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FACTORS AFFECTING THE EFFICACY OF TWO TURFGRASS GROWTH REGULATORS, TRINEXAPAC-ETHYL AND V-10029

By

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ABSTRACT

FACTORS AFFECTING THE EFFICACY OF TWO TURFGRASS GROWTH REGULATORS, TRINEXAPAC-ETHYL AND V-10029

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Trinexapac-ethyl is a foliar absorbed turfgrass growth regulator that inhibits shoot growth in many turfgrass species. Research initiated in 1995 showed the addition of Sylgard 309® + 28% urea ammonium nitrate could significantly enhance the efficacy of trinexapac-ethyl on four cool-season turfgrass species. Ammonium sulfate compensated for reductions in trinexapac-ethyl efficacy when hard water was the carrier and increased the rainfastness of trinexapac-ethyl for perennial ryegrass. The plant base was determined to be a preferred site of absorption for ^{14}C-trinexapac-ethyl in Kentucky bluegrass while absorption by the leaf blade could be enhanced by adding Sylgard 309®. Translocation of ^{14}C-trinexapac-ethyl in Kentucky bluegrass was acropetal when the material was absorbed by the plant base and basipetal when the material was absorbed by the leaf blade. An experimental turfgrass growth regulator, V-10029, significantly suppressed seedhead formation and shoot growth in five cool-season turfgrass species but was more injurious than trinexapac-ethyl, due to its herbicidal mode of action.

INTRODUCTION

Trinexapac-ethyl is a foliar absorbed turfgrass growth regulator that has been commercially available since 1993. Trinexapac-ethyl inhibits the biosynthesis of gibberellic acid by inhibiting the 3β-hydroxylation of GA_{20} to GA_1. Compared to the activity of other turfgrass growth regulators that inhibit gibberellin biosynthesis, this inhibition appears very late in the pathway, occurring immediately prior to biosynthesis of the primary active gibberellin that stimulates shoot elongation. Compounds such as paclobutrazol and flurprimidol inhibit gibberellin biosynthesis by blocking an earlier step in the pathway.

The singularity of the mode of action seen with trinexapac-ethyl, coupled with its relative market infancy, create a multitude of research areas that need to be addressed with this compound. Research concerning the physiological effects of applying turfgrass growth regulators, especially on a long-term basis, has been limited. Commercially available products such as trinexapac-ethyl may impact the responses of turfgras species to a variety of environmental and cultural stresses. The purpose of the research presented in this thesis was to determine the influence of several factors related to growth regulator application on the efficacy of trinexapac-ethyl and of an experimental growth regulator, V-10029, which has an herbicidal mode of action.

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SPRAY APPLICATION PARAMETERS THAT INFLUENCE THE GROWTH INHIBITING EFFECTS OF TRINEXAPAC-ETHYL

Matthew James Fagerness

ABSTRACT

Trinexapac-ethyl is a foliar absorbed cyclohexanedione turfgrass growth regulator that can inhibit shoot growth in a broad range of turfgrass species. Greenhouse studies were conducted with trinexapac-ethyl to investigate the effects of hard water, rainfastness, photolability, and spray carrier volume on efficacy. Results were compared to those obtained with the cyclohexanedione herbicide, sethoxydim. Studies with Kentucky bluegrass, perennial ryegrass, creeping bentgrass, and tall fescue showed that the adjuvant combination of Sylgard 309® plus 28% urea ammonium nitrate (UAN) could significantly enhance the efficacy of trinexapac-ethyl when applied at or below 0.382 kg ha^{-1}. Ammonium sulfate compensated for reductions in both trinexapac-ethyl and sethoxydim activity on perennial ryegrass when hard water was the carrier. Ammonium sulfate increased the rainfastness of trinexapac-ethyl on perennial ryegrass to a greater extent than did Sylgard 309® while the rainfastness of sethoxydim was only increased by the latter. Photolabilty of formulated trinexapac-ethyl on perennial ryegrass was not observed to be a liability. Increasing spray carrier volume did not significantly influence the efficacy of trinexapac-ethyl on perennial ryegrass, although efficacy enhancements observed with additions of ammonium sulfate were only apparent at low volumes. The impact of ammonium salts on trinexapac-ethyl activity had a broad range of implications for applications of this growth regulator.

Abbreviations: UAN - urea ammonium nitrate, E formulation - emulsifiable concentrate formulation, AMS - ammonium sulfate, UV - ultraviolet, DAT - days after treatment

INTRODUCTION

Foliar absorbed herbicides provide effective post-emergence control of a broad range of agronomic weeds. Uptake by the shoots speeds the arrival of active ingredient at the target tissue, as compared to root absorbed materials. However, efficacy of foliar absorbed herbicides is dependent on a greater number of application parameters than for herbicides applied to the soil. Examples of such parameters are adjuvants, chemical rainfastness, carrier water quality, chemical photolability, and spray carrier volume.

Trinexapac-ethyl is a foliar absorbed turfgrass growth regulator that can cause growth inhibition, with maximum efficacy at 14-21 days after treatment, in numerous turfgrass species (Johnson, 1993; Johnson, 1994). Trinexapac-ethyl falls into the cyclohexanedione class of herbicide chemistry, having structural similarity to both sethoxydim and clethodim, two common graminicides. Spray application parameter effects on trinexapac-ethyl efficacy may therefore follow the same trends that exist for sethoxydim and/or clethodim. The label for trinexapac-ethyl identifies a broad range of effective spray carrier volumes (187-1683 l ha^{-1}), achievement of rainfastness within one hour after application, and no need for an adjuvant to enhance efficacy. There is little evidence available to either support or discount these stipulations.

Adjuvants may enhance spray droplet coverage on plant leaves and chemical absorption (Wanamarta et al., (1989a); Bridges et al., 1991; Bridges et al., 1992). These effects may be due to a number of possible mechanisms, including cuticle solubilization and physical interaction with the herbicide in question (Wanamarta et al., (1989a)).

Adjuvants can thus be used to increase herbicide efficacy, enhance activity of photolabile herbicides, or overcome problems with antagonism from other chemicals and/or solution salts (Campbell and Penner, 1985; Penner, 1989; Hazen and Krebs, 1992; McInnes et al., 1992). Many adjuvants have been tested for enhancement of either sethoxydim or clethodim with varying results (Wanamarta et al., (1989a); Bridges et al., 1992; Hazen and Krebs, 1992; Jordan et al., 1996). Therefore, the choice of adjuvant can be very critical. Herbicide applications on grasses may show a favorable response to additions of organosilicone surfactants, offering potential for these adjuvants to enhance herbicide efficacy (Field and Bishop, 1988; Roggenbuck et al., 1990; Sun et al., 1996).

Chemical rainfastness is the time required after a chemical application for enough absorption to occur so that activity is not diminished by subsequent rainfall removing the chemical from the leaf surface. Postemergence herbicides with slow rates of foliar absorption are often susceptible to losses of activity via this mechanism. Thus, the influence of adjuvants in enhancing foliar absorption has been a logical area of interest. Organosilicone surfactants have the potential for increasing the rainfastness and/or efficacy of some herbicides (Jansen, 1973). However, the mechanism by which such improvements act is disputed. Field and Bishop (1988) document reduced spray solution surface tension as a result of organosilicone surfactant action. Accelerated absorption would enhance rainfastness. They assumed increased absorption was related to herbicide penetration through the stomatal pore. However, this mechanism doesn't explain variable efficacy responses between organosilicone surfactants which similarly reduce spray solution surface tension. Enhanced cuticular penetration thus appears responsible for the activity enhancement (Roggenbuck et al., 1990). Sun et al. (1996) document rainfastness as soon as 15 minutes after application of primisulfuron on velvetleaf with an organosilicone surfactant. The overall potential of these surfactants to increase rainfastness is clear and warrants investigation with any chemical where rainfastness may need to be increased.

Carrier water quality can affect absorption and/or activity of herbicides due to the presence of Na^{+}, Ca^{++}, Mg^{++}, and Fe^{+++}. Glyphosate activity is reduced in the presence of many soluble cations because it forms a conjugate salt with the inorganic cation (Stahlman and Phillips, 1979; Nalewaja and Matysiak, 1993; Thelen et al., 1995). This antagonism is increased with high spray carrier volumes (Sandberg et al., 1978). Antagonism of clethodim is seen in the presence of sodium bicarbonate but is not seen with a different graminicide, quizalofop (McMullan, 1994). Antagonism between sethoxydim and Na-bentazon, through a similar formation of a Na-sethoxydim conjugate salt is also well documented (Jordan and York, 1989; Wanamarta et al., (1989b); Wanamarta et al., 1993; Nalewaja et al., 1994; Thelen et al., 1995).

These antagonisms can be overcome with adjuvants. Addition of ammonium salts effectively restores herbicide activity by replacing the metal cation portion of the inactive conjugate salt with ammonium, forming a new conjugate that has higher solubility and thus is more readily absorbed (Jordan and York, 1989; Wanamarta et al., 1989; Nalewaja and Matysiak, 1993; Wanamarta et al., 1993; Thelen et al., 1995). Other methods such as replacing tank mixed applications of Na-bentazon and sethoxydim with sequential applications also overcome this antagonistic effect (Rhodes and Coble, 1983). The specific susceptibility of some herbicides, especially the cyclohexanediones, to antagonism with inorganic metal cations provides a basis for research with other products showing similar chemistry.

Chemical photolability, most commonly due to the effects of ultraviolet (UV) light, can reduce the efficacy of some herbicides. Cyclohexanedione grass herbicides are particularly susceptible to photolability (Zorner et al., 1989; Bridges et al., 1992; Hazen and Krebs, 1992; McInnes et al., 1992; McMullan, 1994; Nalewaja et al., 1994; McMullan, 1996). The same researchers suggest a slower rate of foliar uptake than photodegradation as the reason why herbicide efficacy is reduced, a mechanism that can be counteracted with an adjuvant. Na^+ in the spray solution inhibits cyclohexanedione foliar absorption and amplified photolability-induced efficacy reductions (McMullan, 1994; Nalewaja et al., 1994). Trinexapac-ethyl is also a cyclohexanedione but is labeled as having rapid foliar absorption and, as such, should be less susceptible to photolability.

The objectives of this research were to test whether spray application parameters that influence cyclohexanedione herbicide efficacy also influence the efficacy of trinexapac-ethyl. These parameters include adjuvants, carrier water quality, rainfastness, chemical photolability and spray carrier volume. Successfully identifying if trinexapac-ethyl applications should follow the same guidelines as those for other cyclohexanedione herbicides may provide valuable information necessary in maximizing efficacy of this turfgrass growth regulator.

MATERIALS AND METHODS

Turfgrass studies involving spray application parameters that impact efficacy of cyclohexanedione herbicides were initiated with trinexapac-ethyl and, in some cases, sethoxydim. Studies in the greenhouse were at 25 C +/- 2 C with supplemental lighting from high-pressure sodium lights providing 1200 μmol photons m^{-2} s^{-1} during 18 hours of daylight. All pots were irrigated daily or as needed and received 5 kg nitrogen ha^{-1} in the form of Peters® 20-20-20 fertilizer on a weekly basis.

Unless otherwise indicated, the specifications for treatment applications were as follows. Treatments were applied with a continuous link-belt sprayer at 170 kPa and 230 l ha^{-1} spray pressure and carrier volume, respectively, with a nozzle height of 30 cm above the canopy. Applied rates for trinexapac-ethyl as the 1E formulation and sethoxydim as the 1.53E formulation were 0.191 kg ha^{-1} and 0.114 kg ha^{-1}, respectively.

