SECTION I. THE EFFECT OF HERBICIDES ON ROOTING OF KENTUCKY BLUEGRASS

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ABSTRACT

A series of studies were conducted over a three year period with varying environmental and management conditions to investigate the effect of herbicides on rooting of Kentucky bluegrass (Poa pratensis L.). Herbicides were applied in late April of each year. Root zone samples were collected throughout each summer and washed through a series of screens to remove the soil particles. Pendimethalin at 1.7 and 3.4 kg ha^{-1} inhibited rooting under low maintenance conditions the first year. None of the treatments inhibited rooting in the field the last two years of the study.

Clear polyethylene tubing was filled with fritted clay, placed in a polyvinyl chloride sleeve, and supported at a 30^{o} angle in the greenhouse. Single tillers of 'Glade' Kentucky bluegrass were established in each tube. Herbicides were applied to the tubes at recommended field rates. Clipping weights were taken weekly and root weights were taken at the termination of the study. Benefin at 2.2 and 3.4 kg ha^{-1}, pendimethalin at 1.7 and 3.4 kg ha^{-1}, DCPA at 11.8 kg ha^{-1}, prodiamine at 0.6 and 1.1 kg ha^{-1}, and fenoxaprop-ethyl at 0.1 kg ha^{-1} inhibited rooting. Inhibition was greater in the upper 14 cm of the profile. Prodiamine at 0.6 and 1.1 kg ha^{-1} reduced clipping weights and the final above ground shoot weight. Fenoxaprop-ethyl and pendimethalin reduced clipping weights slightly.

Chemical names used: N-butyl-N-ethyl-2,6-dinitro-4-(trifluoromethyl)benzenamine (benefin); dimethyl tetrachloroterephthalate (DCPA); (±)-2-{4-[(6-chloro-2-

benzoxazolyl)oxyl]phenoxy}propanoic acid (fenoxaprop-ethyl; N-(1-ethylpropyl)-3,4-dimethyl-2,6-dintrobenzenamine (pendimethalin); N^3,N^3-di-n-propyl-2,4-dinitro-6-(triflouromethyl)-m-phenylenediamine (prodiamine).

INTRODUCTION

Use of preemergence herbicides for selective control of annual grasses is an integral part of most turf management programs. Efficacy of the herbicides in controlling weeds such as crabgrass (Digitaria spp.) and goosegrass (Eleusine india L. Gaertn.) is well established, but they also can be detrimental to the perennial turf species causing yellowing or browning of shoots (4), reduced clipping weight (7), and lowered shoot density (9) have been reported. Preemergence herbicides also effect below-ground growth of the turf species. DCPA reduces the number of tillers and number and length of rhizomes of 'Merion' Kentucky bluegrass (3). Christians (1) reported that oxadiazon (3-[2,4-dichloro-5-(1-methylethoxy)phenyl]-5-(1,1-dimethylethyl)-1,3,4-oxadiazol-2-(3H)-one) and bensulide (O,O-bis(1-methylethyl)-S-{2-[(phenylsulfonyl)amino]ethyl}phosphorodithioate) reduced dry root weights of four Kentucky bluegrass cultivars while DCPA had no effect. Bandane (polychlorodicyclopentadiene) and calcium arsenate reduced combined root and rhizome weight in 'Kenblue' Kentucky bluegrass while siduron, benefin, besulide, and DCPA had no effect (8). Bensulide inhibited rooting of 'Merion' Kentucky bluegrass in the upper 5 cm of soil while DCPA had no effect, but in the next 5 cm of the soil column, bensulide stimulated rooting compared to the control (2). Prodiamine reduced root mass of 'Nugget' Kentucky bluegrass while bensulide, benefin, DCPA, and oxadiazon had no effect (5). The highly variable and often conflicting results from these studies reveal the need for more investigation of the potentially detrimental effects of these herbicides. The objective of these studies that were conducted over a three year period with varying environmental and management conditions, was to investigate the effect of preemergence herbicides on rooting of Kentucky bluegrass.

