CHAPTER 2.0

EVALUATION OF GRAMINICIDES FOR BERMUDAGRASS (CYNODON DACTYLON) CONTROL IN SETHOXYDIM-TOLERANT CORN (ZEA MAYS)

2.1 ABSTRACT

Field experiments were conducted in 1996 and 1997 to evaluate the efficacy of graminicides alone and in combination with broadleaf herbicides for bermudagrass control with sethoxydim-tolerant corn. The specific objectives of this research were: (1) to evaluate the effect of graminicides including clethodim, fluazifop-P, quizalofop-P, and sethoxydim, and method of application, on crop tolerance and bermudagrass (Cynodon dactylon L.) control; and (2) to evaluate the effect of herbicide combinations with sethoxydim on crop tolerance and bermudagrass control. Experimental treatments included broadcast and directed postemergence applications of sethoxydim, fluazifop-P, quizalofop-P, clethodim, and fluazifop-P plus fenoxaprop-P and sethoxydim in combination with atrazine plus bentazon, dicamba, 2,4-D amine, atrazine plus dicamba, bromoxynil, nicosulfuron, primisulfuron, halosulfuron, primisulfuron plus prosulfuron, flumiclorac, pyridate, and bentazon. The graminicides, clethodim, fluazifop-P, quizalofop-P, and sethoxydim generally provided good control of bermudagrass. Sethoxydim and quizalofop-P were not toxic to sethoxydim-tolerant corn when applied as either broadcast or directed postemergence treatments. Clethodim caused severe crop

response when applied broadcast or directed. Combinations of sethoxydim with broadleaf herbicides also provided good control of bermudagrass. Some antagonism of sethoxydim in combination treatments with bentazon and bentazon plus atrazine was observed.

Nomenclature: atrazine, 6-chloro N2-ethyl-N4-isopropyl-1,3,5-triazine-2,4-diamine; bentazon, 3-isopropyl-1H-2,1,3-benzothiadiazin-4(3H)-one 2,2-dioxide; bromoxynil, (phenol): 3,5-dibromo-4-hydroxybenzonitrile; clethodim, (E,E)-(+/-)-2-[1-[[(3-chloro-2-propenyl)oxy]imino]propyl]-5-[2-(ethylthio)propyl]-3-hydroxy-2-cyclohexen-1-one; dicamba,3,6-Dichloro-2-methoxybenzoic acid, or 3,6-dichloro-anisic acid; 2,4-D, 2,4-dichlorophenoxyacetic acid; fenoxaprop, (+/-)-2-[4-[(6-chloro-2-benzoxazolyl)oxy]phenoxy]propanoic acid; fluazifop, (+/-)-2-[4-[[5-(trifluoromethyl)-2-pyridinyl]oxy]phenoxy]propanoic acid; flumiclorac, [2-chloro-4-fluoro-5-(1,3,4,5,6,7-hexahydro-1,3dioxo-2H-isoindol-2-yl]phenoxy]acetic acid; halosulfuron-methyl, methyl 5-{[(4,6-dimethoxy-2-pyrimidinyl)amino]carbonylaminosulfonyl}-3-chloro-1-methyl-1H-pyrazole-4-carboxylate; nicosulfuron, 2-[[[[(4,6-dimethoxy-2-pyrimidinyl)amino]carbonyl]amino]sulfonyl]-N,N-dimethyl-3-pyridinecarboxamide; primisulfuron, 2-[[[[[4,6-bis(difluoromethoxy)-2-pyrimidinyl]amino]carbonyl]amino]sulfonyl]benzoic acid; prosulfuron,1-(4-methoxy-6-methyl-triazin-2-yl)-3-[2-(3,3,3-triflu-oropropyl)-phenylsulfonyl]-urea; pyridate, O-(6-chloro-3-phenyl-4-pyridazinyl) S-octyl carbonothioate; quizalofop, (+/-)-2-[4-[(6-chloro-1,4-dihydro-1,4-dioxo-2-naphthalenyl)acetamide; sethoxydim, 2-[1-(ethoxyimino)butyl]-5-[2-(ethylthio)propyl]-3-hydroxy-2-cyclohexen-1-one; bermudagrass, Cynodon dactylon (L.) Pers., #1 CYNDA; corn, Zea mays L

Additional Index Words: postemergence directed application, clethodim, fenoxaprop-P, fluazifop-P, quizalofop-P, sethoxydim, CYNDA.