Adjuvant Impact on Trinexapac-ethyl Efficacy

Studies were initiated in September, 1995 to evaluate the impact of an activator organosilicone adjuvant on the efficacy of trinexapac-ethyl, applied to four cool-season turfgrass species. Plant material studied was 'Georgetown' Kentucky bluegrass (*Poa pratensis* L.), 'Mondial' perennial ryegrass (*Lolium perenne* L.), 'Putter' creeping bentgrass (*Agrostis palustris* Huds.), and 'Triathlon', a blend of three varieties of tall fescue (*Festuca arundinacea* Schreb.). Plugs of 1-year old tall fescue were imported as sod from the Hancock Turfgrass Research Center in East Lansing, MI to the greenhouse, where they were placed into 946-ml pots containing Baccto® potting media and allowed to acclimate over a two week period before being sprayed. The other turfgrasses were established from seed at recommended seeding rates three months prior to the studies.

The study was done twice in September, 1995 with Kentucky bluegrass, creeping bentgrass, and tall fescue. Perennial ryegrass was sprayed in January, 1996. Treatments for each species included a control and trinexapac-ethyl at 0.048 kg ha^{-1} (tall fescue only), 0.095 kg ha^{-1}, 0.191 kg ha^{-1}, 0.382 kg ha^{-1}, and 0.763 kg ha^{-1} (all species but tall fescue). All treatments were sprayed with or without Sylgard 309® +28% urea ammonium nitrate (UAN) adjuvant (5.0 ml l^{-1} and 10.0 ml l^{-1}, respectively).

Carrier Water Quality and Chemical Rainfastness

Studies were initiated in the fall of 1995 to evaluate adjuvants for enhancing both carrier water quality and chemical rainfastness, with respect to sethoxydim and trinexapac-ethyl efficacy. Applications were made to 2-month old 'Mondial' perennial ryegrass (*Lolium perenne* L.), originally seeded into Baccto® potting media in 946-ml pots at 293 kg seed ha^{-1}. Pilot studies were conducted to determine rates for sethoxydim and trinexapac-ethyl which would be less than fully effective, such that effects of adjuvants would be detectable.

Carrier water quality studies were sprayed in September and October, 1995 for both sethoxydim and trinexapac-ethyl treatments. Three carrier solutions were selected: deionized water, 0.5 mg l^{-1} calcium acetate, and 0.5 mg l^{-1} magnesium acetate. The pH of each stock solution was determined. Trinexapac-ethyl and sethoxydim treatments were applied in each carrier solution, with or without ammonium sulfate (AMS) at 5.0 g l^{-1}.

For rainfastness studies, trinexapac-ethyl and sethoxydim treatments were applied with each of the following adjuvant combinations: no adjuvant, AMS at 5.0 g l^{-1}, Sylgard 309® at 5.0 ml l^{-1}, and Sylgard 309® plus AMS. A simulated 1.25 cm of rainfall was applied at 303 kPa, 20 cm above the canopy surface in 1.25 minutes. Chemical treatments were given each of the following four rainfall events: no rainfall event, a rainfall event immediately after chemical treatment, and rainfall events either 15 or 30 minutes after treatment. The experiment had three replications and was repeated.

Chemical Photolability

A study was initiated in April, 1996 to evaluate the potential for high intensity UV light to reduce the efficacy of both sethoxydim and trinexapac-ethyl. The plant material used was 8-month old 'Mondial' perennial ryegrass, originally seeded into Baccto® potting media at 293 g seed ha^{-1}.

Chemical treatments included sethoxydim and trinexapac-ethyl, with or without Sylgard 309® adjuvant at 5.0 ml l^{-1} . UV light exposure for each treatment was for 0, 20, or 40 minutes after spray application in a Rayonet® photochemical reactor containing 12 high intensity UV bulbs around the interior perimeter. Light intensity in the chamber was 15 W m^{-2}.

Spray Carrier Volume

Studies were initiated in September, 1996 to determine the effects of adjuvants and spray carrier volume on trinexapac-ethyl efficacy in the greenhouse and to determine the effects of spray carrier volume and mowing height on trinexapac-ethyl efficacy in the field. Plant material was 1-year old 'Mondial' perennial ryegrass, originally seeded into Baccto® potting media at 293 g seed ha^{-1}, for the greenhouse study and 3-year old 'Blacksburg' Kentucky bluegrass, established in a native sandy clay loam soil at the Hancock Turfgrass Research Center in East Lansing, MI.

Greenhouse treatments included four adjuvant combinations: no adjuvant, Sylgard 309® at 5.0 ml l^{-1}, AMS at 5.0 g l^{-1}, and Sylgard 309® plus AMS; each was applied with or without trinexapac-ethyl. All treatments including trinexapac-ethyl and/or adjuvant were sprayed at each of five spray carrier volumes (187 l ha^{-1}, 561 l ha^{-1}, 935 l ha^{-1}, 1309 l ha^{-1}, and 1683 l ha^{-1}) which encompassed the range indicated on the trinexapac-ethyl label.

A 7.32 m by 14.64 m field plot was staked out and split into three equal-sized 4.88 m by 7.32 m areas. Each of these areas was mowed at a different cutting height (5, 7.5, and 10 cm). Single treatment plot area was 1.22 m by 2.44 m. All plots were irrigated daily or as needed and received 25 kg N ha^{-1} in the form of urea (46-0-0) on a biweekly basis.

The study was initiated in September, 1996 in the early morning. Air temperature was 19 C and wind speed was negligible. Each mowing height block received three chemical treatments plus an untreated control treatment. Trinexapac-ethyl as the 1E formulation was applied with a backpack sprayer at a rate of 0.287 kg ha^{-1} for each of the three spray carrier volumes (187 l ha^{-1}, 561 l ha^{-1}, and 1683 l ha^{-1}). Clippings were collected at 7, 14, 21, and 28 days after treatment. Clippings were oven-dried for 48 hours and then weighed. The study was a 3 by 4 randomized complete block design and all treatments had three replications.

The turfgrasses in the greenhouse pots were maintained at a 4 cm cutting height (2 cm for creeping bentgrass) before studies were sprayed and mowed back to this height when data was collected. Evaluation of trinexapac-ethyl growth inhibition was determined by production of clipping fresh weight. Clipping weights were determined at 7, 14, and 21 days after treatment. The multiple species study had an additional clipping harvest at 28 DAT. Efficacy of sethoxydim treatments was based on visual injury ratings (0-10 scale: 0=uninjured, 10=complete burndown) taken at 12, 16, and 20 days after treatment. All greenhouse studies were completely randomized designs, had four replications per treatment, and were repeated, unless otherwise indicated. Data reflect combined means from both runs of repeated studies. Statistical analyses were based on factorial analysis of variance, with significance set at the 5% level. In the carrier volume study, the percent of control data were transformed to the arcsine for analysis of variance and mean separation.

RESULTS AND DISCUSSION

Adjuvant Impact on Trinexapac-ethyl Efficacy

The magnitude of growth inhibition by trinexapac-ethyl differed for the different species in this study. Maximum growth inhibition of trinexapac-ethyl occurred at either two to three weeks after treatment with all of the species, supporting specifications given on the chemical label.

All trinexapac-ethyl treatments, with or without Sylgard 309® plus 28% UAN, significantly reduced clipping production in Kentucky bluegrass 7 days after treatment (DAT). The adjuvant significantly enhanced the performance of trinexapac-ethyl at 0.095 kg ha^{-1} 7 DAT (Table 1). Trinexapac-ethyl efficacy, at the lower two rates, was enhanced by the adjuvant 14, 21, and 28 DAT. Trinexapac-ethyl at 0.382 kg ha^{-1} and at 0.763 kg ha^{-1} performed equally well for the first two weeks of the study but trinexapac-ethyl at the higher rate caused greater growth inhibition over the last two weeks. Trinexapac-ethyl at all rates, with the adjuvant, was still inhibiting growth 28 DAT.

Trinexapac-ethyl, at all rates, inhibited growth of perennial ryegrass 7 DAT. However, among trinexapac-ethyl treatments, little significance was observed (Table 2). A notable exception at 7 DAT was the enhancement of growth inhibition caused by the adjuvant at the 0.095 kg ha^{-1} rate. A similar enhancement was observed 14 DAT. High variation between treatment replicates at 28 DAT resulted in a lack of significant growth inhibition in almost all treatments.

Trinexapac-ethyl, at all rates, inhibited the growth of creeping bentgrass 7 DAT but no differences between treatments were observed. The adjuvant significantly enhanced trinexapac-ethyl at both 0.095 kg ha^{-1} and at 0.191 kg ha^{-1} 14 DAT (Table 3). A similar enhancement occurred 21 DAT.

Trinexapac-ethyl at 0.048 kg ha^{-1} was included exclusively with tall fescue and it did not inhibit growth throughout the study. Trinexapac-ethyl did not have a significant overall impact on tall fescue as few treatments successfully inhibited shoot growth (Table 4). The adjuvant enhanced trinexapac-ethyl at 0.095 kg ha^{-1} 14 DAT but other enhancements were not observed.

Growth of creeping bentgrass was the most inhibited by trinexapac-ethyl whereas growth of tall fescue was the least inhibited, due to differences in maturity level between the two species. Growth of Kentucky bluegrass and perennial ryegrass was inhibited to a similar extent. Trinexapac-ethyl at 0.763 kg ha^{-1} was generally the most effective treatment applied. However, trinexapac-ethyl at this rate was at least twice the recommended rate for all the species and was often seen to cause both visual injury and discoloration unacceptable to turfgrass managers.

The selected Sylgard 309® plus 28% UAN adjuvant combination was effective in enhancing the efficacy of trinexapac-ethyl. Growth inhibition in tall fescue was usually unaffected by the addition of the adjuvants. However, growth of all other species was generally more inhibited by trinexapac-ethyl with the adjuvant than without it. The adjuvant often reduced the necessary application rate of trinexapac-ethyl for a given response level. The exact mechanism for such an enhancement was not explored in this study but probably was a function of both of the constituents in the adjuvant.

Carrier Water Quality and Chemical Rainfastness

Perennial ryegrass was sensitive to the effects of both trinexapac-ethyl and sethoxydim. Seven DAT, the potentially antagonistic impact of calcium and magnesium in the water carrier on trinexapac-ethyl efficacy was not yet evident and AMS did not impact efficacy (Table 5). However, at 14 DAT, trinexapac-ethyl applied in calcium and magnesium carrier solutions without AMS had clipping production equal to that for the untreated control. Trinexapac-ethyl applied in calcium and magnesium carrier solutions with AMS, conversely, significantly decreased clipping production. This effect diminished by 21 DAT.

Sethoxydim injury was significantly enhanced by the addition of AMS to both the calcium and magnesium carrier solutions at both 12 and 16 DAT (Table 6). Twenty DAT, the level of injury in all treatments was greater than 60% and no significant differences among treatments were observed.

The pH values for the calcium and magnesium carrier solutions were 7.1 and 7.5, respectively. The influence of pH on the results appeared negligible. Although significant differences were observed between treatments for both chemicals, the results may have reflected the low 5.0 g l^{-1} level of AMS that was used. AMS levels of 10 g l^{-1} and 20 g l^{-1} are commonly used in many herbicide applications. The potential for AMS to offset the antagonistic effects of hard water cations is clear and AMS may have had even a greater positive impact in these studies had the level included been greater.

Clipping production was significantly reduced by all trinexapac-ethyl treatments in rainfastness studies. Rainfastness of trinexapac-ethyl was also significantly increased by the three adjuvants selected for these studies. Seven DAT, AMS seemed to play an important role in enhancing efficacy as only treatments containing AMS produced significantly fewer clippings than treatments without adjuvants for any of the washoff times (Table 7).

Fourteen DAT, all trinexapac-ethyl treatments containing Sylgard 309® and most containing AMS showed enhanced efficacy, as compared to treatments without an adjuvant, at all three washoff times (Table 7). Loss of trinexapac-ethyl activity due to washoff was observed with washes at both 0 and 15 minutes after application. Compared to their unwashed counterparts, only trinexapac-ethyl with Sylgard 309® plus AMS at the 0 minute washoff and trinexapac-ethyl with AMS at the 15 minute washoff had no loss of activity due to the washoffs. By 30 minutes after treatment, washoff had no significant impact on trinexapac-ethyl activity.

