the fall to make an application to achieve better *P. annua* reduction. The second conclusion was the benefit of an April application. The April application resulted in greater *P. annua* reduction from just having prior fall applications. The applications may be acting as a

postemergence and/or preemergence. The postemergence activity is acting on the *P. annua* plants present but the preemergence activity may be a result of the prior fall applications having removed *P. annua* leaving bare soil giving control of germinating *P. annua*. The third conclusion was related to the effect multiple applications have on *P. annua* reduction. More applications usually result in a greater reduction of *P. annua*. Even though greater reduction in *P. annua* is possible by waiting until after freezing temperatures, this can be overcome with multiple applications. This could be beneficial if a little *P. annua* reduction was desired, instead of making two applications the more beneficial technique may be to only make a single application late in the season. If there is a large amount of *P. annua* present, instead of three applications, waiting and make two applications late in the season may give the same amount of control that three applications would. The end result would give both economical and environmental benefits.

Table 3.1. 1990-91 MULTIPLE ETHOFUMESATE APPLICATIONS FOR SAFETY AND *Poa annua* CONTROL†

ETHOFUMESATE RATES (kg a.i. ha^{-1}) AND TIMINGS‡	11/6/90	3/21/91	5/9/91		5/23/91	
	Injury (1-9)§		% Poa	% Cover	% Poa	% Cover
1) Control	9.0	8.0	53	100	62	100
2) 0.8 Sept & 0.8 Oct	7.0	6.3	23	99	43	100
3) 0.8 Sept & 0.8 Oct & 0.8 Nov	7.0	5.3	8	100	13	100
4) 0.8 Sept & 0.8 Oct & 0.8 Nov & 0.8 Apr	6.7	5.3	5	99	7	99
5) 0.8 Sept & 0.8 Oct & 0.8 Apr	7.0	6.0	17	99	22	100
6) 0.8 Sept & 1.7 Oct	7.0	4.0	13	99	25	100
7) 0.8 Sept & 1.7 Oct & 0.8 Nov	6.3	2.3	6	94	13	99
8) 0.8 Sept & 1.7 Oct & 1.7 Nov	7.0	2.3	2	92	7	97
9) 0.8 Sept & 0.8 Oct & 1.7 Nov	6.7	4.3	6	98	7	100
10) 0.8 Sept & 1.7 Oct & 0.8 Apr	7.0	4.0	12	97	17	100
11) 0.8 Sept & 1.7 Oct & 0.8 Nov & 0.8 Apr	6.3	3.0	1	96	3	98
12) 0.8 Sept & 1.7 Oct & 1.7 Nov & 0.8 Apr	6.7	1.7	1	88	2	95
13) 0.8 Sept & 0.8 Oct & 1.7 Nov & 0.8 Apr	6.7	4.0	3	97	3	99

Table 3.1. (cont'd).

ETHOFUMESATE RATES (kg a.i. ha^{-1}) AND TIMINGS	11/6/90	3/21/91	5/9/91		5/23/91	
	Injury		% Poa	% Cover	% Poa	% Cover
14) 1.7 Sept & 1.7 Oct	4.0	3.0	3	94	13	97
15) 1.7 Sept & 1.7 Oct & 0.8 Nov	4.0	3.0	4	93	5	97
16) 1.7 Sept & 1.7 Oct & 1.7 Nov	4.0	2.0	2	87	3	94
17) 1.7 Sept & 1.7 Oct & 0.8 Nov & 0.8 Apr	4.0	2.3	0	82	1	93
18) 1.7 Sept & 1.7 Oct & 0.8 Apr	4.0	3.7	8	87	5	94
19) 1.7 Sept & 0.8 Oct & 1.7 Nov	4.0	3.3	1	86	4	97
20) 1.7 Sept & 1.7 Oct & 1.7 Nov & 0.8 Apr	4.0	1.7	0	63	2	83
21) 1.7 Sept & 0.8 Oct & 1.7 Nov & 0.8 Apr	4.0	2.7	1	85	1	94
LSD (P= 0.05)	**0.7**	**1.4**	**6.8**	**12.3**	**7.2**	**5.7**

† - Study Located at Detroit Golf Club

‡ - Treated 9/17/90, 10/11/90, 11/6/90 and 4/11/91

§ - Injury 1-9 scale; 1= completely dead, 9= no injury, <6.5 unacceptable for golf course fairway

Table 3.2. 1991-92 ETHOFUMESATE SAFETY ON KENTUCKY BLUEGRASS AT FAIRWAY HEIGHT

ETHOFUMESATE RATES (kg a.i. ha^{-1})†	INJURY RATING (1-9)‡			PERCENT COVER	
	11/14/91	**4/27/92**	**5/13/92**	**4/27/92**	**6/17/92**
0.8 + 0.8	7.3	7.8	9.0	96	98
1.7 + 1.7	6.0	6.0	9.0	73	91
0.8 + 0.8 + 0.8	7.5	6.7	8.8	88	94
1.7 + 1.7 + 1.7	6.0	2.7	9.0	18	77
Control	8.0	9.0	9.0	100	100
LSD (P= 0.05)	**0.2**	**0.7**	**NS**	**11**	**13**

† - Treated 9/24/91, 10/20/91 and 11/14/91

‡ - Injury 1-9 scale; 1= completely dead, 9= no injury, <6.5 unacceptable for a golf course fairway