Abbreviations: DAT, days after treatment.

"[1]Letters following this symbol are a WSSA-approved computer code from Composite List of Weeds, Revised 1989. Available from WSSA, 810 East 10th Street, Lawrence, KS 66044-8897 ."

2.2 INTRODUCTION

Bermudagrass, recognized as one of the world's worst weed problems (Holm et al. 1972), is a vigorous, competitive perennial, which reproduces via seeds, stolons, and rhizomes (Gleason 1958; Hitchcock 1950). Bermudagrass has consistently been ranked as one of Virginia's worst weed species (Dusky 1997; Street 1994; Witt 1991), and in 1997 was rated as the tenth most common and fourth most troublesome weed species in Virginia corn production (Dusky 1997). Bermudagrass control in corn has been particularly difficult because control programs have relied upon cultural and mechanical procedures and the use of soil incorporated herbicides. These programs generally do not provide complete control, and the requirement for herbicide incorporation precludes their use in reduced tillage or no-till systems (Stevens 1986). Selective postemergence herbicides for bermudagrass control in corn have not been available.

Several herbicides, members of the aryloxyphenoxy propionates and the cyclohexanedione families of chemistry, have been developed and registered, in the last 15 years. They provide selective, postemergence control of annual and perennial grass weeds in broadleaf crops (Ware 1994). These herbicides, which are collectively referred to as graminicides due to their specificity for grass weeds, act on the lipid synthesis pathway by inhibiting acetyl-CoA carboxylase (ACCase) (Ahrens 1996). Both classes of chemistry afford high activity against many grasses at economical rates, and can be applied to most broadleaf crops with little risk of injury (Meister 1996).

Recently, sethoxydim tolerant corn plants have been regenerated from tissue cultures selected for callus growth in the presence of sethoxydim (Parker et al. 1990a;

Parker et al. 1990b). These plants exhibited a 40-fold increase in tolerance to sethoxydim relative to plants regenerated from tissue not exposed to the herbicide. The resistance originates from a nuclear mutation resulting in an altered form of the ACCase enzyme (Marshall et al. 1992). In field studies, sethoxydim applied at 0.88 kg/ha, approximately four times the field use rate, was non-injurious to the sethoxydim-resistant (SR) corn line (Dotray et al. 1993).

The benefit of weed control in corn has been studied and documented. Stoller et al. (1979) investigated yellow nutsedge (Cyperus esculentus L. # CYPES) competition in corn and found that when no control was practiced, yields were reduced 17% in a moderate infestation (initial infestation 300 tubers/m2) and 41% in a heavy infestation (initial infestation 1200 tubers/m2). Young et al. (1984) conducted field studies to determine the competitive nature of quackgrass (Elytrigia repens (L.) Nevski # AGRRE) in corn and found densities of 745 shoots/m2 reduced corn yields an average of 37% and significantly reduced corn height and ear length. Giant foxtail (Setaria faberi Herrm.) has been reported to cause yield losses of as much as 26% in corn, and shattercane (Sorghum bicolor (L.) Moench. # SORVU) has been shown to reduce corn yield by as much as 75% (Beckett et al. 1988).

No previous research has been conducted to determine the competitive effects of varying bermudagrass densities on corn growth and yield. However, the Herbicide Decision Model for Postemergence Weed Control in Field Crops (HERB) program, developed at North Carolina State University to estimate the effects of various single and mixed weed populations on crop growth and yield, estimates corn yield losses at 0.6% for the competition from 4 bermudagrass plant/100 ft2 and 52.2% for competition from 999 bermudagrass plants/100 ft2 (A. C. York, personal communication, 1998).

The development and commercialization of sethoxydim-tolerant corn would provide significant new options for postemergence control of grass weeds in corn. Sethoxydim has the potential to be used for control of grass weeds at the time of no-till corn establishment, as a supplement to preemergence herbicides for control of escaped grass weeds, or as a total postemergence treatment in combination with broadleaf herbicides (E. S. Hagood, personal communication, 1996, 1998; Young 1996). In particular, this technology has application for selective postemergence control of bermudagrass or other grass species for which other control options are not available.

The objectives of this research were: (1) to evaluate the effects of sethoxydim and other graminicides, applied either as postemergence broadcast or postemergence directed treatments, on sethoxydim-tolerant corn vigor and bermudagrass control, and (2) to evaluate the effects of herbicide combinations with sethoxydim on control of bermudagrass.