Twenty-one DAT, the positive impact of AMS on trinexapac-ethyl rainfastness had disappeared. Loss of trinexapac-ethyl activity due to washoff occurred with AMS and with Sylgard 309® plus AMS at the 0 minute washoff time and with AMS at the 30 minute washoff time (Table 7). Trinexapac-ethyl with Sylgard 309® suffered no loss of activity at any of the washoff times.

All sethoxydim treatments showed significantly greater injury than untreated controls over the duration of the study. None of the adjuvants enhanced sethoxydim activity in the unwashed treatments. However, significant losses of activity were observed with all washoff treatments. Sylgard 309® was the only adjuvant that restored activity lost due to washoff (Table 8).

Overall, trinexapac-ethyl seemed to be more rainfast than was sethoxydim. The label for trinexapac-ethyl indicates rainfastness within one hour of application. Results from these studies suggested rainfastness was more rapid than that, especially when an adjuvant was included. AMS, with or without Sylgard 309®, significantly increased the rainfastness of trinexapac-ethyl while it had no impact on the rainfastness of sethoxydim. Sylgard 309® increased the rainfastness of both cyclohexanediones.

Chemical Photolability

Neither sethoxydim nor trinexapac-ethyl treatments suffered any loss of activity from the effects of UV light exposure. Sethoxydim was expected to lose activity under such conditions while the impact on trinexapac-ethyl was unknown (Zorner et al., 1989; Hazen and Krebs, 1992; McInnes et al., 1992; Nalewaja et al., 1994; McMullan, 1996). Newer formulations of sethoxydim contain additives inhibitory to UV photodegradation. It does not appear that trinexapac-ethyl, applied as the 1E formulation, is susceptible to loss of activity due to photolability.

Spray Carrier Volume

AMS enhanced trinexapac-ethyl efficacy in the greenhouse at 187 l ha^{-1} but insignificantly or negatively impacted efficacy at higher volumes 14 DAT (Figure 1). The observed enhancement supported results seen in the carrier water quality study. However, the lack of enhancement seen at 561 l ha^{-1} or greater was probably related to the low AMS concentration, 5.0 g l^{-1}. At high spray volumes, the ratio of ammonium to Ca^{++} and Mg^{++} in the hard water may have been insufficient to offset the negative impact of hard water cations on uptake. AMS has the potential to enhance trinexapac-ethyl efficacy across a broad range of spray carrier volumes but it is recommended that a higher level of AMS be included at higher volumes to adequately account for hard water cations.

A significant interaction between mowing height and spray carrier volume was observed at 21 DAT. Results were not conclusive at 7, 14, or 28 DAT. Carrier volume significantly impacted trinexapac-ethyl efficacy at the 5 cm and 10 cm mowing heights (Figures 2 and 3). A denser canopy stimulated by lateral growth and a higher canopy with more leaf tissue may necessitate higher spray carrier volumes for applications to the 5 cm and 10 cm mowing heights, respectively. Treatments mowed at 7.5 cm, with predominance of neither lateral development nor excess leaf matter, responded equally well to trinexapac-ethyl at all spray carrier volumes (Figure 4). Because a significant interaction occurred when trinexapac-ethyl exhibited maximum efficacy at 21 DAT, an interaction between cutting height and spray carrier volume may have significant implications for field applied trinexapac-ethyl.

It is suggested, based on results from greenhouse studies, that adjuvants have a beneficial impact on trinexapac-ethyl efficacy, rainfastness, and activity in hard water, especially at lower spray carrier volumes. The role of AMS in overcoming hard water problems with trinexapac-ethyl is likely a key factor in explaining increased rainfastness and enhanced efficacy observed with trinexapac-ethyl treatments containing AMS. Uptake of trinexapac-ethyl seemed to be inherently more rapid than absorption of sethoxydim.

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Table 1: Trinexapac-ethyl efficacy on 'Georgetown' Kentucky bluegrass: the effect of application rates and Sylgard 309® plus 28% urea ammonium nitrate.

Trinexapac-ethyl rate	Time after application (days)							
	7		14		21		28	
	-adj.	+adj.	-adj.	+adj.	-adj.	+adj.	-adj.	+adj.
kg ha^{-1}	Clipping production (% of control)							
0	100	89	100	107	100	111	100	106
0.095	76	53	88	60	90	78	101	78
0.191	60	45	56	31	70	47	75	66
0.382	49	36	36	23	51	19	70	45
0.763	31	28	21	15	16	10	37	24
$LSD_{0.05}$	18		18		17		18	

Table 2: Trinexapac-ethyl efficacy on 'Mondial' perennial ryegrass: the effect of application rates and Sylgard 309® plus 28% urea ammonium nitrate.

Trinexapac-ethyl rate	Time after application (days)					
	7		14		21	
	-adj.	+adj.	-adj.	+adj.		
kg ha^{-1}	Clipping production (% of control)					
0	100	89	100	88	100	82
0.095	62	38	51	27	85	57
0.191	46	41	30	20	54	37
0.382	59	38	39	23	55	27
0.763	39	29	19	10	27	17
$LSD_{0.05}$	24		23		29	

Table 3: Trinexapac-ethyl efficacy on 'Putter' creeping bentgrass: the effect of application rates and Sylgard 309® plus 28% urea ammonium nitrate.

Trinexapac-ethyl rate	Time after application (days)					
	7		14		21	
	-adj.	+adj.	-adj.	+adj.	-adj.	+adj.
$kg\ ha^{-1}$	Clipping production (% of control)					
0	100	104	100	95	100	119
0.095	55	38	35	17	60	41
0.191	51	38	31	13	60	22
0.382	34	38	14	12	24	14
0.763	33	32	15	6	12	10
$LSD_{0.05}$	30		15		35	

Table 4: Trinexapac-ethyl efficacy on 'Triathlon' tall fescue: the effect of application rates and Sylgard 309® plus 28% urea ammonium nitrate.

Trinexapac-ethyl rate	Time after application (days)							
	7		14		21		28	
	-adj.	+adj.	-adj.	+adj.	-adj.	+adj.	-adj.	+adj.
kg ha^{-1}	Clipping production (% of control)							
0	100	102	100	101	100	118	100	106
0.048	91	76	93	79	109	93	105	103
0.095	85	63	82	50	104	74	95	82
0.191	75	60	65	44	90	68	78	68
0.382	62	57	39	38	52	52	66	57
$LSD_{0.05}$	25		22		34		25	

Table 5: Effects of hard water cations and ammonium sulfate (AMS) on trinexapac-ethyl activity in perennial ryegrass.

	Time after application (days)					
	7		14		21	
Treatment	- AMS	+ AMS	- AMS	+ AMS	- AMS	+ AMS
	Clipping production (% of control)					
Control	100	121	100	141	100	121
Trinexapac-ethyl in deionized water	63	66	38	50	12	37
Trinexapac-ethyl in 5.0 g l^{-1} calcium acetate	71	82	55	43	38	38
Trinexapac-ethyl in 5.0 g l^{-1} magnesium acetate	80	69	78	36	53	33
$LSD_{0.05}$	39		47		29	

Table 6: Effects of hard water cations and ammonium sulfate (AMS) on sethoxydim activity in perennial ryegrass.

Treatment	Time after application (days)					
	12		16		20	
	- AMS	+ AMS	- AMS	+ AMS	- AMS	+ AMS
	(% injury †)					
Control	0	0	0	0	0	0
Sethoxydim in deionized water	41	48	68	79	74	83
Sethoxydim in 5.0 g l^{-1} calcium acetate	34	49	61	77	68	83
Sethoxydim in 5.0 g l^{-1} magnesium acetate	34	42	59	73	64	77
$LSD_{0.05}$	8		11		17	

† % injury values were converted from an original 0-10 rating scale where 0=uninjured, 10=dead

Table 7: Rainfastness characteristics of trinexapac-ethyl applied to perennial ryegrass.

		Time after application (days)											
		7				14				21			
		Adjuvant				Adjuvant				Adjuvant			
Treatment	Washoff interval	None	AMS	Sylgard 309	Sylgard 309+AMS	None	AMS	Sylgard 309	Sylgard 309+AMS	None	AMS	Sylgard 309	Sylgard 309+AMS
	minutes	Clipping production (% of control)											
Control	None	100	100	100	100	100	100	100	100	100	100	100	100
Trinexapac-ethyl	None	67	49	57	57	43	18	16	14	70	43	42	39
Trinexapac-ethyl	0	69	52	62	51	60	53	29	23	91	124	59	74
Trinexapac-ethyl	15	59	47	66	70	46	25	29	30	70	68	59	55
Trinexapac-ethyl	30	67	51	56	59	51	24	27	19	97	83	60	60
$LSD_{0.05}$		15				12				29			

Table 8: Rainfastness characteristics of sethoxydim applied to perennial ryegrass.

		Time after application (days)											
		12				16				20			
		Adjuvant				Adjuvant				Adjuvant			
Treatment	Washoff interval	None	AMS	Sylgard 309	Sylgard 309+AMS	None	AMS	Sylgard 309	Sylgard 309+AMS	None	AMS	Sylgard 309	Sylgard 309+AMS
	minutes	(% injury)											
Control	None	0	0	0	0	0	0	0	0	0	0	0	0
Sethoxydim	None	60	56	53	59	75	74	71	77	84	86	83	89
Sethoxydim	0	21	24	44	36	41	41	61	49	57	66	78	72
Sethoxydim	15	19	29	49	44	45	41	67	56	59	66	83	80
Sethoxydim	30	25	35	44	42	40	51	53	56	56	74	76	81
$LSD_{0.05}$		10				10				7			

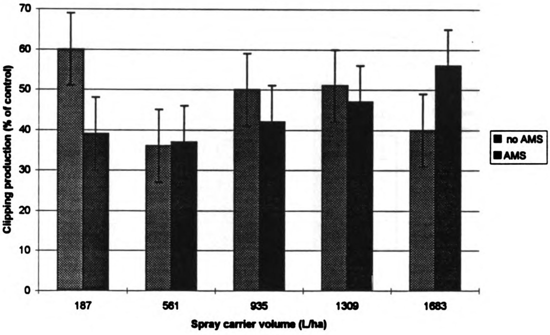

Figure 1: Effects of spray carrier volume and ammonium sulfate on 'Mondial' perennial ryegrass 14 days after treatment.

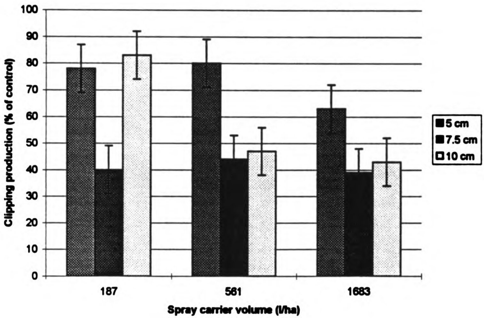

Figure 2: Effects of spray carrier volume on clipping production 21 days after treatment for 'Blacksburg' Kentucky bluegrass mowed at 5, 7.5, and 10 cm.

APPENDIX A

Table A1: Specifications for greenhouse spray carrier volume treatments

Spray Carrier Volume (l ha^{-1}) †	Spray Pressure (kPa)	Tee-Jet® Nozzle Type Used
187	68	8001E (100 mesh screen)
561	265	80015 (100 mesh screen)
935	136	8004VS (50 mesh screen)
1309	224	8004VS (50 mesh screen)
1683	272	SS8005 (50 mesh screen)

† All treatment applications were made with a nozzle height of 20 cm above the canopy surface.

Table A2: Specifications for field spray carrier volume treatments.

Spray Carrier Volume ($l\ ha^{-1}$) †	Spray Pressure (kPa)	Walking Speed ($cm\ s^{-1}$)	Tee-Jet® Nozzle Type Used
187	177	152.40	8002 (50 mesh screen)
561	258	60.96	8002 (50 mesh screen)
1683	252	30.48	8006 (50 mesh screen)

† All treatment applications were made with a nozzle height of 30 cm above the canopy surface.