MATERIALS AND METHODS

Field studies

A preliminary field study was conducted in the summer of 1985. The experiment was divided into high and low maintenance studies. The high maintenance area received 4.5 kg nitrogen ha^{-1} yr^{-1} and irrigation to prevent moisture stress. The low maintenance study received 1.7 kg N ha^{-1} yr^{-1} and no irrigation beyond that needed to facilitate root sampling. Both studies were in a randomized complete block design with four replications.

The high maintenance study took place on an 'Enmundi' Kentucky bluegrass turf mowed at 6 cm. The soil type was Nicollet(fine loamy mixed mesic Aquic Hapludoll) with a pH of 7.5, 10 mg kg^{-1} phosphorus, 80 mg kg^{-1} potassium, and 23 g kg^{-1} organic matter. Treatments included benefin at 2.2 and 3.4 kg ha^{-1}, bensulide at 8.4 and 15.7 kg ha^{-1}, DCPA at 11.8 and 16.8 kg ha^{-1}, and oxadiazon at 2.2 and 4.0 kg ha^{-1}. The herbicides were applied on 20 April 1985. On 5 June 1985, eight 20 cm deep samples were taken from each plot. After the thatch and vegetation was removed, the samples were divided into four parts by depth; 0-5, 5-10, 10-15, and 15-20 cm. The samples were washed through a series of screens, the finest being 18 mesh, to remove the sand and soil, oven-dried, and weighed.

The low maintenance study took place on a golf course fairway of unknown cultivar(s) of Kentucky bluegrass mowed at 3.8 cm. The soil type was Webster(fine loamy mixed mesic Typic Hapludoll) with a pH of 7.5, 25 mg kg^{-1} P, 98 mg kg^{-1} K, and 50 g kg^{-1} organic matter.

Treatments included bensulide at 9.0 and 14.0 kg ha^{-1}, DCPA at 11.8 kg ha^{-1}, pendimethalin at 1.7 and 3.4 kg ha^{-1}, and oxadiazon at 3.4 kg ha^{-1}. The chemicals were applied on 25 April 1985. Samples were taken on 25 June and 8 August. Because of the very dry conditions, only 15 cm deep samples could be taken. The samples were divided into three depths; 0-5, 5-10, and 10-15 cm. These samples were processed as in the high maintenance study except that these samples were also ashed at 500°C for 24 hours. Root weights were determined by weight loss during ashing.

Identical studies were run in 1986 and 1987 under high and low maintenance regimes. These studies were conducted on a Nicollet soil the Iowa State Horticulture Research Station north of Ames, Iowa. The high maintenance studies were on soil with a pH of 7.2, 13 mg kg^{-1} P, 85 mg kg^{-1} K and 23 g kg^{-1} organic matter. The high maintenance areas received 4.5 kg N ha^{-1} yearly and irrigation to prevent moisture stress. The low maintenance studies were on soil with a pH of 7.0, 12 mg kg^{-1} P, 90 mg kg^{-1} K and 23 g kg^{-1} organic matter. The low maintenance areas received 1.2 kg N ha^{-1} yearly and no irrigation outside that which was needed to facilitate sampling. Both areas were mowed at 6 cm. Treatments included benefin at 2.2 and 3.4 kg ha^{-1}, bensulide at 8.4 and 15.7 kg ha^{-1}, DCPA at 11.8 and 16.8 kg ha^{-1}, oxadiazon at 2.2 and 4.5 kg ha^{-1}, pendimethalin at 1.7 and 3.4 kg ha^{-1}, prodiamine at 0.6 and 1.1 kg ha^{-1}, fenoxaprop-ethyl at 0.1 kg ha^{-1}. The herbicides were applied in late April of each year. All studies were in randomized block designs with four replications.