2.3 MATERIALS AND METHODS

Field experiments to evaluate the effects of sethoxydim and other graminicides in corn, applied either as postemergence broadcast or postemergence directed treatments, on SR corn vigor and bermudagrass control were conducted in Isle of Wight County, Va. in 1996, in James City County, Va. in 1997, and in Augusta County, Va. in 1996 and 1997. Experiments to evaluate the effects of herbicide combinations with sethoxydim on bermudagrass control were conducted in King William Co., VA in 1996 and King and Queen Co., VA in 1997, and in Augusta Co., VA in 1996 and 1997. Information concerning the edaphic characteristics of each experimental site is contained in Table 2.1. All experiments were located in areas of naturally occurring bermudagrass infestation.

Corn was grown using conventional tillage methods using a commercial planter delivering approximately 79,000 seeds/ha. Information on planting dates and corn hybrids is contained in Table 2.2. For all experiments, atrazine [6-chloro-N-ethyl-N'-(1-methylethyl)-1,3,5-triazine-2,4-diamine] at 1.7 kg ai/ha plus metolachlor [2-chloro-N-(2-ethyl-6-methylphenyl)-N-(2-methoxy-1-methylethyl)acetamide] at 2.2 kg ai/ha were applied preemergence for control of annual broadleaf weeds and grasses.

In all experiments, individual plots consisted of two 76-cm corn rows 7.6 meters in length. Herbicide applications were made to an area 1.8 m wide centered over the two treated rows. Two corn rows which did not receive treatment were located between each treated experimental unit, and served as buffers.

Herbicide applications were made using a CO2-pressurized backpack sprayer delivering 210 L/ha of water at 220 kPa through flat fan spray tips[2]. All herbicides treatments included crop oil concentrate[3] at 1.0 % (v/v). Broadcast postemergence applications were made using a 4-nozzle boom with a 1.8 meter effective swath width. Post-directed treatments were made with a single nozzle boom with a .45m effective swath and four passes per plot. Postemergence applications dates and corn and bermudagrass growth stages at the time of application are contained in Table 2.2.

In all experiments treatments were arranged in a randomized complete block design with four replications. The dependent variables evaluated included corn vigor reduction, bermudagrass control, and corn yield. Observations were made at 7 d intervals and utilized visual estimates of crop injury and weed control. Visual estimates used a 0 to 100 scale where 0 signifies no crop or weed injury and 100 signifies death of the crop or complete weed control. For each experiment, data from two evaluation dates are presented, including representative data from one early and one late-season evaluation. For all studies, crop response and bermudagrass control data taken at harvest did not differ appreciably with data from the later evaluation presented. Corn yields were obtained by hand harvesting treated rows and yields were adjusted to 15.5 % moisture content. All data were subjected to analysis of variance and means separated using Fishers Protected LSD with a significance level of $\alpha = 0.05$.

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[2]Teejet 8003 flat fan spray tips. Spraying Systems Co., North Ave., Wheaton, IL 60287.

[3]Crop-Surf Oil Concentrate , 83% Parrafin Base Petroleum Oil. Universal Cooperatives Inc., 7801 Metro Pkwy., Minneapolis, MN 55440.

2.4 RESULTS AND DISCUSSION

Graminicide and method of application effects on bermudagrass control, corn vigor, and corn yield were observed in all experiments (Tables 2.3-2.6). Observations taken at 25 and 69 DAT in 1996 showed that neither sethoxydim nor quizalofop-P caused significant injury to the crop, regardless of application method (Table 2.3). Broadcast applications of fluazifop-P, and both broadcast and postemergence directed applications of clethodim caused severe crop damage. No injury was observed with postemergence directed fluazifop-P.

Bermudagrass control varied from 83-95% control at 25 DAT across graminicide and application methods. Control was only 50% by 69 DAT with broadcast sethoxydim, 78% with broadcast quizalofop, and 28% with broadcast clethodim. Control ranged from 83-100% with other treatments at 69 DAT. Improved control with directed sethoxydim and quizalofop-P relative to control in broadcast applications probably resulted from improved herbicide coverage with the directed treatments. Improved control with directed clethodim relative to control with broadcast applications also resulted from improved coverage. It is also likely that the severe crop damage observed with broadcast clethodim eliminated competitive effects at the corn canopy on bermudagrass.