CHAPTER 2

^{14}C-TRINEXAPAC-ETHYL ABSORPTION AND TRANSLOCATION IN KENTUCKY BLUEGRASS

^{14}C-TRINEXAPAC-ETHYL ABSORPTION AND TRANSLOCATION IN KENTUCKY BLUEGRASS

Matthew James Fagerness

ABSTRACT

Trinexapac-ethyl is a foliar-applied growth regulator for turfgrass that can reduce mowing frequency, clipping production, and enhance turfgrass color. ^{14}C-Trinexapac-ethyl was used to evaluate absorption and subsequent ^{14}C-trinexapac-ethyl translocation in hydroponically grown 'Blacksburg' Kentucky bluegrass (*Poa pratensis* L.). The magnitude and rate of ^{14}C trinexapac-ethyl absorption by various organs was as follows: plant base > leaf blade > roots. Over the time period of 0 to 24 hours, maximum absorption by the plant base was obtained in 8 hours and by the leaf blade in 24 hours. Absorption by the roots was negligible. Addition of an activator organosilicone adjuvant, Sylgard 309®, significantly enhanced ^{14}C-trinexapac-ethyl absorption by the leaf blade one hour after application but did not enhance absorption by the plant base. Of the ^{14}C-trinexapac-ethyl absorbed by the plant base, over 50% was translocated to the plant foliage after 24 hours. Of the ^{14}C-trinexapac-ethyl absorbed by the leaf blade, one-third was translocated after 24 hours; the direction of movement was predominantly basipetal. Less than 5% of absorbed ^{14}C-trinexapac-ethyl from either site was translocated to roots or to rhizomes with daughter plants, explaining the lack of inhibition of lateral turfgrass growth. Combined effects of enhanced leaf blade absorption, basipetal translocation from the leaf blade, and acropetal translocation from the plant base of ^{14}C-trinexapac-ethyl helped explain the positive impact of Sylgard 309® on efficacy and rainfastness of trinexapac-ethyl.

Abbreviations: HAT - hours after treatment

INTRODUCTION

The use of ^{14}C-labeled xenobiotics is a common tool for evaluating absorption and translocation patterns of these compounds. Trinexapac-ethyl is a foliar absorbed cyclohexanedione plant growth regulator. Specificity for uptake of trinexapac-ethyl among foliar sites is unknown for trinexapac-ethyl although leaf blades come into more direct contact with the spray droplets than do other tissues. Barrett and Bartuska (1982) found the stem, as compared to the leaves, to be a preferred site of uptake for an experimental growth retardant, PP333. Speed of absorption of foliar applied chemicals can be important in both efficacy and chemical rainfastness. Results from Al-Khatib et al. (1992) suggest that most herbicide absorption occurs within 24 hours of application. Trinexapac-ethyl, labeled as being rainfast within one hour of application, should conform to this pattern.

The absorption pattern of a given herbicide can be affected positively by adjuvants or negatively by antagonistic chemicals and/or ions. The absorption of sethoxydim by leaves was dramatically reduced in the presence of bentazon (Rhodes and Coble, 1984). Ammonium salts were able to counteract this antagonism (Wanamarta et al., 1993) and were able to increase leaf absorption of picloram (Moxness and Lym, 1989). Crop oil concentrate adjuvants increase the absorption of fluazifop, quizalofop, and sethoxydim in oats (Manthey et al., 1992). Organosilicone surfactants enhance the efficacy of many herbicides and can be excellent surface wetting agents (Jansen, 1973; Roggenbuck et al., 1990). The optimal adjuvants for enhancing trinexapac-ethyl efficacy have not been determined.

Systemic herbicide translocation from the site of uptake to the meristems can be as important a factor in determining efficacy as absorption for herbicides affecting meristematic activity. Phloem transport can be slow (Derr et al., 1985; Peregoy et al., 1990; Camacho et al., 1991). Instances where plants transclocate herbicides basipetally through phloem more rapidly may relate to observed patterns of efficacy (Hart and Penner, 1993). Response to fluazifop was dependent on translocation (Derr et al., 1985). When slow basipetal translocation does not coincide with observed patterns of herbicide efficacy, alternate sites of uptake and translocation patterns may contribute to activity (Achhireddy et al., 1985). Dicamba, for example, is translocated acropetally in several species, the mechanism for which may or may not be phloem transport (Al-Khatib et al., 1992). Translocation of the cyclohexanedione herbicide, sethoxydim, is both acropetal and basipetal (Wills, 1984). Potential impact of trinexapac-ethyl on lateral turf growth was addressed by Calhoun (1996), who reported divot closure rates in creeping bentgrass treated with trinexapac-ethyl to be equal to or higher than those for untreated controls. The translocation pattern for trinexapac-ethyl is not known but may be largely dependent on the preferred site of absorption.

The objectives of this research were to (i) determine the preferred site of absorption for ^{14}C-trinexapac-ethyl, (ii) determine the effect of an organosilicone surfactant on absorption of ^{14}C-trinexapac-ethyl, and (iii) determine the translocation patterns of ^{14}C-trinexapac-ethyl over a 24 hour period from three sites of uptake. The goal was to increase the understanding of foliar absorption and translocation patterns for trinexapac-ethyl such that efficacy may be maximized.

MATERIALS AND METHODS

Plant material for all studies was 2-year old 'Blacksburg' Kentucky bluegrass (*Poa pratensis* L.), originally obtained as sod from the Hancock Turfgrass Research Center in East Lansing, MI. Sod pieces were placed into 25 cm by 50 cm flats containing a coarse soil (23% gravel, 77% sand) in the greenhouse and allowed three weeks to establish. The soil type was chosen so that the plants could later be removed from the soil with a minimal amount of root damage. The greenhouse was at 25 C +/- 2 C with supplemental lighting from high-pressure sodium lights providing 1200 μmol photons m^{-2} s^{-1} of light during 18 hours of daylight. All flats were irrigated regularly and received 10 kg nitrogen ha^{-1} per week. The rate of nitrogen application was higher than normal for maintenance of greenhouse plants because the soil used was coarse and leached readily.

Plants were established hydroponically prior to the ^{14}C-trinexapac-ethyl absorption and translocation studies. The hydroponic solution used was a modified Hoagland's solution derived for hydroponic establishment of creeping bentgrass. Aliquots of this solution were made using six stock nutrient solutions, each containing one or more essential nutrients (Menn and McBee, 1970). Deionized water was the carrier for stock solutions and the Hoagland's nutrient solution. One-half and one-quarter strength versions of the same Hoagland's solution were used in some instances. Treatment solutions were made using 1,2,6-^{14}C-labeled trinexapac-ethyl with 94.8% purity and a specific activity of 1,139,600 Bq mg^{-1} (Figure 1).

Absorption Studies

Individual plants were established in full strength Hoagland's solution by removing them from the soil, rinsing them free of debris, and wrapping the base of the plant with a slit cut foam plug. Plugs were then inserted through small holes in a colored plastic lid so the roots could suspend freely in the solution below. The solution was aerated using an air stone attached to an electric air pump. Plants studied were selected for both health and size-based uniformity. Experiments were conducted with individual plants wrapped in a foam plug and suspended into 120 ml jars containing 100 ml of one-half strength Hoagland's solution. A one-quarter strength solution was used for root absorption experiments to minimize solute interference with ^{14}C-trinexapac-ethyl uptake. All jars were wrapped with aluminum foil.

The specifications for 200 µl treatment stock solutions differed according to the type of experiment (Table 1). Absorption experiments for the roots, the leaf blade, and the plant base were conducted over a three week period in May and June of 1996, while those involving the adjuvant were conducted in November, 1996. Leaf blades and plant bases were treated with a 2 µl droplet of treatment stock solution containing a quantity of trinexapac-ethyl based on a 0.191 kg ha^{-1} rate (Table 1); delivery was with a 10 µl Hamilton® syringe. 4 µl droplets were placed in the rootzone solution for the root absorption experiment. Treated plant parts were washed for 45 seconds with a 1:1 methanol:water solvent at 0, 1, 4, 8, or 24 hours after treatment (HAT). (The 8 HAT wash was excluded in the adjuvant study). The choice of solvent and duration of wash were based on solubility of trinexapac-ethyl, previous work with cyclohexanedione herbicides, and a time threshold, beyond which the solvent could extract absorbed material

(Devine et al., 1984; Wills, 1984). Each combination of treated plant site and washoff time had four replications.

Rinsates were collected in 20 ml liquid scintillation vials, each containing 3 ml of 1:1 methanol:water. Two 2-ml aliquots from each rootzone solution which had directly received ^{14}C-trinexapac-ethyl for the root absorption experiment were similarly collected. The solutions were then diluted to a total volume of 15 ml with Safety Solve® liquid scintillation cocktail and analyzed in a liquid scintillation counter. Differences in radioactivity between the applied droplets and the collected rinsates were presumed to be the amounts of ^{14}C taken up by each plant. ^{14}C in 2 ml aliquots taken from each rootzone solution was determined to evaluate the amount of ^{14}C in root absorption experiments that was not absorbed.

Translocation Studies

Studies were initiated in June, 1996 to measure translocation of ^{14}C-trinexapac-ethyl from three sites of uptake. A similar study evaluating two sites of uptake with plants that had rhizomes with daughter plants was initiated in September, 1996. Plants for the June study were established and selected as for absorption studies. Plants for the September study were planted into a coarse sand and allowed to generate rhizomes with daughter plants. The parent and daughter plants were subsequently transferred to a one-half strength Hoagland's solution. The colored lid for pots was prepared with a 0.5 cm by 7.5 cm slit so both the parent and daughter shoots could be equally supported above the solution.

Treatments were applied from a stock solution containing the following: 50 µl ^{14}C-trinexapac-ethyl, 118.85 µl formulation blank (taken from a 1:100 stock solution), and 31.15 µl deionized water. Sites of uptake were the leaf blade, the plant base, and the roots for the June study, which had six replications per treatment. The September study had four replications per treatment and did not evaluate roots as a site of uptake. Two 2-µl droplets containing 3700 Bq of ^{14}C were applied to the leaf blade or the plant base and in one 4-µl droplet to the rootzone solution. A ten-fold increase in radioactivity, as compared to absorption studies, was used to ensure traceability of the ^{14}C as it was translocated. Twenty four hours after treatment, treated plant parts were rinsed with 1:1 methanol:water; rinsates and aliquots from directly treated rootzone solutions were analyzed for ^{14}C.

Plants were segmented based on the original site of ^{14}C uptake (Table 2). Segments were kept at -10 C until they were oxidized in a biological oxidizer. Efficiency of the oxidizer was greater than 95% and was determined by oxidizing a known quantity of ^{14}C placed on a piece of paper towel and then calculating the percent recovery. $^{14}CO_2$ from oxidized samples was trapped in a 2:1 Safety Solve®:CarbosorbII® cocktail. Each sample was then radioassayed in a liquid scintillation spectrometer. Combined radioactivity from rinsates and all plant segments was used to determine the percent recovery of ^{14}C for each site of uptake. Percent recoveries of ^{14}C were 96%, 75%, and 82% for ^{14}C-trinexapac-ethyl applied to the roots, base of the plant, and leaf blade, respectively, in June, 1996. Percent recoveries of ^{14}C were 76% and 79% for ^{14}C-trinexapac-ethyl applied to the base of the plant and leaf blade, respectively, in September, 1996. The foam plugs that supported the plant bases accounted for a portion of the unrecovered ^{14}C. Distributions of translocated ^{14}C-trinexapac-ethyl were expressed as percentages of absorbed ^{14}C.

All studies were completely randomized designs and were repeated. Data reflect combined means from two experiments. Statistical analyses were based on analysis of variance and/or simple linear regression with significance set at the 5% level.