Table 3.3. 1991-92 ETHOFUMESATE SAFETY ON BENTGRASS VARIETIES AT GREENS HEIGHT

		ETHOFUMESATE RATE (kg a.i. ha^{-1})†								
		0.6			0.8			Control		
Species	Cultivar	10/18/91	11/8/91	4/29/91	10/18/91	11/8/91	4/19/92	10/18/91	11/8/91	4/1/92
A. castellana	BR 1518	7.7‡	5.0	6.8	8.0	4.7	5.8	8.7	8.3	8.0
	Egmont	8.3	6.7	7.3	8.3	5.0	4.3	9.0	9.0	8.0
colonial	Allure	8.3	6.3	6.7	8.0	5.3	5.8	9.0	8.3	8.0
	Bardot	8.3	6.7	7.8	8.3	5.0	5.3	9.0	8.3	8.0
	Tracenta	8.3	5.7	6.5	8.0	4.0	4.7	9.0	8.3	8.0
creeping	Carmen	8.3	8.0	7.8	8.0	8.0	7.8	8.3	9.0	8.0
	Cobra	8.7	8.3	7.8	8.7	8.3	8.0	9.0	9.0	7.8
	Emerald	8.3	8.0	7.7	8.3	8.0	7.5	9.0	8.7	8.0
	Forbes 89-12	8.3	8.7	8.0	8.3	8.7	7.7	9.0	9.0	8.0
	MSCB-6	8.3	8.7	8.0	8.0	8.7	8.0	9.0	9.0	8.0
	MSCB-8	8.3	8.7	7.8	8.3	8.7	7.8	8.7	9.0	8.0
	National	9.0	8.3	8.0	8.3	8.0	7.7	9.0	8.3	7.3
	Normarc 101	9.0	9.0	8.0	8.7	9.0	7.7	9.0	9.0	7.8
	SR 1020	8.7	8.3	8.0	8.3	8.3	7.8	8.7	9.0	7.8

Table 3.3. (cont'd).

		ETHOFUMESATE RATE (kg a.i. ha^{-1})								
		0.6			**0.8**			**Control**		
Cultivar	**Species**	10/18/91	11/8/91	4/19/92	10/18/91	11/8/91	4/19/92	10/18/91	11/8/91	4/19/92
creeping	Penncross	8.7	9.0	8.0	8.7	9.0	7.8	9.0	9.0	7.8
	Pennlinks	8.7	9.0	8.0	8.7	9.0	8.0	8.7	9.0	8.0
	Providence	8.7	9.0	8.0	8.3	9.0	7.7	9.0	9.0	8.0
	Putter	8.3	8.7	7.8	8.3	8.7	7.8	8.7	9.0	7.8
	TAMU 88-1	8.3	8.7	7.8	8.3	8.3	7.7	9.0	9.0	7.5
	UM 84-01	7.7	7.0	8.0	8.0	6.3	7.2	8.0	8.7	7.7
	WVPB 89-D-15	8.3	8.3	7.8	8.3	8.0	7.8	9.0	9.0	8.0
	88.CBE	9.0	9.0	7.8	9.0	8.7	7.8	8.7	9.0	7.7
	88.CBL	9.0	8.7	7.8	8.7	8.0	7.8	9.0	9.0	7.8
	LSD (P= 0.05)	**0.2**	**0.7**	**0.8**	**0.2**	**0.7**	**0.8**	**0.2**	**0.7**	**0.8**

† - Treated 9/24/91 and 10/16/91

‡ - Injury 1-9 scale; 1= completely dead, 9= no injury, <6.5 unacceptable for a golf course green

Table 3.4. 1991-92 WALNUT HILLS MULTIPLE ETHOFUMESATE APPLICATIONS†

ETHOFUMESATE APPLICATION TIME	INJURY (1-9)‡			PERCENT *P. annua*			PERCENT COVER	
	12/9/91	4/10/92	4/28/92	10/17/91	5/7/92	5/19/92	4/10/92	5/19/92
CONTROL	8.2	7.8	9.0	67	78	72	100	100
SEPT 15§	8.5	7.7	9.0	55	82	55	100	100
OCT 1¶	7.8	8.0	9.0	62	57	50	98	100
OCT 15#	6.3	7.8	9.0	58	70	53	97	100
NOV 1††	7.8	7.0	9.0	53	25	28	98	100
NOV 15‡‡	8.2	7.0	9.0	53	47	32	100	100
SEPT 15, OCT 1	6.7	7.7	8.7	52	53	30	87	100
SEPT 15, OCT 15	6.8	7.3	8.8	62	58	55	92	100
SEPT 15, NOV 1	8.2	6.8	9.0	65	58	28	97	100
SEPT 15, NOV 15	8.2	7.5	9.0	60	28	37	98	100
OCT 1, OCT 15	5.7	7.0	8.7	57	45	47	85	99
OCT 1, NOV 1	7.0	7.0	9.0	52	45	22	92	100
OCT 1, NOV 15	7.2	7.3	8.8	57	48	28	93	100
OCT 15, NOV 1	6.0	4.2	8.7	52	43	17	52	100
OCT 15, NOV 15	6.2	5.3	8.8	65	30	12	68	100
NOV 1, NOV 15	7.7	5.3	8.3	57	43	38	68	100
SEPT 15, OCT 1, OCT 15	3.8	5.2	6.7	58	23	15	57	97
SEPT 15, OCT 1, NOV 1	5.0	3.8	5.2	57	22	22	62	95
SEPT 15, OCT 1, NOV 15	6.0	5.2	7.2	62	53	43	78	97
SEPT 15, OCT 15, NOV 1	5.7	5.3	7.0	72	65	35	68	91
SEPT 15, OCT 15, NOV 15	6.2	6.3	7.8	68	55	38	73	99

Table 3.4. (cont'd).