Highest corn yields were observed in response to directed applications of sethoxydim, where bermudagrass control was excellent and no crop injury was observed. Yields with quizalofop-P treatments and directed fluazifop-P were equivalent to yields with sethoxydim treatments. Yield reductions were observed with broadcast fluazifop-P and with clethodim, and were related to observed crop injury.

Crop response to graminicide applications was substantially less in the 1997 James City experiment, than observed in 1996 (Table 2.4). As observed in 1996, only broadcast applications of fluazifop-P and broadcast and directed applications of clethodim caused significant crop injury. This damage ranged from 9-25% at 24 DAT and 13-36% at 72 DAT. The combination of fluazifop-P plus fenoxaprop-P, applied only in 1997, caused 10 and 15% injury with broadcast application at 24 and 72 DAT, respectively.

Bermudagrass control ranged from 86-99% with quizalofop-P and 81-96% with fluazifop-P (Table 2.4). These control levels were significantly higher than those afforded by sethoxydim, where control ranged from 65-73%. Control levels observed in response to application of clethodim or fluazifop-P plus fenoxaprop-P were intermediate, and ranged from 73-76% and 75-90%, respectively. No significant advantage of directed application over broadcast for bermudagrass control was observed in this experiment.

Corn yield response to herbicide application and bermudagrass control was less in the 1997 experiment than observed in 1996. The lower levels of crop injury from fluazifop-P and clethodim were not reflected in reduced yields, and bermudagrass control was sufficient to preclude loss from competition. No explanation for the tendency for reduced corn yield with directed fluazifop-P was apparent.

In the 1996 Augusta County experiment, only broadcast applications of fluazifop-P and clethodim caused significant crop damage, which ranged from 13-28 and 19-36% across evaluation dates, respectively (Table 2.5). Excellent bermudagrass control was observed in response to both broadcast and directed applications of quizalofop-P and fluazifop-P across evaluation dates. These control levels ranged from 94-99 and 86-96%, respectively. Sethoxydim provided 80-86% bermudagrass control, while clethodim provided 78-90% control of this species. No significant differences in corn yield were observed. The lack of differential yield response can be attributed to low levels of crop injury. The lack of differential yield response between the control and treated plots can be attributed to the high amount of soil moisture in the 1996 season, crop yields in the controls were reduced by bermudagrass.

The 1997 Augusta County experiment was affected by severe drought. At 21 DAT, only slight crop injury was observed from broadcast applications of fluazifop-P, clethodim, and fluazifop-P plus fenoxaprop-P. By 35 DAT, corn vigor had declined due to moisture stress to the extent that differential corn vigor reductions due to herbicide treatment could not be discerned. Bermudagrass control from all treatments was substantially less in 1997 than in 1996 at this location, and reflects reduced graminicide uptake in drought stressed bermudagrass plants. No treatment gave over 51% bermudagrass control at either 21 or 35 DAT. Corn yields were extremely and did not vary significantly as a function of herbicide treatment.

The results of experiments to evaluate bermudagrass control with broadcast and directed applications of graminicides demonstrate highest potential for crop injury from clethodim and fluazifop-P. Generally, broadcast fluazifop-P and both broadcast and directed clethodim caused significant corn damage. No significant injury was observed with sethoxydim, or directed quizalofop-P, and only slight injury with broadcast quizalofop-P or fluazifop-P plus fenoxaprop-P. Bermudagrass control was generally highest with quizalofop-P and fluazifop-P, where excellent control was observed, except in the 1997 Augusta County experiment where drought reduced weed susceptibility to graminicides. Corn yields were reduced in response to severe crop response from broadcast fluazifop-P and broadcast and directed clethodim treatments in 1996, but generally were not reduced in response to lower levels of crop damage in other experiments. Herbicide treatments provided bermudagrass control sufficient to preclude yield loss via competition.

Significant effects of herbicide combinations with sethoxydim on bermudagrass control and corn yield were observed in all experiments (Tables 2.7-2.10). In the 1996 King William experiment neither sethoxydim alone nor in combination with broadleaf herbicides caused significant injury to the crop (Table 2.7). Bermudagrass control varied from 36-83% at 26 DAT. The highest levels of control were afforded by sethoxydim alone and in combination with bromoxynil, primisulfuron, dicamba, 2,4-D amine, and primisulfuron plus prosulfuron. Control was reduced to 36% with sethoxydim plus halosulfuron, 39% with sethoxydim plus dicamba plus atrazine, 48% with sethoxydim plus bentazon, 45% with sethoxydim plus bentazon plus atrazine, and 50% with sethoxydim plus flumiclorac. By 72 DAT, bermudagrass recovery from herbicide treatments was evident, and no treatment provided over 20% control.