RESULTS AND DISCUSSION

Absorption Studies

There were marked differences between the leaf blade, the plant base, and the roots, in terms of both rate and total absorption of ^{14}C- trinexapac-ethyl (Figure 2). The leaf blade absorbed only 4% of applied ^{14}C-trinexapac-ethyl before the immediate washoff but had absorbed 31% by one HAT. Absorption increased consistently over the next three washoff periods, culminating in maximum absorption of 70% by 24 HAT. The base of the plant absorbed 29% of applied ^{14}C- trinexapac-ethyl before the immediate washoff and had absorbed 80% by one HAT. At this point, the absorption rate slowed down, reaching a maximum by 8 HAT and a level of 94% 24 HAT. The roots absorbed little ^{14}C-trinexapac-ethyl, taking up only 5% of applied material after 24 hours. Commercially, trinexapac-ethyl is foliar applied so the results from the root absorption experiment were not surprising. The plant base was the preferred site of absorption for ^{14}C-trinexapac-ethyl. Thus, the amount of trinexapac-ethyl reaching the plant base may be a major factor in determining efficacy.

The organosilicone surfactant, Sylgard 309®, is an activator adjuvant that was determined to be capable of enhancing trinexapac-ethyl efficacy (data not presented). Absorption studies with ^{14}C-trinexapac-ethyl plus Sylgard 309® were conducted with the intent of determining whether enhanced absorption, surface movement to a preferred site of absorption such as the plant base, or both were involved in the observed enhancement of trinexapac-ethyl efficacy.

Absorption of ^{14}C-trinexapac-ethyl by the plant base was unaffected by the addition of Sylgard 309® at any of the washoff times (Figure 3b). Absorption of ^{14}C-trinexapac-ethyl by the leaf blade was unaffected by the addition of Sylgard 309® at 0, 4, and 24 HAT. However, significant enhancement of absorption with Sylgard 309® occurred 1 HAT, the increase being from 21% to 51% (Figure 3a). Absorption of ^{14}C-trinexapac-ethyl was so rapid that a measurable amount of absorption occurred in less than the 45 seconds it took to wash the ^{14}C-trinexapac-ethyl off of either the leaf blade or the plant base for the zero time treatment.

Enhanced early absorption of ^{14}C trinexapac-ethyl by leaf blades when Sylgard 309® was included could provide greater trinexapac-ethyl rainfastness. Absorption by both the leaf blade and plant base was greater than 50% after one hour when Sylgard 309® was added to the treatment solution. The reduction of surface tension of spray droplets with Sylgard 309® allow more of the spray solution to move on the surface of the plant to the base of the plant, which is the preferred site of absorption.

Translocation Studies

The direction and extent of ^{14}C-trinexapac-ethyl translocation was dependent on the site of uptake. The base of the plant absorbed 96% of applied ^{14}C-trinexapac-ethyl while the leaf blade absorbed 70% of applied ^{14}C-trinexapac-ethyl in 24 hours. Roots absorbed 2% of applied ^{14}C-trinexapac-ethyl in 24 hours and translocated acropetally 50% of what was absorbed (Table 3).

The leaf blade retained greater than 60% of the ^{14}C it absorbed after 24 hours (Table 3). One percent of absorbed ^{14}C moved acropetally while 32% moved basipetally and accumulated in a variety of tissues. The plant base accumulated 11% of absorbed ^{14}C. Roots accumulated 5% of the absorbed ^{14}C.

Greater than 75% of ^{14}C absorbed by the base of the plant was translocated acropetally to the plant foliage over 24 hours. Roots accumulated less than 5% of absorbed ^{14}C while the other 18% remained in the base of the plant (Table 3).

The leaf blade and the plant base were the two sites of absorption evaluated in translocation studies involving rhizomes/daughter plants. Greater than 70% of the ^{14}C-trinexapac-ethyl applied to the leaf blade was absorbed while the plant base absorbed greater than 85% of applied ^{14}C-trinexapac-ethyl.

Translocation of absorbed ^{14}C from the leaf blade was as follows: 36% translocated to other foliar tissues, 4% translocated to the roots, and 3% translocated to the rhizome/daughter plant after 24 hours (Table 4). The other 57% remained in the leaf blade.

Translocation of ^{14}C absorbed by the base of the plant was as follows: 61% translocated acropetally, 3% translocated to the roots, and 3% translocated to the rhizome/daughter plant after 24 hours (Table 4). The other 33% remained in the base of the plant.

Acropetal translocation of ^{14}C from the plant base and basipetal translocation of ^{14}C from the leaf blade observed in both studies appeared related to the activity of trinexapac-ethyl observed in turfgrasses. Preferred directional translocation from both sites of uptake would result in a convergence of the active ingredient at the intercalary meristems, which are the primary sites of growth inhibition for trinexapac-ethyl. The leaf blade retained more ^{14}C after 24 hours than did the plant base. The rinsate from the leaf blade washoff after 24 hours also contained more ^{14}C than that from the plant base. These results were again indicative of the plant base being the preferred site of absorption for trinexapac-ethyl and the potential for an adjuvant to increase leaf blade absorption. The lack of significant ^{14}C translocation to the roots suggested that any effects trinexapac-ethyl may have on the roots are a function of its effects on shoot growth. The similar lack of significant translocation to rhizome tissues suggested that trinexapac-ethyl has little impact on lateral development of rhizomatous turfgrass species such as Kentucky bluegrass.

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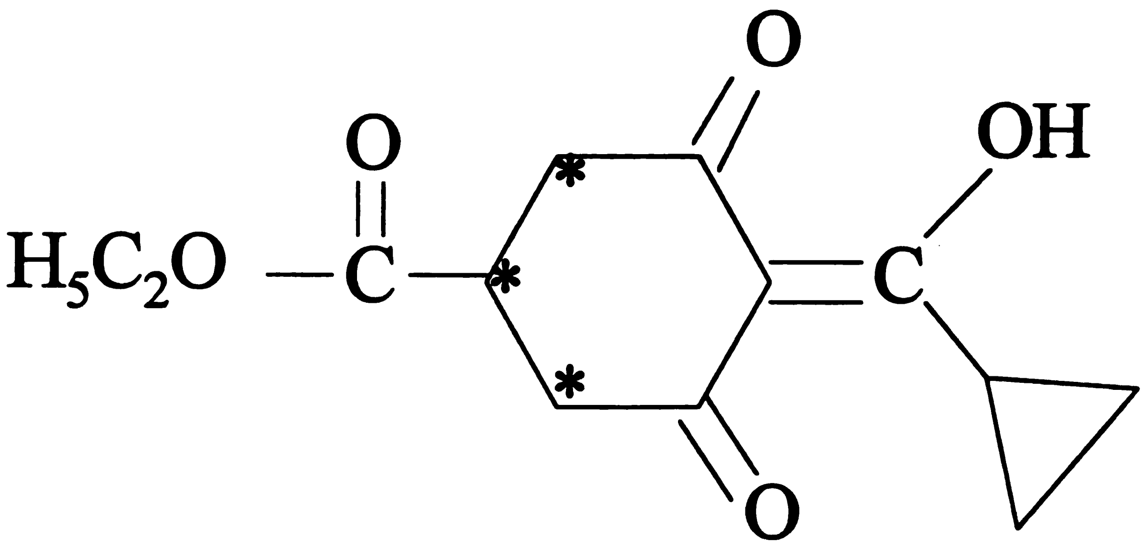


Figure 1: Chemical structure for 1,2,6-^{14}C-trinexapac-ethyl.

Table 1: Content of absorption study ^{14}C treatment solutions.

Absorption Study	Deionized H_2O	Cold trinexapac-ethyl †	^{14}C trinexapac-ethyl	Formulation blank †	Adjuvant ‡
	μl				
Root/Leaf/ Plant base	57.43	108.8	10 (370 Bq)	23.77	none
Leaf/Plant base with Adjuvant	7.43	108.8	10 (370 Bq)	23.77	50

† Amounts listed taken from a 1:100 source:deionized water solution.

‡ Amount listed taken from a 1:50 Sylgard 309®:deionized water solution.

Table 2: Plant segmentation in translocation studies

Site of Uptake	Segments
Plant base	Roots ‡
	Plant base ‡
	Foliage ‡
	Rhizomes with daughter plant †
Roots	Roots
	Plant base
	Foliage
Leaf Blade	Roots ‡
	Plant base
	Treated leaf ‡
	Leaves above the treated leaf
	Stem of treated leaf
	Sheath of treated leaf
	Rhizomes with daughter plant †
	Other foliage ‡

† Applicable to the September, 1996 study but not the June, 1996 study.
‡ Segments analyzed in the June, 1996 and in the September, 1996 studies.

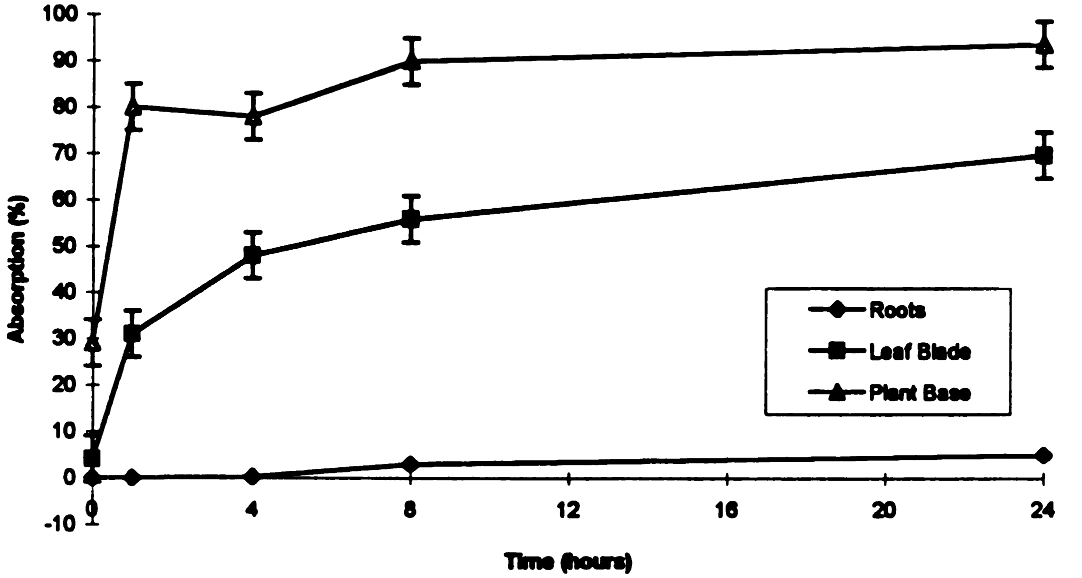


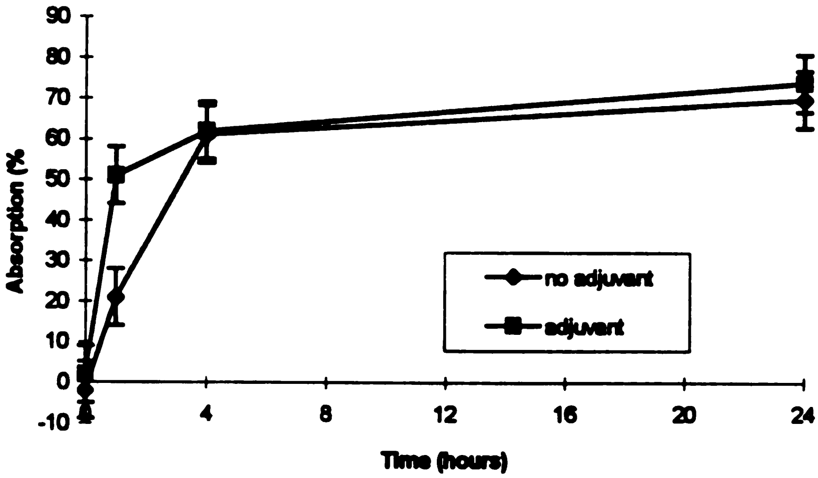
Figure 2: Absorption patterns of ^{14}C-trinexapac-ethyl over a 24 hour period from three sites of uptake. The patterns are represented by the following regression data:

Roots: $Y=0.219x + .042$ $r^2=.901$

Leaf Blade: $Y^2=1043.1x^{0.5} + 15.9$ $r^2=.995$

Plant Base: $Y=0.96\ln x + 84$ $r^2=.951$

3a



3b

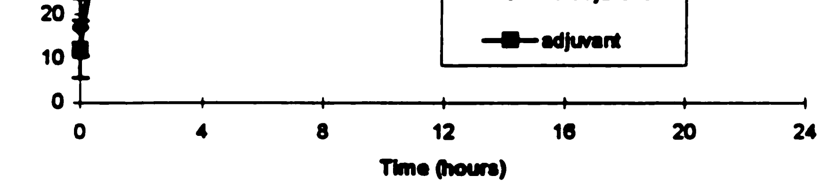


Figure 3a,b: The effect of Sylgard 309® on absorption of ^{14}C-trinexapac-ethyl by the leaf blade (Figure 3a) and by the plant base (Figure 3b).

