Effects of ethephon on growth and morphology of perennial grasses

by

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GENERAL INTRODUCTION AND LITERATURE REVIEW

In 1880, von Sachs first popularized the concept of chemical messengers that were synthesized by the plant and then translocated throughout it to control the growth and formation of plant organs. However, it was not until 1926 that Went isolated a growth-promoting chemical messenger from oat (*Avena sativa* L.) coleoptiles. This was the first naturally occurring plant growth regulator (PGR) to be isolated, and it later was named auxin by Kogl and Haagen-Smit in 1931 (Taiz and Zeiger, 1991).

A PGR is an organic compound that is active at low concentrations ($<1\text{mM}$) and modifies one or more specific physiological processes within a plant. A PGR can be either a naturally occurring, endogenous compound, known as a phytohormone, or a synthetic substance that is applied exogenously to bring about some physiological change within the plant (Basra, 2000).

Phytohormones

Auxin

Auxin is responsible for many facets of normal plant growth and development, most notably cell elongation, maintenance of apical dominance, and mediation of some tropic responses. After its initial discovery, control of all growth and

development was attributed to auxin. However, other endogenous phytohormones were identified, gibberellins, cytokinins, abscisic acid, and ethylene, and the true nature of hormonal control over plant growth and development was elucidated (Taiz and Zeiger, 1991).

Gibberellins

Japanese scientists discovered gibberellins in the 1930's while performing plant pathogen studies. A disease caused by the fungus *Gibberella fujikuroi* (Saw.) Wt. resulted in rice (*Oryza sativa*) plants that grew excessively tall, ultimately leading to death. Yabuta and Hayashi isolated and identified an active compound from the fungus, which they named gibberellin. Scientists at the University of California- Los Angeles later isolated naturally occurring gibberellins from several plant species. Active gibberellins are responsible for many physiological effects, such as a stimulation of stem elongation via increased cell division and elongation (Taiz and Zeiger, 1991).

Cytokinins

Attempts to find substances that initiate and sustain the proliferation of plant tissue in culture lead to the discovery of cytokinins. Skoog from the University of

Wisconsin-Madison found that autoclaved herring sperm, when in the presence of auxin, resulted in large increases in cell division. Kinetin, a by-product of the autoclaved DNA, was determined to be the factor that promoted cell division. In the 1960's, naturally occurring plant cytokinins with similar biological effects as kinetin were first isolated from maize (*Zea mays* L.). In addition to increasing cell division, cytokinins also promote adventitious bud formation, leaf expansion, and chlorophyll synthesis (Taiz and Zeiger, 1991).

Abscisic Acid

In the 1960's, abscisic acid was identified and characterized by two independent laboratories. One research group was studying compounds responsible for the abscission of fruits and the other was investigating bud dormancy. Absciscic acid stimulates the closure of stomata and acts to promote seed and bud dormancy. Interestingly, abscisic acid is responsible for abscission in few plant species, although it was originally isolated as an abscission-promoting factor (Taiz and Zeiger, 1991).

Ethylene

Deleterious effects of illuminating gas on plant growth led to the discovery of ethylene. Illuminating gas was produced by the partial combustion of coal and was used extensively as a fuel source for street lamps in the 19th century. It was observed that trees growing in the vicinity of street lamps defoliated at an accelerated rate and exhibited a stunted growth habit. Laboratory work by the Russian scientist Neljubov confirmed that ethylene was the biologically active component of illuminating gas. Conclusive proof that ethylene was an endogenous, naturally occurring PGR was detailed in 1934 by the English scientist Gane. Exposure of plants to ethylene generally results in the “triple-response,” which is a horizontal growth habit, inhibition of stem elongation and swelling of the stem. Ethylene also moderates fruit ripening, senescence, and abscission (Abeles et al., 1992).