Eight 2.5 cm diameter samples were taken from each plot using a soil testing probe in late May, late June, and late July. After the thatch and vegetation was removed, the samples were divided into two parts by depth; 0-7.5 and 7.5-15 cm. The soil was removed by washing the samples through screens, the finest being 18 mesh. Oven dry weights were taken after drying at 100°C for 24 hours. Ash weights were taken after ashing at 500°C for 24 hours. Root weights were determined by weight loss during ashing.

The high maintenance study of 1986 was on a 'Midnight' Kentucky bluegrass while the low maintenance study was on a 'Parade' Kentucky bluegrass. Treatments were applied on 25 April 1986. The area received 6.3 cm of precipitation within 12 hours following treatment. Root samples were taken on 28 May, 30 June, and 31 July 1986. Due to the relatively wet and mild summer, there was little difference in moisture levels between the high and low maintenance regimes.

The high maintenance study of 1987 was on a Premium Sod Blend of Kentucky bluegrass consisting of 25% each of the cultivars 'Adelphi', 'Glade', 'Parade', and 'Rugby'. The low maintenance study was conducted on 'Parade' Kentucky bluegrass. Treatments were applied on 23 April. Samples were taken on 25 May, 26 June, and 28 July 1987.

Greenhouse studies

A greenhouse study was initiated to further study herbicide effects on Kentucky bluegrass in Sept. 1987. Four mil thick clear polyethylene tubing with 3.2 cm outside diameter was sealed on one end and punctured to provide drainage. Four hundred grams of fritted clay(Balcones

Absorb-n-Dry™) was mixed with 3.1 grams of Osmocote™ 14-14-14 fertilizer and poured into the tube. The height of the clay column was 58 cm. The tube was placed in a 60 cm polyvinyl chloride(PVC) pipe, 4.3 cm outside diameter. The tubes were vibrated and watered thoroughly to settle the media. Mortite™ was also wrapped around the outside of the clear tube to prevent light from entering between the tube and the PVC to reduce algal growth.

'Glade' Kentucky bluegrass was germinated in fritted clay. After four weeks, single uniform tillers were planted in the tubes and watered thoroughly until they were established. The tubes were angled 30^{o} from vertical to force the roots to grow down the lower side of the tubing.

The herbicides were applied 10 days after establishment of the grass plants. Treatments were identical to those in the 1986 and 1987 field studies. The granular herbicides were applied by hand while the liquid herbicides were applied in 1 ml distilled water tube^{-1} with a spray mist atomizer attached to an air pressure pump. A randomized complete block design with four replications was used. The tubes were watered thoroughly prior to application and the herbicides were watered in with 20 ml distilled water tube^{-1}.

The tubes were irrigated weekly with 20 ml distilled water which was the equivalent of 2.5 cm of water week^{-1}. Because of decreasing natural light intensity and duration, high pressure sodium lamps were used in the last month of the experiment. The average light intensity was 675 uMol sec^{-1} m^{-2} and the photoperiod was 14 hours. The air temperature was maintained at 25$\pm$2^{o}C.

Root growth was visually monitored along the lower surface of the clear tubing. Maximum root depth was measured from the intersection of crown and clay weekly and at the termination of the experiment. The plants were mowed at 6.4 cm and fresh shoot weight were recorded. The plant material was harvested 60 days after herbicide application. The columns were divided into two 28 cm sections and the roots were harvested by splitting the polyethylene tube and washing the clay away. Roots were oven dried at 80° C for 24 hours. The above ground tissue was severed from the roots at the crown and fresh weights were taken.

The study was repeated beginning Dec. 1987. The high pressure sodium lamps were used throughout the experiment. The plants were harvested only 35 days after herbicide application because a number of plants had rooted to the bottom of the tubes.