No significant response of corn yield to herbicide treatments was observed (Table 2.7). Yields from treated plots were not higher than those from control plots. The lack of differential yield response to herbicide treatments reflects bermudagrass recovery and poor control observed in later evaluations, and wet growing conditions throughout the season.

In King and Queen County in 1997 the use of sethoxydim alone or in combination with broadleaf herbicides did not cause significant injury to the crop (Table 2.8). At 26

DAT, bermudagrass control varied from 63 to 85% across treatments. The highest levels of control were provided by sethoxydim alone and in combination with bromoxynil, primisulfuron, dicamba, 2,4-D amine, dicamba plius atrazine, halosulfuron, primisulfuron plus prosulfuron, and flumiclorac. Control was reduced to 63% with sethoxydim in combination with bentazon and 73% with sethoxydim plus bentazon plus atrazine. It is likely antagonism of sethoxydim by bentazon caused the significant reduction in bermudagrass control in the bentazon and bentazon plus atrazine treatments (Holshouser and Coble 1990). By 61 DAT bermudagrass control ranged from 35 to 86% control (Table 2.8). Sethoxydim combinations with bentazon, bentazon plus atrazine, dicamba, 2,4-D amine, and primisulfuron plus prosulfuron provided reduced bermudagrass control relative to that provided by sethoxydim alone. All other combinations provided control equivalent to that of sethoxydim alone. At both 26 and 62 DAT the lowest level of bermudagrass control was provided by sethoxydim in combination with bentazon at 63 and 35%, respectively.

In the 1996 Augusta County experiment neither sethoxydim alone nor in combination with broadleaf herbicides caused significant crop response at 26 or 54 DAT (Table 2.9). At 26 DAT bermudagrass control ranged from 48 to 90%. All combination treatments provided bermudagrass control equivalent to that with sethoxydim alone except for the combination with bentazon plus atrazine, where control was reduced to 48%. By 54 DAT, bermudagrass control with sethoxydim alone was 83%. Combinations of sethoxydim with bromoxynil, primisulfuron, bentazon, dicamba plus atrazine, halosulfuron, primisulfuron plus prosulfuron, flumiclorac, pyridate, and primisulfuron provided control equivalent to treatment with sethoxydim alone, which ranged from 78 to

91%. Bermudagrass control with sethoxydim plus dicamba and sethoxydim plus 2,4-D amine was reduced slightly to 74 and 68% respectively. The combination of sethoxydim plus bentazon plus atrazine caused control to be reduced to 48%.

No herbicide combination caused corn yield to differ significantly from that yield observed with sethoxydim alone (Table 2.9). This lack of differential yield response can be attributed to relatively uniform levels of bermudagrass control across treatments, and the lack of broadleaf weed pressure in the experimental area which resulted from the preemergence atrazine and metolachlor treatment, and wet growing conditions throughout the season.

The Augusta experiment was affected by drought in 1997. Only slight crop vigor reduction was observed at 21 DAT (Table 2.10). At 21 DAT, bermudagrass control reflected reduced uptake of graminicides due to moisture stress. Control ranged from 35 to 60% at 21 DAT and by 35 DAT bermudagrass recovery was evident with control ranging from only 0 to 14% across all treatments. By 35 DAT, corn vigor had declined due to moisture stress to the extent that differential corn vigor reductions due to herbicide treatment could not be discerned.

Corn yields in the 1997 experiment were low due to drought stress. Yields reflected lack of bermudagrass control observed in the later evaluations, and the general effects of the drought stress.

The overall results of these experiments indicate that both sethoxydim and quizalofop-P are not injurious to sethoxydim-tolerant corn with either postemergence broadcast or postemergence directed application. Postemergence directed application of fluazifop-P significantly reduced corn injury relative to broadcast postemergence application. Clethodim caused corn injury regardless of application method. Bermudagrass control with sethoxydim in combination with broadleaf herbicides was generally equivalent to that with sethoxydim alone. Some antagonism of sethoxydim activity was noted with some combinations, particularly with bentazon containing treaments.

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