Other PGRs

The number of widely accepted phytohormones is expected to grow as new compounds with growth-regulating properties are discovered. Other hormone-like compounds that affect plant growth but are not generally classified as phytohormones include brassinosteroids, salicylates, jasmonates, and polyamines (Salisbury and Ross, 1992).

Hormonal Control of Growth and Development

Naturally occurring PGRs respond to temporal and environmental stimuli to regulate the growth and development of plants. Few stages of plant ontogeny and developmental processes are controlled specifically by individual PGRs, but rather by multiple PGRs working together. The varied plant responses to PGRs are mediated by several factors, including plant species, the developmental stage of the tissue or organ, the relative concentration of each phytohormone, and the sensitivity of the tissue to the phytohormone at that point of development (Taiz and Zeiger, 1991).

Synthetic PGRs

Applications of synthetic PGRs are becoming more prevalent in the agricultural industry as a means to improve crop yield or quality. Chemical manipulation of plant growth and development, however, is not a new phenomenon. Since the 1930's, exogenously applied PGRs have been used to augment or suppress the levels of several phytohormones (Nickell, 1983).

Synthetic auxins were the first chemical, exogenously applied PGRs and were used to promote adventitious root formation on cuttings, control abscission, and to delay bud break. Synthetic PGRs since have been created that can be used to

manipulate all stages of crop development from germination to senescence and abscission (Nickell, 1983).

PGRs and the Turfgrass Industry

Overview

Plant growth regulators have been used by the turfgrass industry to prevent seed-head formation and to reduce vertical shoot growth and associated mowing expense. However, most PGRs have not been accepted broadly as management tools due to the discoloration and phytotoxicity they cause (Nickell, 1983).

PGR Classification System

Plant growth regulators utilized for turfgrass often are categorized as either a Type I or Type II PGR. Type I PGRs inhibit cell division or cytokinin synthesis in meristematic regions, whereas Type II PGRs inhibit gibberellin biosynthesis. Type I PGRs are often older materials that are absorbed by the leaves and often phytotoxic. However, Type I PGRs are effective seedhead formation inhibitors (Watschke et al., 1992).

Type II PGRs are generally absorbed via the crown or root, although trinexapac-ethyl can be absorbed by the leaves. Type II PGRs often are less phytotoxic than

Type I PGRs, which is beneficial when they are used on intensely cultivated turfgrass areas. Type II PGRs, however, are rarely as effective as Type I PGRs at reducing seedhead formation (Watschke et al., 1992).

Ideal Plant Growth Regulator

An ideal turfgrass PGR inhibits vertical growth, while maintaining acceptable color, density, and uniformity of treated turfgrass stands. Phytotoxicity must be minimal. Horizontal growth also should be permitted to allow for the continued regeneration of new shoots and leaves. Constant renewal of leaves, tillers, rhizomes, and stolons is essential to maintain a healthy grass stand that is resistant to wear, stress, and pest pressure (Nickell, 1983).

An ideal PGR also has predictable long-term growth inhibition effects. Plant growth regulators that promote a flush of growth after growth-regulating activity has expired can be detrimental to turf quality, and they increase maintenance costs. Similarly, PGRs should not initially stimulate the growth of turfgrasses after application (Nickell, 1983).

A PGR also should retard the growth of a number of different turfgrass species in a uniform manner. Turfgrass stands are rarely monocultures, but rather they are often comprised of two or more species in order to best adapt to diverse

microclimates, e.g., shade or full sun. It is essential, therefore, that a PGR uniformly suppress the growth of many turfgrass species in a similar way to insure that the homogeneity of a turfgrass sward is not affected adversely (Christians and Nau, 1984; Nickell, 1983).

Historical Perspective

Maleic hydrazide (1,2-dihydro-3,6-pyridazinedione) was first utilized on turfgrass in the 1950's. Maleic hydrazide is a Type I PGR, as it retards the growth of grasses by inhibiting cell division. Maleic hydrazide dramatically limits plant growth and inhibits seedhead formation, and it also results in severe phytotoxicity and a reduction of root growth, thus limiting its use to low maintenance turf (Duell, 1989).