ETHOFUMESATE APPLICATION TIME	INJURY			PERCENT *P. annua*			PERCENT COVER	
	12/9/91	4/10/92	4/28/92	10/17/91	5/7/92	5/19/92	4/10/92	5/19/92
SEPT 15, NOV 1, NOV 15	7.2	4.7	8.3	58	35	37	65	100
OCT 1, OCT 15, NOV 1	4.8	3.3	6.8	52	33	5	53	98
OCT 1, OCT 15, NOV 15	4.3	1.8	5.5	68	32	38	35	97
OCT 1, NOV 1, NOV 15	6.3	4.5	7.5	63	78	65	58	100
OCT 15, NOV 1, NOV 15	6.0	2.8	6.7	65	40	42	45	100
SEPT 15, OCT 1, OCT 15, NOV 1	3.7	2.2	3.8	65	26	22	38	85
SEPT 15, OCT 1, OCT 15, NOV 15	3.8	3.0	4.5	57	32	35	38	87
SEPT 15, OCT 1, NOV 1, NOV 15	5.7	2.5	6.3	48	27	27	43	95
SEPT 15, OCT 15, NOV 1, NOV 15	5.7	2.0	4.8	62	48	22	27	92
OCT 1, OCT 15, NOV 1, NOV 15	4.5	2.5	5.7	63	50	30	43	97
SEPT 15, OCT 1, OCT 15, NOV 1, NOV 15	3.7	1.8	3.2	55	13	3	40	70
LSD (P= 0.05)	**1.0**	**1.9**	**2.1**	**NS**	**30**	**33**	**23**	**11**
LSD (P= 0.10)	**0.9**	**1.6**	**1.7**	**NS**	**25**	**28**	**19**	**9**

† - Study Located at Walnut Hills Country Club
‡ - Injury 1-9 scale; 1= completely dead, 9= no injury, <6.5 unacceptable for a golf course fairway
§ -13.3 C minimum air temperature three day average before application, 11.7 C minimum air temperature day of application, 6.1 C minimum air temperature three day average after application
¶ -5.6 C minimum air temperature three day average before application, 13.3 C minimum air temperature day of application, 7.8 C minimum air temperature three day average after application
# --0.6 C minimum air temperature three day average before application, -3.3 C minimum air temperature day of application, -0.6 C minimum air temperature three day average after application
†† -9.4 C minimum air temperature three day average before application, 5.6 C minimum air temperature day of application, -0.6 C minimum air temperature three day average after application
‡‡ --2.2 C minimum air temperature three day average before application, 0.6 C minimum air temperature day of application, -1.1 C minimum air temperature three day average after application

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Chapter 4

GREENHOUSE STUDIES ON THE EFFECT OF COLD TEMPERATURE ON ETHOFUMESATE EFFICACY.

ABSTRACT

Ethofumesate [2-ethoxy-2, 3-dihydro-3, 3-dimethyl-5-benzofuranyl methanesulfonate] provides little reduction of *P. annua* populations when applied in the summer but fall applications give a greater reduction. Temperature appears to have an effect on ethofumesate efficacy. Greenhouse studies indicated freezing temperatures prior to an ethofumesate application is more effective in *P. annua* reduction than when not subjected to freezing temperatures. Two different studies were used to evaluate this hypothesis. Studies involved the use of visual and regrowth measurements to evaluate the relationship of freezing temperatures and ethofumesate applications. Plants exposed to freezing temperatures prior to an application of ethofumesate consistently were injured more and had less growth than those plants not exposed to freezing temperatures. Field application of ethofumesate could be more effective is applied after freezing temperatures.

INTRODUCTION

Selective control of *P. annua* has become a possibility only in the last eight years. Ethofumesate is a unique herbicide which provides selective *P. annua* control (Ball and Roberts 1974, Dernoeden and Turner 1988, Dickens 1981, Shearman 1986). One unique characteristic of ethofumesate is the application timing. According to the label the first application of ethofumesate is not to be applied until after the first of September. Another characteristic of ethofumesate is the need for multiple applications to achieve acceptable control of *P. annua* (Coats and Krans 1986, Shearman 1986).

Some inconsistent results have been seen with this application schedule. Some years turf managers may see acceptable results and in other years they may see little if any control of *P. annua*.

The hypothesis developed was that the temperature around the time of application influences the efficacy of ethofumesate on *P. annua*. Growth chamber studies were designed with the objective of determining the relationship between temperature and ethofumesate. The objective of this study was to determine the effect of freezing temperatures prior to an application of ethofumesate on *P. annua* growth and dry matter production.

MATERIAL AND METHODS

P. annua was taken from the Hancock Turfgrass Research Center, East Lansing, Michigan and transplanted into 355 ml styrofoam cups containing Baccto (Michigan Peat Company) potting media. Plant material was approximately 7.6 cm thick (soil and thatch) when placed into the cups. The cups were placed in the greenhouse and watered as needed to prevent desiccation of plant material. Supplemental lighting from fluorescent lights provided a 16 hour day length. Greenhouse temperatures were maintained at 20/18°C day/night cycle and relative humidity at 40-75%. Plants were fertilized with Peters Professional Water Soluble Fertilizer Source 20-0-20 at 237 ppm N 9.3 m^{-2} every two weeks. Plant material remained in the greenhouse for approximately two weeks to allow for recovery from transplanting.