RESULTS AND DISCUSSION

Field studies

In the June sampling of the low maintenance study of 1985, the plots treated with pendimethalin at 1.68 and 3.36 kg ha^{-1} had lower total root weights than the control plots (Table 1). There were no differences in either total root weights or in root weights of individual depths in any of the sampling dates of the other studies. The summer of 1985 was a very hot and dry, stressful summer for a grass plant, especially under low maintenance conditions. Plants under stress are more susceptible to herbicide damage than vigorous plants that can grow out of the damage. The summers of 1986 and 1987 were less stressful for the grass plants which could explain why there was root inhibition only in 1985.

The susceptibility to herbicide damage has been shown to vary among cultivars of Kentucky bluegrass (1,6,7). Of the cultivars used in these studies, only 'Enmundi' Kentucky bluegrass has been studied for susceptibility to preemergence herbicide damage. Oxadiazon at 4.5 and 9.0 kg ha^{-1} and bensulide at 8.4 and 15.7 kg ha^{-1} reduced the rooting of 'Enmundi' Kentucky bluegrass in the greenhouse (1) but these chemicals had no observable effect on 'Enmundi' in this field study.

Greenhouse studies

Because of the nature of the greenhouse study, root growth could be more accurately observed and quantified than in the field. The three dinitroaniline herbicides, benefin, pendimethalin, and prodiamine, were consistently injurious to the roots. Benefin at 2.2 kg ha^{-1} reduced rooting 53% in the first experiment but had no effect in the second (Table 2). The 3.4 kg ha^{-1} rate of benefin reduced rooting in both studies, 47% in the first and 23% in the second. Pendimethalin at 1.7 kg ha^{-1} reduced total root weight 32% in the first experiment and 23% in the second. The 3.4 kg ha^{-1} rate was more damaging reducing root weight 44% and 28% respectively. Fenoxaprop-ethyl reduced root weight 37% only in the first study. Prodiamine, consistently the most damaging of the herbicides, reduced root weights by as much as 71%. DCPA at 11.8 kg ha^{-1} reduced total root weight 25% in the first experiment. The 16.80 kg ha^{-1} rate of DCPA reduced total root weight 39% in the second study.

The herbicides often inhibited rooting in the first experiment only to have no effect in the second experiment. Assuming that the only difference in the two experiments was the duration, the grass plants might be a little slower in reacting to these rates of herbicides and any damage that might have occurred later did not surface during the shortened time of the second experiment.

Severe root inhibition was often seen in the top 10-14 cm of the column with normal root growth below this area in the first study. The tubes were divided into three depths in the second study; 0-14 cm, 14-28 cm, and 28-56 cm to quantify this observation. Root inhibition consistently took place in the the upper 28 cm of the column and more precisely, the top 14 cm of the column. No inhibition was seen in the lower depths of the column and there were no differences in depth of rooting at any time in the experiments. Preemergence herbicides may only affect the roots near the soil surface with normal root growth deeper in the profile. This may be a problem with shallow-rooted turf species.

The apparent difference in root inhibition between the field and greenhouse studies may be because of the conditions under which the studies took place. A very dense turf combined with a thatch layer and fine soil particles probably intercepted the herbicide preventing it from penetrating into the soil. The large particles of fritted clay and thin grass cover in the greenhouse allowed the herbicides to reach the media surface and penetrate into the column coming into contact with the roots. The damage only occurred in the upper portion of the column, probably only as deep as the herbicides penetrated. Herbicides may be more damaging in porous soils where they can come into contact with the roots. Soils with fine particle structure may bind the herbicides tighter and prevent them from coming into contact with the roots.

Prodiamine at 0.6 and 1.1 kg ha^{-1} consistently reduced clipping weights 75% and more throughout both experiments (Table 3). Both rates of prodiamine reduced the final above ground shoot weight 73% in the first experiment whereas the low rate reduced final shoot weight 33% in the second experiment and the high rate reduced it 66%. Fenoxaprop-ethyl reduced clipping weights the first three weeks after application in the first experiment whereas pendimethalin reduced clipping weights 28 and 42 days after application in the first study.