Mefluidide (N- {2,4-dimethyl- 5- [[(trifluoromethyl) sulfonyl] amino] phenyl} acetamide) also dramatically suppresses growth and seedhead formation of grasses. Mefluidide was first used as a PGR on turfgrass in the 1970's. Mefluidide is a Type I PGR, and it reduces turfgrass growth by limiting cell division. Although mefluidide gained some acceptance by turfgrass managers, its phytotoxicity limited its use primarily to low-maintenance areas such as roadsides (Duell, 1989).

In the 1980's amidochlor and paclobutrazol were labeled for use on grasses. These materials are absorbed by the roots of the turfgrass plant and offer dramatic improvements over older PGRs. Amidochlor {N- [(acetylamino)- methyl]- 2- chloro- N- (2, 6 diethylphenyl) acetamide} is a Type I PGR that inhibits cytokinin, and to some degree, gibberellin biosynthesis. It can be applied in a much higher dose than the labeled rate with little foliar damage. Cost, however, is a limiting factor. Amidochlor is several times more expensive than the previously mentioned materials (Duell, 1989).

Paclobutrazol [2RS, 3RS)- 1- (4- chlorophenyl)- 4, 4- dimethyl- 2- (1H- 1, 2, 4- triazol- 1- yl) pentan- 3- ol] is a Type II PGR. Like amidochlor, paclobutrazol is not as phytotoxic as older turfgrass PGRs, yet it produces acceptable reductions in turf growth. Although both chemicals restrict grass growth, results are often variable. Their need to be watered into the soil to be effective is also detrimental, as they can be used only in areas with irrigation. Their inability to inhibit seedhead formation also limits their acceptance by turfgrass managers (Duell, 1989).

Trinexapac-ethyl [4- (cyclopropyl- α - hydroxy- methylene)- 3,5- dioxo- cyclohexane-carboxylic acid ethyl ester] was the first PGR to gain wide acceptance from turfgrass managers. Trinexapac-ethyl is a Type II gibberellin inhibitor like paclobutrazol. Trinexapac-ethyl was first released in 1992, and it effectively retards

the growth of most species of turfgrass with only minor phytotoxic effects.

Trinexapac-ethyl is also absorbed by the leaves, and therefore, it does not need to be watered into the soil in order to be effective. These characteristics make trinexapac-ethyl an effective PGR, which is reflected by its widespread usage in the turfgrass industry (Diesburg, 2000).

Ethephon

Ethephon [(2- chloroethyl) phosphonic acid] is an ethylene-evolving compound that was first synthesized by Russian researchers Kabachnik and Rossiiskaya in 1946. During the late 1960's, Amchem Products, Inc., released ethephon commercially as a PGR. The chemical is relatively stable below pH 3.5, but it hydrolyzes quickly above pH 5, producing ethylene, and phosphate and chloride ions. Ethephon is used currently as a PGR on several agricultural crops for many diverse purposes, such as growth retardation, flower induction and flower and fruit thinning (Abeles et al., 1992).

Ethephon as a turfgrass PGR

The effects of ethephon on the morphology and growth of some perennial grasses have been reported. Van Andel (1973) and van Andel and Verkerke (1978)

noted that ethephon caused a reduction in leaf length, while simultaneously promoting internode elongation in Kentucky bluegrass (*Poa pratensis* L.), a species that normally produces long leaves and a compact stack of nonelongated internodes. Leaf growth inhibition and internode elongation were attributed to differential effects of ethephon on gibberellin activity in the two tissues, but this explanation is not satisfactory in all cases.

The role of gibberellin in internode elongation was defined clearly by demonstrating that exogenously applied gibberellins or ethephon promote internode elongation. Moreover, when gibberellin inhibitors are applied along with ethephon, internode elongation does not occur (van Andel, 1973). These research results do not support the gibberellin-mediated decrease in leaf blade growth, however.