Plant material was then placed in a growth chamber at 21/10°C with a 9/15 hours day/night cycle to begin acclimation. This continued for five days with an additional five days at 4/4°C under the same day/night cycle before plants were subjected to freezing temperatures.

Plant material was subjected to freezing temperatures in a freezer prior to ethofumesate application. Temperatures were -6°C during the night cycle

and 3°C during the day. Duration of the freeze cycles before chemical application were 0, 1, 2, 4, and 8 days for the first two experiments; 0, 5, and 10 days for the third experiment; 0 and 5 days for the fourth. After ethofumesate was applied, plants were again placed in a growth chamber at 21/10°C with a 9/15 hours day/night cycle.

Prior to plant material being placed in the 4/4°C acclimation temperatures, plants were mowed weekly at a height of 2.5 cm. Plants were again mowed weekly after the application of ethofumesate at 0.6 cm. In studies one and two, visual evaluations were used to make observations of differences among treatments. The results from the two studies were inconclusive and a more quantitative measurement was needed which would possibly show significant differences. In the third and fourth studies regrowth was mowed off above the lip of the cup at 0.6 cm using scissors. Clippings were collected with a vacuum cleaner, placed in a tared beaker and fresh weights determined. Then data was converted and reported as percent control. This continued for a total of four collection dates.

A randomized complete block design with four replications was used for experiments one and two. For experiments one and two, plant material was subjected to a freezing duration of 0, 1, 2, 4, and 8 days before treatment with 0.8 kg a.i. ha^{-1} of ethofumesate. Studies three and four used a factorial design

with four replications. Freezing duration of 0, 5, and 10 days in study three or 0 and 5 days in study four were one factor and ethofumesate rates of 0.0, 0.2, 0.6 and 0.8 kg a.i. ha^{-1} were a second factor. Freezing duration was prior to the application of ethofumesate. Ethofumesate treatments were applied using a track sprayer delivering 187 L ha^{-1} at .22 MPa.

RESULTS AND DISCUSSION

Comparing summer versus fall applications (Table 4.1) shows that little injury resulted from summer applications but the same applications in the fall displayed a marked increase in injury. This led to the idea that temperatures at the time ethofumesate is applied are related to *P. annua* reduction.

The control plants in study one showed little injury with only the plants in freezing temperatures 8 days significantly injured (Table 4.2).

The treated plants even without freezing temperatures prior to treatment showed some injury. This injury was not as severe as those plants having a freezing duration prior to an ethofumesate treatment. The treated plants not exposed to freezing temperatures began to show some recovery, but the treated plants exposed to freezing temperatures did not. This same trend was evident in study two (Table 4.3), but there were no significant differences among freezing intervals.

A more quantitative measurement was used to evaluate significant differences. Clippings collected from plant material were used to evaluate percent control when ethofumesate was applied after freezing temperatures. This technique was modified into a rate study with plant material subjected to freezing temperatures for 0, 5 or 10 days before treatment.

One week after treatment (Table 4.4) the three rates of ethofumesate applied to the plants in freezing temperatures 10 days were giving almost 75 percent reduction or better along with the high rate on the plants in freezing temperatures 5 days. The plants in freezing temperatures 5 days at the low rate and all rates on all plants receiving no freezing temperatures had less than 50 percent reduction. The only exception being the high rate on the plants in freezing temperatures 0 days. The second and third mowing had near 100 percent reduction from the two highest rates of the plants in freezing temperatures 5 and 10 days. The fourth mowing had 100 percent reduction with the two high rates on plants in freezing temperatures 5 and 10 days and the high rate on the plants receiving no freezing temperatures. This may be better observed graphically (Figure 4.1 and 4.2) showing percent reduction at various rates for different freezing durations.

These results were consistent with a fourth study (Table 4.5). Because of limitations of plant material only 0 and 5 day freezing duration was possible. Percent reduction for treated plants in freezing temperatures were consistently higher than treated plants never exposed to freezing temperatures (Figure 4.3 and 4.4).

This study did show good significant results on the final mowing. Plants receiving a freezing duration prior to an application of ethofumesate

resulted in greater *P. annua* reduction than if no freezing duration was encountered. This same trend has been observed in the field (Chapter 3).

Before data was converted to percent reduction the fresh weights revealed that the frozen controls consistently had less clippings than the unfrozen controls. This was not totally unexpected due to the susceptibility of *P. annua* to cold temperatures (Beard 1973). Some of the injury and reduction are possibly a result of cold temperatures. This may explain why freezing temperatures prior to an application of ethofumesate has an effect on the *P. annua*. Some of the plants may have been killed or injured because of the cold temperatures. Making the application of ethofumesate on less *P. annua* and/or injured plants makes the end result appear as greater reduction. In comparison ethofumesate applications made to plants receiving no freezing temperatures prior to being treated have to work on non-injured *P. annua*. Ethofumesate may also be more effective in the fall because of the germination cycle of *P. annua* (Chapter 2). During the warmer months of summer *P. annua* is still germinating. Injured turf could recover by new seedlings filling in bare ground. During the fall *P. annua* germination declines. Turf that has been injured from ethofumesate has less of a potential for new seedlings filling in injured turf areas when germination rates are lower.