Even though many of the herbicides inhibited rooting, very few inhibited top growth of the grass plants. With the high maintenance, low stress conditions found in the greenhouse, a grass plant could appear healthy even though root growth was inhibited as happened in this study. Healthy top growth may not be reflective of the safety of herbicides to Kentucky bluegrass. Observations on the effect on rooting is needed before one can be confident of the safety of the herbicide.

The results of this study combined with past literature on this subject suggest that herbicides can inhibit rooting of Kentucky bluegrass. The considerable variation in the reports on rooting reveal that the herbicides may not consistently inhibit rooting under all conditions but can be very damaging under certain conditions. More research is needed to clarify exactly which cultivars of Kentucky bluegrass under which environmental conditions and maintenance practices are susceptible to root inhibition by herbicides.

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Table 1: Root weights from the 1985 field study expressed as percent of control

		Maintenance		
		High	Low	
Treatment	kg ha^{-1}	June	June	Aug
Control	--	100	100	100
Benefin	2.2	89		
Benefin	3.4	83		
Bensulide	8.4	75		
Bensulide	9.0		88	86
Bensulide	14.0		94	97
Bensulide	15.7	100		
DCPA	11.8	87	100	95
DCPA	16.8	86		
Oxadiazon	2.2	79		
Oxadiazon	3.4		110	96
Oxadiazon	4.0	79		
Pendimethalin	1.7		81	82
Pendimethalin	3.4		80	85
$LSD_{.05}$		NS	17	NS

Table 2: Rooting of the greenhouse study expressed in percent of the control

		Experiment I			Experiment II			
		0-28	28-56		0-14	14-28	28-56	
Treatment	kg ha^{-1}	cm	cm	Total	cm	cm	cm	Total
Control	—	100	100	100	100	100	100	100
DCPA	11.8	70	142	75	98	102	141	105
DCPA	16.8	82	77	81	67	51	71	61
Oxadiazon	2.2	110	118	111	98	81	109	94
Oxadiazon	4.5	91	86	91	89	74	106	86
Bensulide	8.4	92	77	91	95	88	124	96
Bensulide	15.7	98	83	97	78	72	120	81
Benefin	2.2	46	60	47	70	85	109	80
Benefin	3.4	51	86	53	67	78	120	77
Pendimethalin	1.7	69	77	68	72	77	98	77
Pendimethalin	3.4	55	79	56	75	58	97	72
Prodiamine	0.6	25	85	29	50	36	25	37
Prodiamine	1.1	28	111	33	41	53	25	48
Fenoxaprop	0.1	63	58	63	95	80	79	88
$LSD_{.05}$		24	NS	24	25	33	NS	28

Table 3: Fresh clippings of greenhouse study expressed in percent of the control

		Experiment I						Experiment II			
		Days following application									
Treatment	kg ha^{-1}	14	21	28	35	42	final	14	21	28	final
Control	—	100	100	100	100	100	100	100	100	100	100
DCPA	11.8	126	86	87	98	75	103	107	98	111	108
DCPA	16.8	150	93	72	110	94	105	73	71	97	87
Oxadiazon	2.2	115	95	83	119	95	111	93	114	99	89
Oxadiazon	4.5	88	98	100	135	94	104	80	96	114	97
Bensulide	8.4	100	86	85	113	84	99	124	109	106	101
Bensulide	15.7	109	93	80	100	84	107	129	111	113	89
Benefin	2.2	112	83	65	83	80	80	127	108	120	92
Benefin	3.4	106	98	78	104	103	95	85	87	114	86
Pendimethalin	1.7	88	79	72	83	92	95	98	80	78	90
Pendimethalin	3.4	73	74	63	69	65	80	80	97	95	89
Prodiamine	0.6	18	26	24	21	19	27	29	15	33	67
Prodiamine	1.1	21	17	13	17	9	28	0	0	1	34
Fenoxaprop	0.1	35	60	67	67	42	73	132	112	113	89
$LSD_{.05}$		47	37	36	38	29	24	73	50	37	29