Leaf files measurements demonstrated that the cell size of ethephon treated-leaves was similar to untreated controls, but the number of cells per file was considerably reduced. This indicated an inhibition of cell division in treated Kentucky bluegrass leaf blades. When gibberellin was applied simultaneously with ethephon, the response was similar to plants treated only with ethephon, that is, elongated internodes and a reduction in leaf blade length caused by decreased cell number. Therefore, gibberellin was ineffective in promoting leaf blade cell division

(van Andel, 1973; Verkerke and van Andel, 1978). Perhaps ethephon also may moderate the concentration or activity of other phytohormones, such as cytokinin. As of yet, however, the exact mechanism of ethephon-induced growth characteristics on grasses remains unknown.

Comparisons between the growth characteristics of Kentucky bluegrass exposed to ethephon and ethylene have been made to determine if the growth regulating activity of ethephon is a result of its release of ethylene during hydrolysis in plant tissue. Both ethephon and ethylene were effective in promoting internode elongation and inhibiting leaf elongation, indicating that ethylene evolution is responsible for the unusual growth response of Kentucky bluegrass to ethephon and not the chloride or phosphate ions formed during ethephon catabolism (Diesburg and Christians, 1993; Poovaiah and Leopold, 1973).

Analogous to the research carried out by van Andel and Verkerke in the 1970's, field trials performed by Christians (1985) and Diesburg and Christians (1989) found comparable ethephon-induced morphological changes in Kentucky bluegrass, i.e., internode elongation and reduced leaf blade length or grass canopy height. Similar responses also were observed in grass swards containing mixtures of Kentucky bluegrass and red fescue (*Festuca rubra* spp. *Rubra* L.) (Dernoeden, 1984) and

mixtures of Kentucky bluegrass, tall fescue (*Festuca arundinacea* Scrib.), and hard fescue (*Festuca ovina* var. *duriuscula* L.) (Christians and Nau, 1984).

The growth of bermudagrass (*Cynodon dactylon* L.) also is affected by ethephon. Ethephon reduced the vertical growth of bermudagrass and promoted more rapid bud and root development (Shatters et al., 1998). Fry (1991) reported that ethephon inhibited the vertical growth of centipedegrass (*Eremochloa ophiuroides* Munro.), producing a uniform turf stand with a desirable blue-green color.

Objectives

The primary objective of this research was to determine the efficacy of ethephon as a turfgrass PGR. Specifically, the objectives were to determine how ethephon affects the leaf, sheath, and internode lengths of several perennial grasses and how it affects the clipping yield and visual quality of creeping bentgrass in direct comparison with trinexapac-ethyl.

Thesis Organization

This thesis is organized into two parts with a general introduction and a general conclusion. The general introduction establishes the topics covered in the thesis and incorporates a review of the literature relevant to this thesis. The first part details

the findings of my greenhouse research experiments. The second part contains the research results from field experiments performed at the Iowa State University Horticulture Research Station. The general conclusion reviews the overall results and conclusions drawn from both parts.

**PART I. EFFECTS OF ETHEPHON ON MORPHOLOGY OF
PERENNIAL GRASSES**

INTRODUCTION

Ethephon affects the growth and development of several plant species and is one of the most widely used plant growth regulators (PGR) in agriculture. Ethephon is used for many diverse purposes, such as growth retardation, flower induction, and flower and fruit thinning (Abeles et al., 1992).

The growth-regulating capability of ethephon has been attributed to its release of ethylene upon catabolism in plant tissue (Diesburg and Christians, 1993; Poovaiah and Leopold, 1973). Ethylene generally is designated as a growth inhibitor, as it retards the growth of stems and roots in many plant species. However, it can also promote shoot elongation in some species, particularly aquatic plants. Increases in stem elongation have been credited to ethylene-mediated changes in the tissue sensitivity or the concentration of other phytohormones, such as gibberellin, auxin, or abscisic acid (Ishizawa and Esashi, 1983; Kende et al., 1998; Raskin and Kende, 1984).