Table 4.1. **SUMMER AND FALL APPLICATION OF ETHOFUMESATE COMPARISON**

	INJURY RATING (1-9)			
ETHOFUMESATE (kg a.i. ha^{-1})	**SUMMER†**		**FALL‡**	
	7/14	7/25	11/6	12/18
0.0	9.0	9.0	9.0	8.0
0.8 + 0.8	7.3	8.7	7.0	6.7
1.7 + 1.7	6.8	7.7	4.0	4.3
LSD (P= 0.05)	**1.1**	**1.3**	**0.7**	**0.9**

† Treated 6/20/90 and 7/11/90

‡ Treated 9/17/90 and 10/11/90

Table 4.2. FREEZING TEMPERATURES PRIOR TO AN APPLICATION OF ETHOFUMESATE (STUDY ONE)

	INJURY RATING (1-9)†							
FREEZING INTERVAL‡	NO ETHOFUMESATE APPLIED				ETHOFUMESATE @ 0.8 kg a.i. ha^{-1}			
	1st§	2nd	3rd	4th	1st	2nd	3rd	4th
0 Days	8.0	8.0	8.0	8.0	1.3	2.0	2.0	2.7
1 Days	8.0	8.0	8.0	8.0	1.0	1.0	1.0	1.0
2 Days	8.0	7.3	6.3	6.3	1.3	1.3	1.3	1.3
4 Days	8.0	8.0	8.0	8.0	1.0	1.3	1.3	1.3
8 Days	6.0	6.0	4.7	4.3	1.0	1.0	1.0	1.0
LSD (P= 0.05)	**1.9**	**2.1**	**2.3**	**2.3**	**1.9**	**2.1**	**2.3**	**2.3**

† - Injury 0-9; 1= completely dead, 9= no injury, and <6.5 unacceptable in a turf situation
‡ - Duration that plants were in freezing temperatures prior to an application of ethofumesate
§ - Mowings after plants were treated with ethofumesate

Table 4.3. FREEZING TEMPERATURES PRIOR TO AN APPLICATION OF ETHOFUMESATE (STUDY TWO)

FREEZING INTERVAL‡	INJURY RATING (1-9)†							
	NO ETHOFUMESATE APPLIED				**ETHOFUMESATE @ 0.8 kg a.i. ha^{-1}**			
	1st§	2nd	3rd	4th	1st	2nd	3rd	4th
0 Day	7.7	8.0	8.0	8.0	2.5	2.0	2.5	4.2
1 Day	8.0	6.7	6.5	7.7	4.7	4.5	5.0	7.7
2 Day	8.0	8.0	8.0	8.0	2.5	1.7	2.0	3.5
4 Day	8.0	7.2	8.0	8.0	4.0	1.7	1.5	2.5
8 Day	8.0	6.7	6.7	7.2	3.0	1.0	1.2	2.5
LSD (P= 0.05)	**1.8**	**2.2**	**2.1**	**2.9**	**1.8**	**2.2**	**2.1**	**2.9**

† - Injury ratings 1-9; 1= completely dead, 9= no injury, and <6.5 unacceptable in a turf situation
‡ - Duration plants were in freezing temperatures prior to an application of ethofumesate
§ - Mowings after plants were treated with ethofumesate

Table 4.4. PERCENT REDUCTION OF POA ANNUA CLIPPING WEIGHTS IN FREEZING TEMPERATURES PRIOR TO AN ETHOFUMESATE TREATMENT (Study Three)

	First Mowing	Final Mowing
0 Freezing Day Duration		
0.0 kg a.i. ha^{-1}	0	0
0.3 kg a.i. ha^{-1}	18	0
0.6 kg a.i. ha^{-1}	42	57
0.8 kg a.i. ha^{-1}	77	100
5 Freezing Day Duration		
0.0 kg a.i. ha^{-1}	0	0
0.3 kg a.i. ha^{-1}	39	26
0.6 kg a.i. ha^{-1}	68	100
0.8 kg a.i. ha^{-1}	73	100
10 Freezing Day Duration		
0.0 kg a.i. ha^{-1}	0	0
0.3 kg a.i. ha^{-1}	73	50
0.6 kg a.i. ha^{-1}	99	100
0.8 kg a.i. ha^{-1}	96	100
ANOVA Table		
Freezing Duration (F)	**	* (21)†
Ethofumesate Rate (E)	***	***
F x E	NS	NS

*, **, *** Significant at the 0.05, 0.01, and 0.001 level of probability, respectively; NS, not significant at P > 0.1.

† Number in parenthesis is LSD value at 0.05 probability level.

Table 4.5. PERCENT REDUCTION OF POA ANNUA CLIPPING WEIGHTS IN FREEZING TEMPERATURES PRIOR TO AN ETHOFUMESATE TREATMENT (Study Four)

	First Mowing	Final Mowing
0 Freezing Day Duration		
0.0 kg a.i. ha^{-1}	0	0
0.3 kg a.i. ha^{-1}	21	37
0.6 kg a.i. ha^{-1}	50	37
0.8 kg a.i. ha^{-1}	32	69
5 Freezing Day Duration		
0.0 kg a.i. ha^{-1}	0	0
0.3 kg a.i. ha^{-1}	37	49
0.6 kg a.i. ha^{-1}	37	83
0.8 kg a.i. ha^{-1}	69	98
ANOVA Table		
Freezing Duration (F)	**	***
Ethofumesate Rate (E)	***	***
F x E	NS	* (23)†

*, **, *** Significant at the 0.05, 0.01, and 0.001 level of probability, respectively; NS, not significant at $P > 0.1$.