Table 3: Translocation of ^{14}C-trinexapac-ethyl from three sites of uptake.

Site of Analysis	Site of ^{14}C-trinexapac-ethyl uptake: Leaf Blade	Plant Base	Roots
	——% of absorbed ^{14}C——		
Roots	5 b ‡	4 c	50 a
Foliage †	N/A	78 a	25 a
Plant Base	11 b	18 b	25 a
Treated Leaf	67 a	N/A	N/A
Leaf Sheath for Treated Leaf	5 b	N/A	N/A
Stem of Treated Leaf	6 b	N/A	N/A
Leaves Above Treated Leaf	1 b	N/A	N/A
Other Tillers	5 b	N/A	N/A

† Refers to all foliar tissue other than the plant base.
‡ Numbers followed by different letters in each respective column are statistically different at the 5% level.

Table 4: Translocation patterns of ^{14}C-trinexapac-ethyl when rhizomes were present.

Site of Analysis	Site of uptake: Leaf blade	Site of uptake: Plant base
	% of absorbed ^{14}C	
Foliage †	36 b ‡	61 a
Treated Plant Part	57 a	33 b
Roots	4 c	3 d
Rhizome/Daughter Plant	3 c	2 d

† Refers to all foliar tissue other than the treated plant part.
‡ Numbers followed by different letters in each respective column are statistically different at the 5% level.

APPENDIX B

Table B1: Contents of stock nutrient solutions.

Chemical Reagent	Quantity ($g\ l^{-1}$)
KNO_3	101.1
$Ca(NO_3)_2$	236.2
$NH_4H_2PO_4$	115.1
$MgSO_4 \times 7H_2O$	246.5
Sequestrene®	11.2
KCl †	3.7
H_3BO_3 †	1.5
$MnSO_4 \times H_2O$ †	0.3
$ZnSO_4 \times 7H_2O$ †	0.6
$CuSO_4 \times 5H_2O$ †	0.1
H_2MoO_4 †	0.1

† Denotes reagents whose amounts were all combined in a single liter of micronutrient stock solution.

Table B2: Contents of full strength Hoagland's solution.

Nutrient Stock Solution	Amount (ml $10l^{-1}$)
KNO_3	60
$Ca(NO_3)_2$	40
$NH_4H_2PO_4$	20
$MgSO_4 \times 7H_2O$	10
Sequestrene®	10
Micronutrients †	10

† Contained all six reagents highlighted in Table 1.

CHAPTER 3

EVALUATION OF V-10029 AND TRINEXAPAC-ETHYL AS TURFGRASS GROWTH REGULATORS ON FIVE COOL-SEASON SPECIES

EVALUATION OF V-10029 AND TRINEXAPAC-ETHYL AS TURFGRASS GROWTH REGULATORS ON FIVE COOL-SEASON SPECIES

Matthew James Fagerness

ABSTRACT

An experimental turfgrass growth regulator, V-10029, was compared with trinexapac-ethyl to evaluate growth inhibition patterns and suppression of seedhead formation; the latter was evaluated for turfgrass species and for the infesting weed species, annual bluegrass. Tall fescue, creeping red fescue, Kentucky bluegrass, perennial ryegrass, and creeping bentgrass were transferred from the field into the greenhouse. V-10029, at three rates (0.015 kg/ha, 0.029 kg/ha, and 0.059 kg/ha), was compared to an untreated control and trinexapac-ethyl at the label rate. Of the eight replications for each treatment, four were not mowed for the purpose of evaluating suppression of seedhead formation and four were used for weekly clipping collection to evaluate growth inhibition. Compared to the untreated control, V-10029 at all three applied rates caused significant suppression of seedhead formation in both tall fescue and perennial ryegrass pots. Trinexapac-ethyl was not as effective. V-10029 caused discoloration in all turfgrass species depending on the rate of application. Patterns of growth inhibition for tall fescue, Kentucky bluegrass, and perennial ryegrass, in response to V-10029 at all rates and to trinexapac-ethyl, were similar on a percent of control basis. Growth of creeping bentgrass was only inhibited by V-10029 at high rates. In contrast, creeping red fescue was significantly injured by V-10029. The greatest growth inhibition, in response to all treatments, occurred 2 to 3 weeks after application. The effect of trinexapac-ethyl faded after 4 weeks while V-10029

was efficacious slightly longer. Observed effects of V-10029 support its known activity as an ALS inhibiting herbicide and therefore as a Class D turfgrass growth regulator.

Nomenclature: V-10029 {sodium 2,6-bis[(4,6-dimethoxypyrimidin-2-yl)oxy]benzoate}, trinexapac-ethyl {4-(cyclopropyl-α-hydroxy-methylene)-3,5-dioxocyclohexanecarboxylic acid ethyl ester}, annual bluegrass (*Poa annua* L.), tall fescue (*Festuca arundinacea* Schreb.), creeping red fescue (*Festuca rubra* L.) , Kentucky bluegrass (*Poa pratensis* L.), perennial ryegrass (*Lolium perenne* L.), creeping bentgrass (*Agrostis palustris* Huds.)

Additional index words: growth inhibition, suppression of seedhead formation, discoloration, clipping collection

INTRODUCTION

Plant growth regulators (PGRs) in turfgrass systems are commonly used to reduce vegetative growth, production of seedheads, or both. Watschke (1985) discussed the impact of plant growth regulators that inhibit mitosis, as compared to plant growth retardants that disrupt cell division and elongation through impact on gibberellin biosynthesis. This breakdown of PGR mode of action was later used to classify PGRs as Type I or Type II (Watschke et al. 1992). Type I PGR's, such as maleic hydrazide {1,2-dihydro-3,6-pyridazinedione} and mefluidide {N-[2,4-dimethyl-5-[[(trifluoromethyl) sulfonyl]amino]phenyl]acetamide}, cause excellent seedhead formation suppression and growth inhibition in turfgrasses but are also injurious (Schott et al. 1980, McCarty et al. 1985, Diesburg and Christians 1989, Johnson 1989, Spak et al. 1993). Type II PGRs, such as paclobutrazol {(+/-)-(R*,R*)-β-[(4-chlorophenyl)methyl]-α-(1,1-dimethylethyl)-1*H*-1,2,4-triazole-1-ethanol}, flurprimidol {α-(1-methylethyl)-α-[4-(trifluoro-methoxy)phenyl]-5-pyrimidine-ethanol}, and trinexapac-ethyl, are less injurious but are also less effective in seedhead formation suppression.

Watschke and DiPaola (1995) reclassified Type II PGRs, based on the site of uptake and the site of inhibition in the gibberellin (GA) biosynthesis pathway. Trinexapac-ethyl is foliar absorbed, inhibits GA biosynthesis late in the pathway, and is classified as a Class A PGR. Paclobutrazol and flurprimidol are root absorbed, inhibit GA biosynthesis earlier, and are thus classified as Class B PGRs. Mitotis inhibiting PGRs that previously were classified as Type I are now Class C. A final class of PGRs, Class D, includes chemicals with herbicidal activity applied at non-lethal rates. V-10029 is a member of this group, showing ALS inhibiting activity (Hopkins 1994, Lim et al. 1997). Proper classification of both current and future plant growth regulators is essential for proper selection of a PGR to use for specific management needs.

Evaluation of new plant growth regulators is a function of several factors that, collectively, determine PGR efficacy. Growth inhibition, seedhead formation suppression, visual quality, and density in turfgrasses are commonly evaluated in PGR studies. Evaluation of experimental PGRs using a range of applied rates is also common. Schott et al. (1980) tested mefluidide at five rates and at different timings of application to evaluate the effects of mefluidide on shoot growth, seedhead initiation, and turfgrass quality. Johnson (1992) evaluated the persistence of trinexapac-ethyl efficacy in bermudagrass. Many studies with new compounds also include a commercial PGR as a tool for comparison (Hoffman and Ilnicki 1989, Johnson 1989, Sawyer and Jagschitz 1989).

Plant growth regulators have been tested on both cool and warm season turfgrasses. Most of these individual studies concentrate on a limited number of species and/or PGRs. Conversely, few studies directly compare the effects of a given PGR across multiple species. Such studies could lead to more flexible uses for PGRs and be useful in instances where multiple species are affected by a single application.

The objectives of this study were to (a) evaluate the ability of V-10029 to inhibit growth and/or suppress seedhead formation, as compared to trinexapac-ethyl, (b) recommend a chemical rate of V-10029 that, when applied, causes growth inhibition without negatively impacting turfgrass color and quality, and (c) compare five cool-season turfgrass species, with respect to patterns of growth inhibition over time, as impacted by V-10029 at three rates and trinexapac-ethyl.

MATERIALS AND METHODS

Studies were initiated in April, 1996 to evaluate the growth inhibiting and seedhead formation suppressing abilities of the experimental V-10029 turfgrass growth regulator, as compared to trinexapac-ethyl. Plant material was 'Penncross' creeping bentgrass, 'Viva/Columbia' Kentucky bluegrass, 'Brightstar/Manhattan/Dimension' perennial ryegrass, 'Triathlon' tall fescue, and 'Hector' creeping red fescue. All species were imported as sod plugs 10 cm in diameter from the Hancock Turfgrass Research Center in East Lansing, MI to the greenhouse, where they were placed into 946 ml pots containing professional potting media[1] and allowed to acclimate over a two week period before treatments were applied. The greenhouse was at 25 C +/- 2 C with supplemental lighting from high-pressure sodium lights providing 1200 $\mu E/m^2/s$ of light during 18 hours of daylight. All pots were irrigated as needed and received nitrogen at 5 kg/ha weekly throughout establishment and the duration of the study.

Treatments were applied using a continuous link-belt sprayer at 170 kPa and 230 l/ha spray pressure and carrier volume, respectively, on May 8 and May 9, 1996. V-10029[2] as the 80W formulation was applied to each species at three rates: 0.015 kg/ha, 0.029 kg/ha, and 0.059 kg/ha. Trinexapac-ethyl[3] was applied as the 1E formulation at a

[1]Baccto® is a product of Michigan Peat Company, Houston, TX

[2]V-10029 is a product of Valent USA Corp., Walnut Creek, CA

[3]Trinexapac-ethyl, sold as Primo®, Ciba-Geigy Corporation, Greensboro, NC

label rate of 0.382 kg/ha for perennial ryegrass and 0.287 kg/ha for the other four species. A 0.25% v/v level of X-77®[4] nonionic surfactant was included in all treatments but the untreated controls. Each treatment had eight replications: four were used to evaluate seedhead formation suppression and four were used to evaluate growth inhibition.

Replications evaluated for growth inhibition were maintained at a 4 cm (2 cm for creeping bentgrass) cutting height before chemical applications. Evaluation of growth suppression was a function of clipping fresh weight, with clippings harvested weekly for seven weeks after treatment. Replications for seedhead formation suppression were unmowed throughout the course of the study and were evaluated through counts of numbers of seedheads per pot at 3 and 6 weeks after treatment. Subjective assessment of turf quality was conducted throughout the course of the study.