Similar responses to ethephon have been noted in some grass species. Much like in aquatic plants, ethephon promotes the formation of elongated internodes in Kentucky bluegrass (*Poa pratensis* L.) (Christians, 1985; Diesburg and Christians, 1989; Diesburg and Christians, 1993; Poovaiah and Leopold, 1973; van Andel, 1973; van Andel and Verkerke, 1978; Verkerke and van Andel, 1978). This response is

curious given that Kentucky bluegrass plants generally produce a compact stack of nonelongated internodes.

As the internodes elongate, grass shoots initially grow upright and then lay flat against the soil surface, producing a stoloniferous-like growth habit (Christians, 1985; Poovaiah and Leopold, 1973). From a turfgrass management perspective, a stoloniferous growth habit would be considered beneficial, as it would allow Kentucky bluegrass to recover more rapidly from stress and injury resulting from sports play.

In addition to increased internode elongation, ethephon also causes a significant reduction in Kentucky bluegrass leaf blade length (Christians, 1985; Diesburg and Christians, 1989; Diesburg and Christians, 1993; Poovaiah and Leopold, 1973; van Andel, 1973; van Andel and Verkerke, 1978; Verkerke and van Andel, 1978). Reduction of leaf length and simultaneous expansion of internodes have been credited primarily to changes in gibberellin concentration and/or activity, although other phytohormones may be involved (van Andel, 1973; van Andel and Verkerke, 1978). The exact mechanism for the ethephon-mediated changes in Kentucky bluegrass morphology remains unknown, however.

Comparable results have been observed in other species of turfgrasses. Wu et al. (1976) and Shatters et al. (1998) noted that ethephon stimulated shoot elongation and

reduced the canopy height of bermudagrass (*Cynodon dactylon* L.). Internode elongation and reduced leaf length also have been reported in ethephon-treated fine fescue (*Festuca rubra* L.) (Nittler and Kenny, 1976).

The use of PGRs as a management tool in the maintenance of highly groomed turfgrass areas has increased in recent years. From a practical standpoint, inhibiting the upright growth of grasses could potentially reduce the labor, fuel and equipment costs accrued as a result of normal maintenance procedures such as mowing. For that reason, it is important to identify PGRs that effectively can limit the vertical growth of many turfgrass species without affecting visual quality or injury recuperative potential.

Previous studies have indicated that ethephon may be used as a PGR to suppress the growth of some grass species, with little visual damage or discoloration (Christians, 1985; Christians and Nau, 1984; Dernoeden, 1984; Diesburg and Christians, 1989; Fry, 1991). It is, therefore, of great importance that the effects of ethephon on the growth of several commonly used turfgrasses be ascertained. The primary objective of this study was to determine ethephon-mediated changes in the shoot morphology of grass species that could potentially contribute to reductions in grass canopy height. Specifically, the effects of ethephon on the leaf blade, sheath,

and internode lengths of five cool-season and three warm-season grasses were determined.

MATERIALS AND METHODS

Grass plugs measuring 3.8 cm in diameter of 'Jackpot' seeded bermudagrass (*Cynodon dactylon* L.), 'Penneagle' creeping bentgrass (*Agrostis palustris* Huds.), 'Shademaster II' fine fescue (*Festuca rubra* L.), common manilagrass (*Zoysia matrella* [L.] Merr.), 'Glade' Kentucky bluegrass (*Poa pratensis* L.), 'Manhattan' perennial ryegrass (*Lolium perenne* L.), 'Renegade' tall fescue (*Festuca arundinacea* Scrb.) and 'Zenith' zoysiagrass (*Zoysia japonica* Steud.) were collected from established turfgrass stands, and the soil was washed from the root system. The plugs were transplanted into 12.7-cm diameter by 15.2-cm deep pots containing Nicollet (fine-loamy mixed, mesic, Aquic Hapludoll) soil and placed into the greenhouse for a minimum of three weeks before initiation of treatments.