† Number in parenthesis is LSD value at 0.05 probability level.

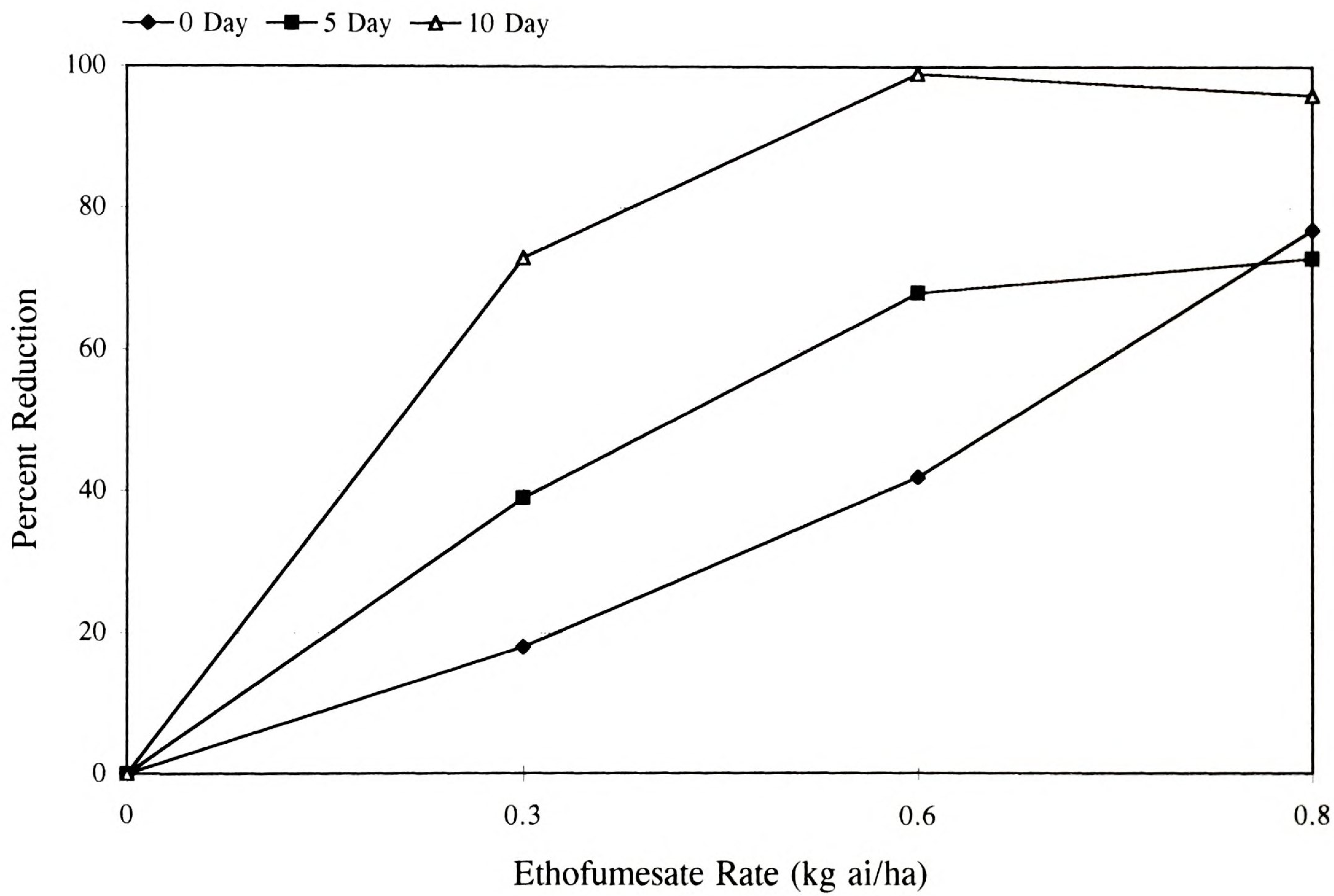

Figure 4.1. Study three- Clipping weights from *P. annua* plants treated with ethofumesate (first mowing).