The study was a completely randomized design and was repeated. Data reflect combined means from two experiments. All data were analyzed using analysis of variance and/or simple linear regression with significance set at the 5% level.

[4]X-77®, Valent USA Corp., Walnut Creek, CA

RESULTS AND DISCUSSION

Seedhead Formation Suppression

Seedhead initiation was insignificant in Kentucky bluegrass, creeping red fescue, and creeping bentgrass. Tall fescue pots had a significant number of seedheads, all of which were annual bluegrass. Only perennial ryegrass produced enough of its own seedheads to be measurable. Long day light conditions allowed for seedhead formation in perennial ryegrass. Compared to the untreated control, V-10029 at all three rates caused significant suppression of annual bluegrass seedhead formation in tall fescue pots and of perennial ryegrass seedhead formation. Trinexapac-ethyl was not as effective in seedhead formation suppression as V-10029 (Table 1).

Growth Inhibition

V-10029 and trinexapac-ethyl were effective in inhibiting growth in all of the turfgrass species (Tables 2 to 6). The pattern of growth inhibition, as evaluated across PGR treatments, differed from species to species, both in terms of magnitude and persistence of inhibition. Growth of perennial ryegrass, Kentucky bluegrass, and tall fescue was similarly inhibited by all PGR treatments.

V-10029 inhibited growth of perennial ryegrass, Kentucky bluegrass, and tall fescue in a rate dependent manner (Tables 2 to 4). The pattern of growth inhibition for trinexapac-ethyl in these species was most analogous to V-10029 at the 0.029 kg/ha rate. The growth inhibiting effects of trinexapac-ethyl and V-10029, at all three rates, were less pronounced in creeping bentgrass than in the other species, perhaps due to the tendency for creeping bentgrass to grow laterally when mature (Table 5). Growth of creeping red fescue was inhibited by V-10029 but injury to the turf was largely responsible for this effect and caused huge variation among treatment replications (Table 6). Trinexapac-ethyl did not injure creeping red fescue but caused little, if any, growth inhibition.

The greatest growth inhibition in all treatments generally occurred around 2 or 3 weeks after treatment (WAT). The effects of trinexapac-ethyl faded by 4 WAT; however, V-10029, at the 0.029 kg/ha and 0.059 kg/ha rates, was efficacious for a longer period of time. V-10029 at the 0.015 kg/ha rate was the least persistent treatment across species with effects lasting only 2 to 3 weeks. V-10029 at the 0.059 kg/ha rate still caused significant growth inhibition in some species when the study concluded 7 WAT but much of this was attributable to unacceptable injury it caused in the turf. Seven WAT, trinexapac-ethyl, V-10029 at 0.015 kg/ha, and V-10029 at 0.029 kg/ha treatments had no longer reduced clipping yield, compared to the untreated control. The predictability of growth inhibition of Kentucky bluegrass by V-10029, as a function of increasing rate, diminished as the study progressed (Figure 1).

V-10029 caused significant discoloration in all the turfgrass species at all three rates of application. The specific extent of discoloration was not rated but was characterized by a yellowing of the turf that appeared within a week of application and persisted until 2 to 3 weeks after application. The extent of discoloration increased as the application rate of V-10029 increased. Trinexapac-ethyl treatments did not cause discoloration in any species and the turfgrasses actually assumed a darker green color as soon as 2 weeks after application.

Visible injury to the turfgrass species occurred with V-10029 at both the 0.029 kg/ha and 0.059 kg/ha rates. V-10029 at 0.029 kg/ha caused injury but the turfgrass was able to recover by 4 to 5 WAT. The turfgrass injured by V-10029 at 0.059 kg/ha did not fully recover by 7 WAT in at least 50% of the treatments. Among the five species, creeping bentgrass showed the greatest recovery from injury caused by V-10029 at 0.059 kg/ha. Injury observed was leaf tip burn and reduced turf density per pot. The extent of injury observed seemed to be proportional to annual bluegrass proliferation within the pot.

Observations made during the study suggested that annual bluegrass, as a weed species, appeared most abundantly in tall fescue and creeping red fescue pots. The creeping red fescue exhibited the least growth among the five species. Annual bluegrass became prominent in some pots of creeping red fescue and certainly impacted the data. Annual bluegrass appeared less frequently in pots treated with V-10029 than in control pots or those treated with trinexapac-ethyl. Annual bluegrass was observed in some of the tall fescue pots but wasn't abundant enough to have any impact on collected data.

V-10029 at 0.029 kg/ha and 0.059 kg/ha caused significant growth inhibition but, in many cases, also caused unacceptable discoloration and/or injury to the turf. Therefore, these rates were determined to be too high for acceptable turfgrass growth regulation in the greenhouse. V-10029 at 0.015 kg/ha was the least effective growth regulator treatment, both in terms of extent of growth inhibition and persistence. V-10029, at this rate, however, caused little or no injury to the turf and discoloration was only slight. V-10029, at an intermediate rate between 0.015 kg/ha and 0.029 kg/ha, would have the greatest potential to combine good growth inhibition with maintenance of acceptable turfgrass quality. A suitable range of application rates that is this narrow would reduce the practicality of V-10029 as a turfgrass growth regulator used for intensively managed turfgrass systems.

The extent of seedhead formation suppression caused by V-10029, coupled with its potential to injure turfgrass at higher rates, were useful in supporting the classification of V-10029 as a PGR. Class A and Class B PGRs are not injurious and are not effective in suppressing seedhead formation (Watschke and DiPaola 1995). Conversely, Class C and Class D PGRs, such as mefluidide and glyphosate (N-(phosphonomethyl)glycine), can be injurious and are very effective in seedhead formation suppression. The known activity of V-10029 as an ALS inhibitor confirms its place as a Class D PGR.

An alternate method of evaluating PGR efficacy was employed by directly comparing the growth suppression patterns for all five species, as influenced by a single PGR treatment (Figures 2 to 5). Perennial ryegrass, Kentucky bluegrass, and tall fescue clipping production, on a percent of control basis, responded similarly to V-10029 at each of the three rates and in response to trinexapac-ethyl at the label rate. Creeping bentgrass was less sensitive to V-10029 than the perennial ryegrass, Kentucky bluegrass, or tall fescue. Creeping red fescue and creeping bentgrass responded similarly to trinexapac-ethyl at the label rate. The injury caused by V-10029, at all rates, to creeping red fescue, however, discounts the merit of including this species in such an evaluation. Ranking the species responses by treatment, would therefore be as follows:

V-10029 (all three rates): Kentucky bluegrass = perennial ryegrass = tall fescue > creeping bentgrass

Trinexapac-ethyl (label rate): Kentucky bluegrass = perennial ryegrass = tall fescue > creeping red fescue = creeping bentgrass

These results may be useful not only in determination of a proper PGR application rate but also in predicting response patterns of different turfgrasses to a given PGR application, especially in instances where multiple species may coexist in a fixed management system (Johnson and Murphy 1996).

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Table 1: Seedhead formation suppression in tall fescue and perennial ryegrass pots, as a function of turfgrass growth regulator treatment.

Treatment	Tall fescue and annual bluegrass 3 WAT*	Perennial ryegrass 3 WAT	Tall fescue and annual bluegrass 6 WAT	Perennial ryegrass 6 WAT
	number of seedheads per pot			
Control	6.0	10.9	12.4	25.0
V-10029 (0.015 kg/ha)	0.5	6.0	1.1	12.9
V-10029 (0.029 kg/ha)	0.4	4.4	1.0	6.6
V-10029 (0.059 kg/ha)	0	3.0	0	5.0
Trinexapac-ethyl (0.382 kg/ha)	1.9	8.5	6.9	15.8
$LSD_{0.05}$	2.8		6.5	

* WAT = weeks after treatment

Table 2: Growth inhibiting effects of V-10029 and trinexapac-ethyl on perennial ryegrass.

Treatment	Time after application (weeks)						
	1	2	3	4	5	6	7
	Clipping production (% of control)						
Untreated Control	100	100	100	100	100	100	100
V-10029 (0.015 kg/ha)	57	59	73	79	85	109	111
V-10029 (0.029 kg/ha)	47	46	62	73	74	96	99
V-10029 (0.059 kg/ha)	35	20	22	32	39	59	63
Trinexapac-ethyl (0.382 kg/ha)	58	42	60	85	92	114	128
$LSD_{0.05}$	9	13	17	20	16	34	29

Table 3: Growth inhibiting effects of V-10029 and trinexapac-ethyl on Kentucky bluegrass.

Treatment	Time after application (weeks)						
	1	2	3	4	5	6	7
	Clipping production (% of control)						
Untreated Control	100	100	100	100	100	100	100
V-10029 (0.015 kg/ha)	68	60	98	97	88	103	93
V-10029 (0.029 kg/ha)	50	32	57	67	59	81	73
V-10029 (0.059 kg/ha)	39	23	31	46	58	65	70
Trinexapac-ethyl (0.287 kg/ha)	74	46	61	82	86	101	108
$LSD_{0.05}$	18	16	23	27	23	31	33

Table 4: Growth inhibiting effects of V-10029 and trinexapac-ethyl on tall fescue.

Treatment	Time after application (weeks)						
	1	2	3	4	5	6	7
	Clipping production (% of control)						
Untreated Control	100	100	100	100	100	100	100
V-10029 (0.015 kg/ha)	55	53	91	82	102	115	102
V-10029 (0.029 kg/ha)	44	25	57	81	86	88	88
V-10029 (0.059 kg/ha)	38	13	31	41	53	60	60
Trinexapac-ethyl (0.382 kg/ha)	69	40	57	74	95	103	107
$LSD_{0.05}$	14	8	18	17	20	149	29

Table 5: Growth inhibiting effects of V-10029 and trinexapac-ethyl on creeping bentgrass.

Treatment	Time after application (weeks)						
	1	2	3	4	5	6	7
	Clipping production (% of control)						
Untreated Control	100	100	100	100	100	100	100
V-10029 (0.015 kg/ha)	95	105	96	100	97	88	100
V-10029 (0.029 kg/ha)	80	89	102	117	106	101	100
V-10029 (0.059 kg/ha)	54	59	67	94	91	85	87
Trinexapac-ethyl (0.382 kg/ha)	64	69	100	103	112	120	120
$LSD_{0.05}$	14	14	22	29	24	20	25

Table 6: Growth inhibiting effects of V-10029 and trinexapac-ethyl on creeping red fescue.

Treatment	Time after application (weeks)						
	1	2	3	4	5	6	7
	Clipping production (% of control)						
Untreated Control	100	100	100	100	100	100	100
V-10029 (0.015 kg/ha)	137	88	99	71	71	74	75
V-10029 (0.029 kg/ha)	126	74	69	43	37	38	49
V-10029 (0.059 kg/ha)	85	64	76	42	48	48	56
Trinexapac-ethyl (0.382 kg/ha)	109	75	98	109	113	127	117
$LSD_{0.05}$	71	36	67	44	46	56	42

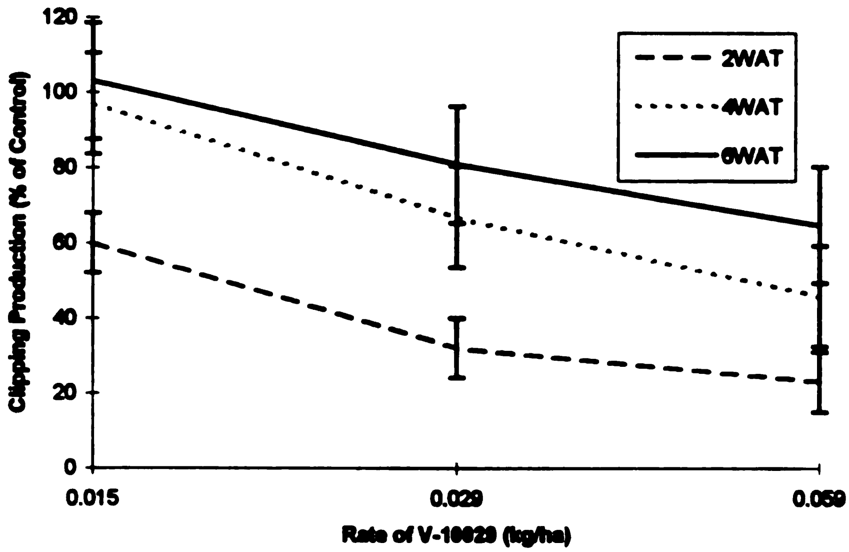

Figure 1: Decreased predictability in the patterns of growth inhibition over time in Kentucky bluegrass, as a function of increasing rate of V-10029. $LSD_{0.05}$ values for 2, 4, and 6 WAT were 16, 27, and 31, respectively while R^2 values for the depicted curves for growth inhibition at 2, 4, and 6 WAT were 0.73, 0.47, and 0.25, respectively.