The plants were supplied with supplemental lighting from high-pressure sodium lamps, and a 16-hour photoperiod was provided. Daytime temperatures were maintained at 21° to 23°C and nighttime temperatures were between 16° and 18°C. The soil was watered as necessary to maintain adequate growth. Before treatment application, the grasses were clipped weekly to a height of approximately 5.0 cm.

Plants were treated with 3.80 kg a.i. ha⁻¹ ethephon by using a spray-mist atomizer powered by an air pump. Untreated controls were sprayed with a volume of distilled water equivalent to that applied with the ethephon treatments. Weekly

clippings ceased after treatment with ethephon, and the grasses were allowed to grow undisturbed.

Weekly measurements of the leaf blade, sheath, and internode lengths of the second youngest fully expanded phytomer were made for a period of 12 weeks after ethephon application. Leaf blade, sheath and internode measurements were recorded as an average of three randomly selected phytomer samples from each pot. At the termination of the study, if applicable, average stolon or rhizome lengths were determined. Average stolon and rhizome length were determined by averaging the lengths of five rhizomes or stolons randomly selected from each pot. In addition, at the end of each experiment, shoot weight after six days of oven drying at 67°C was measured.

Two identical studies were performed; the first experiment was initiated 6 October 1999 and concluded 29 December 1999, the second experiment began 2 February 2000 and ended 26 April 2000. The studies were organized as randomized complete block designs with four replications per treatment. Data were combined from the 1999 and 2000 studies and analyzed by using the General Linear Model (GLM) procedure of the Statistical Analysis System software (SAS, 1996). Orthogonal contrasts were performed to determine differences between the untreated control and ethephon treatments within each species.

RESULTS

Ethephon reduced the leaf blade length of all species in this study, and the timing and duration of this response was variable (Table 1). Fine fescue and Kentucky bluegrass produced shorter leaf blade lengths during every week of the study after the ethephon application (Table 1). Ethephon-treated fine fescue and Kentucky bluegrass produced leaf blades that were 20% to 72% and 26% to 55% shorter, respectively, than the leaf blades of untreated plants. There was a delay of one week after ethephon application before the length of tall fescue leaf blades was affected (Table 1). During the remaining 11 weeks of the study ethephon-treated tall fescue exhibited leaf blades that were 33% to 42% shorter than the leaf blades of untreated tall fescue plants. The leaf blade length of perennial ryegrass was reduced by ethephon for 7 of the 12 weeks of the study. Leaf blade length was reduced by as much as 28% compared with untreated perennial ryegrass plants (Table 1). Bermudagrass leaf blade length decreased for the first five weeks immediately after ethephon application, resulting in leaf blade lengths as much as 45% shorter than the untreated control (Table 1). Ethephon also decreased the leaf blade lengths of zoysiagrass and manilagrass, by as much as 33% and 36%, respectively, compared with leaf blades from their untreated controls (Table 1). Ethephon-treated creeping bentgrass exhibited a reduction in leaf blade length in the second and third weeks of

TABLE 1. Leaf blade length of eight perennial grass species as affected by application of 3.80 kg ethephon ha⁻¹. †