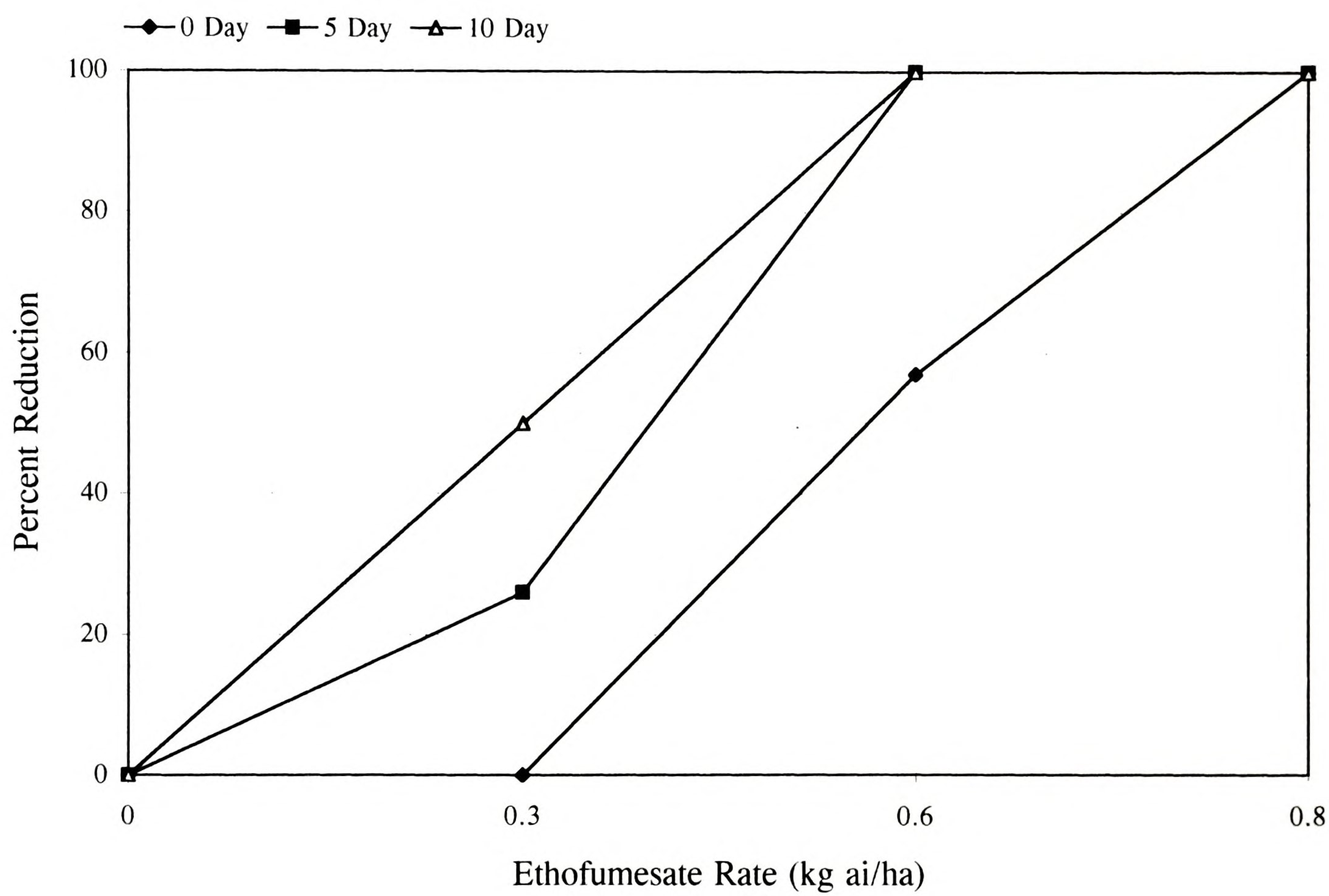

Figure 4.2. Study three- Clipping weights from *P. annua* plants treated with ethofumesate (final mowing).