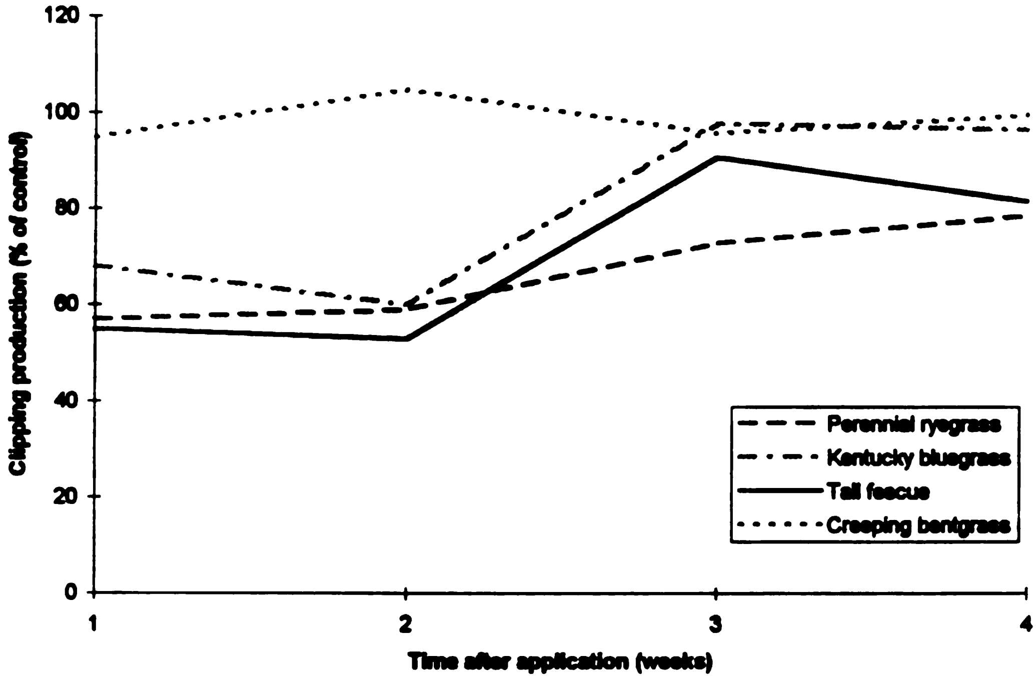

Figure 2: Growth inhibiting effects of V-10029 (0.015 kg/ha) across four turfgrass species. The $LSD_{0.05}$ values for weeks 1, 2, 3, and 4 were 17, 19, 28, and 24, respectively.

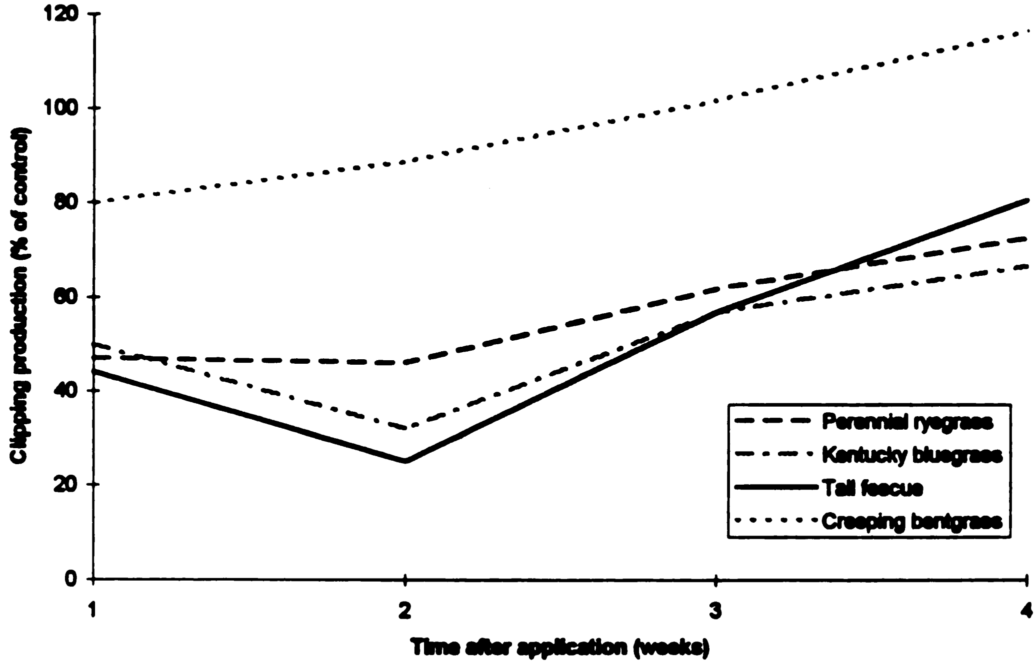

Figure 3: Growth inhibiting effects of V-10029 (0.029 kg/ha) across four turfgrass species. The $LSD_{0.05}$ values for weeks 1, 2, 3, and 4 were 13, 17, 21, and 29, respectively.

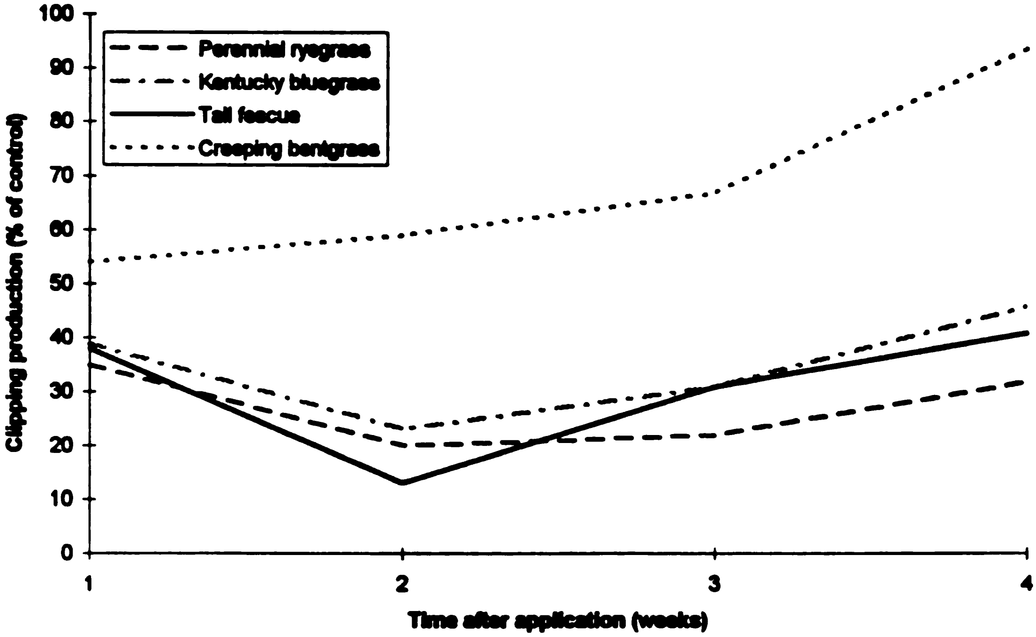

Figure 4: Growth inhibiting effects of V-10029 (0.059 kg/ha) across four turfgrass species. The $LSD_{0.05}$ values for weeks 1, 2, 3, and 4 were 13, 15, 21, and 25, respectively.

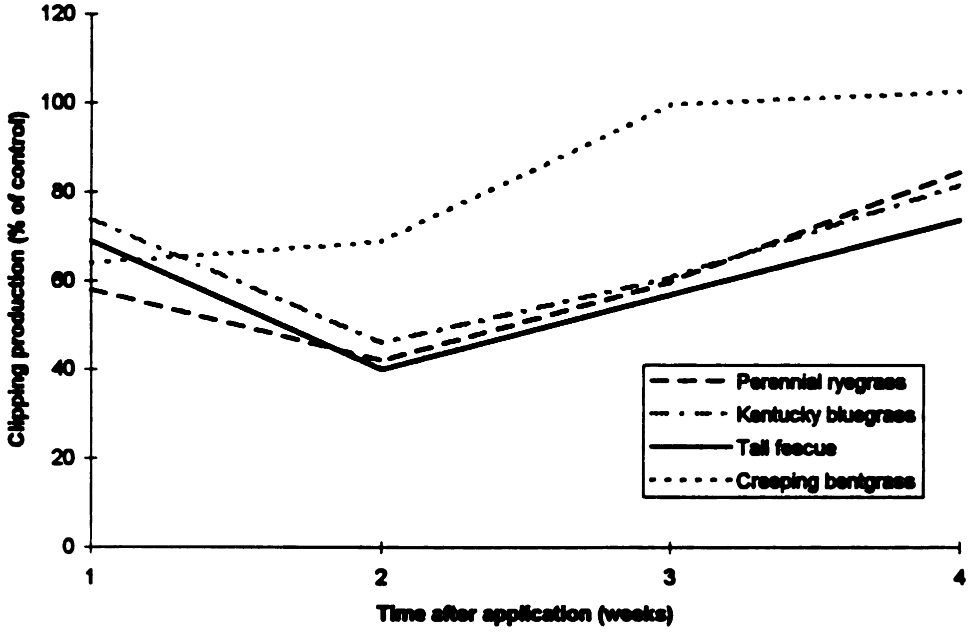

Figure 5: Growth inhibiting effects of trinexapac-ethyl (0.287 kg/ha for Kentucky bluegrass; 0.382 kg/ha for perennial ryegrass, tall fescue, and creeping bentgrass) across four turfgrass species. The $LSD_{0.05}$ values for weeks 1, 2, 3, and 4 were 34, 19, 32, and 34, respectively.

CONCLUSIONS

The spectrum of the research detailed in this thesis was diverse. As such, valuable information regarding the performance of turfgrass growth regulators was obtained, using techniques not confined to a specific discipline. Research investigating spray application parameters that may affect the performance of trinexapac-ethyl illustrated the multi-faceted benefits of adjuvants, as pertains to efficacy, rainfastness, and activity in a hard water carrier of trinexapac-ethyl.

The potential benefit of adjuvants was further explored using ^{14}C-labeled trinexapac-ethyl. The direct role of adjuvants in enhancing absorption and the ancillary role of promoting surface movement to alternate sites of absorption are believed to be very crucial in obtaining a good understanding of how trinexapac-ethyl exerts its activity and how efficacy may be enhanced. Patterns of absorption and translocation for trinexapac-ethyl seem to correspond with activity at the intercalary meristems in turfgrass plants.

V-10029 was compared with trinexapac-ethyl as a turfgrass growth regulator and was superior in terms of suppressing seedhead formation. However, levels of growth inhibition were comparable between the two PGRs and more injury was seen with V-10029 than with trinexapac-ethyl, due to the activity of V-10029 as an ALS inhibiting herbicide. Species comparisons showed tall fescue, perennial ryegrass, and Kentucky bluegrass to respond similarly to both trinexapac-ethyl and V-10029, offering some usefulness in growth inhibition predictability where multiple species coexist.