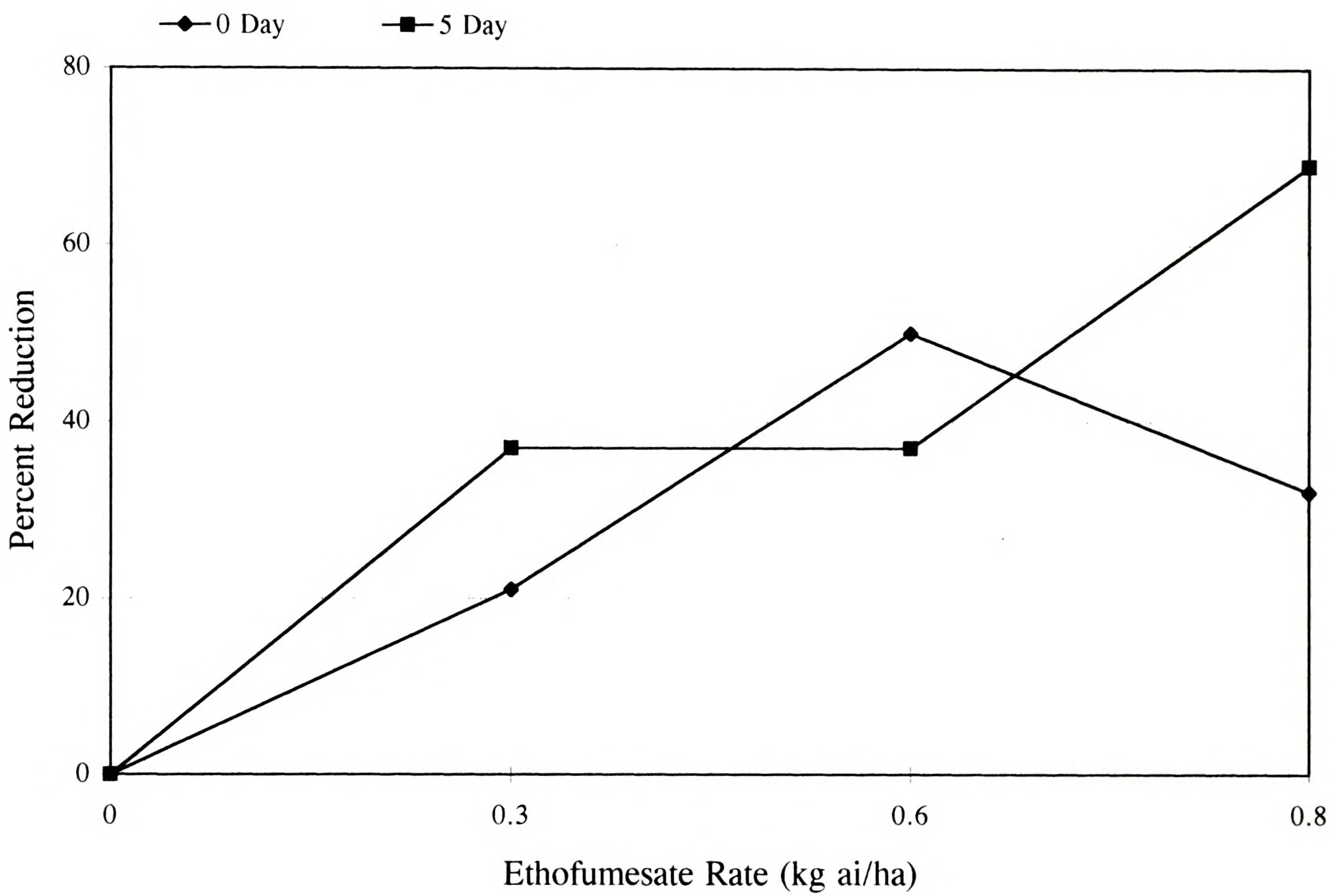

Figure 4.3. Study four- Clipping weights from *P. annua* plants treated with ethofumesate (first mowing).

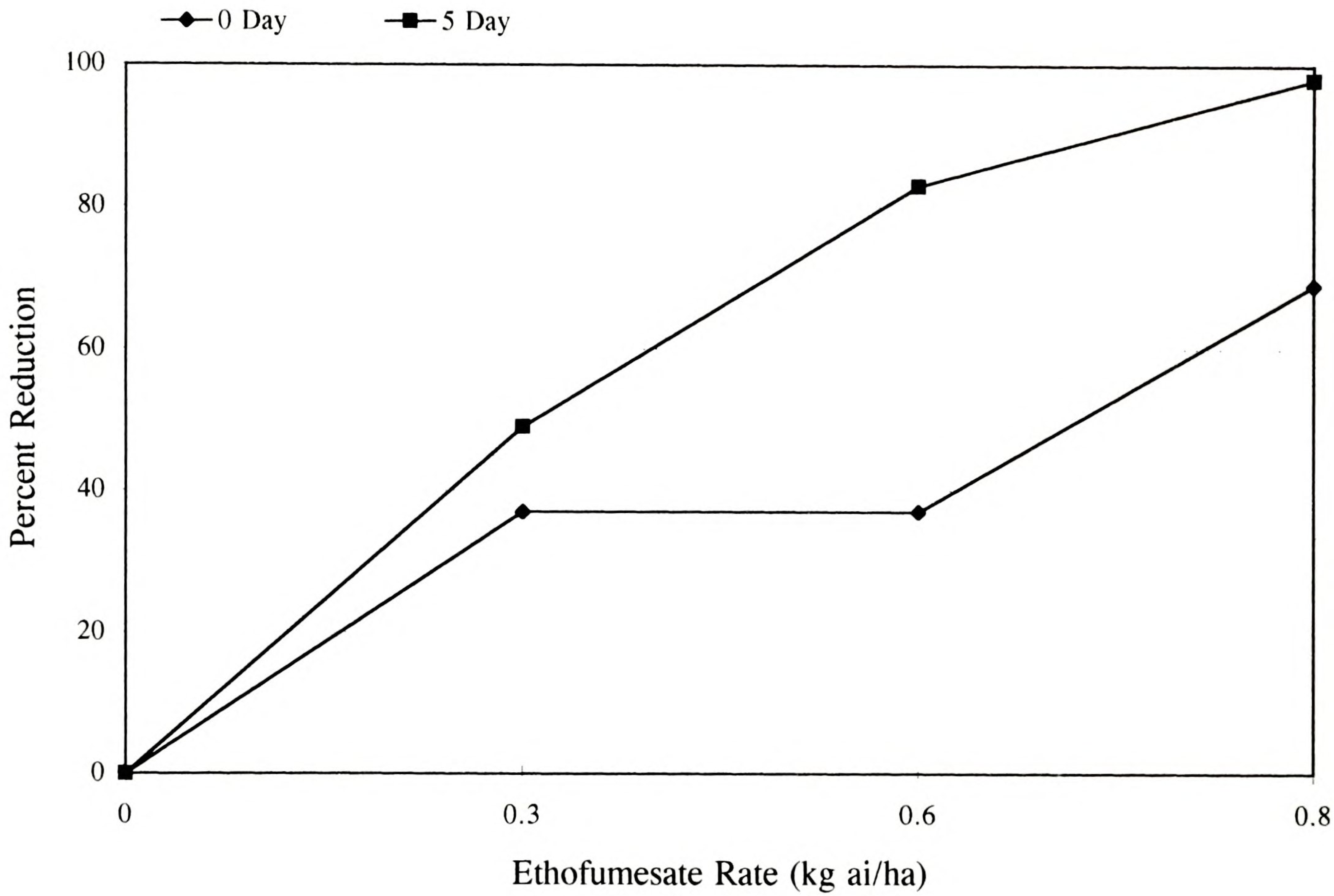

Figure 4.4. Study four- Clipping weights from *P. annua* plants treated with ethofumesate (final mowing).

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