Week	Species							
	Bermudagrass		Creeping bentgrass		Fine fescue		Kentucky bluegrass	
	Control	Ethephon	Control	Ethephon	Control	Ethephon	Control	Ethephon
	cm							
1	4.95 a‡	3.63 b	4.07 a	3.24 a	8.61 a	5.72 b	7.97 a	5.92 b
2	5.60 a	3.45 b	5.23 a	2.70 b	8.64 a	6.87 b	10.34 a	8.26 b
3	5.13 a	3.00 b	4.65 a	2.99 b	9.95 a	4.88 b	12.30 a	8.13 b
4	4.85 a	2.68 b	4.19 a	3.12 a	9.47 a	2.61 b	11.81 a	7.30 b
5	4.59 a	2.90 b	3.89 a	3.63 a	9.10 a	2.88 b	13.39 a	7.10 b
6	3.87 a	3.17 a	3.99 a	3.53 a	9.65 a	3.71 b	12.18 a	5.48 b
7	4.07 a	3.49 a	4.25 a	3.23 a	9.23 a	3.68 b	13.47 a	6.31 b
8	4.71 a	4.01 a	4.80 a	3.62 a	9.90 a	3.91 b	13.44 a	6.74 b
9	5.85 a	4.44 a	3.97 a	3.92 a	10.02 a	3.97 b	13.45 a	6.83 b
10	4.57 a	3.89 a	4.14 a	3.20 a	9.04 a	4.20 b	14.19 a	7.60 b
11	4.45 a	4.36 a	4.02 a	3.40 a	10.15 a	4.96 b	13.98 a	8.55 b
12	4.32 a	4.10 a	4.33 a	3.21 a	10.85 a	5.15 b	14.39 a	7.75 b

Week	Species							
	Manilagrass		Perennial ryegrass		Tall fescue		Zoysiagrass	
	Control	Ethephon	Control	Ethephon	Control	Ethephon	Control	Ethephon
	cm							
1	3.91 a	3.70 a	7.05 a	6.71 a	5.94 a	6.15 a	4.12 a	4.13 a
2	5.17 a	4.58 a	8.79 a	8.44 a	9.40 a	6.28 b	6.43 a	5.85 a
3	5.44 a	4.20 a	9.67 a	8.20 b	11.04 a	6.80 b	8.68 a	6.42 b
4	5.51 a	3.43 b	11.01 a	8.95 b	11.15 a	6.50 b	8.34 a	5.75 b
5	6.39 a	4.08 b	12.09 a	8.67 b	10.74 a	6.55 b	7.66 a	7.10 a
6	5.80 a	4.34 b	11.38 a	10.30 a	11.52 a	7.44 b	9.43 a	6.33 b
7	7.20 a	4.57 b	11.39 a	9.32 b	10.62 a	6.76 b	10.72 a	8.31 b
8	6.55 a	5.70 a	10.68 a	11.14 a	9.70 a	6.92 b	9.55 a	8.75 a
9	6.88 a	5.76 a	12.18 a	11.52 b	10.61 a	7.67 b	10.40 a	10.34 a
10	7.50 a	6.96 a	12.69 a	11.59 a	10.65 a	8.20 b	12.73 a	11.44 a
11	8.50 a	6.88 b	13.84 a	12.23 b	12.00 a	9.20 b	12.33 a	12.19 a
12	9.37 a	7.61 b	14.28 a	11.85 b	12.23 a	8.10 b	13.06 a	13.05 a

† Data were combined and averaged from the 1999 and 2000 studies

‡ Leaf blade lengths within the same species and week marked with the same letter are not significantly different at $P \leq 0.05$.

the study (Table 1). Leaf blade lengths decreased by 48% and 36%, respectively, compared with untreated creeping bentgrass plants during these weeks (Table 1).

In the two weeks following ethephon application, sheath length initially was increased in Kentucky bluegrass by 14% and 25%, respectively. However, sheath length was reduced by ethephon-treatment by as much as 28% during the next ten weeks (Table 2). The sheath lengths of bermudagrass, creeping bentgrass, fine fescue, and zoysiagrass were at times also reduced following the application of ethephon, but their response was variable. Zoysiagrass treated with ethephon produced sheaths as much as 25% shorter than the untreated zoysiagrass control (Table 2). Ethephon-treated bermudagrass produced sheaths that were 31% shorter compared with the untreated control during the third week of the study (Table 2). The second week after ethephon application, treated creeping bentgrass produced sheaths that were 23% shorter than untreated controls (Table 2). During the first and eighth weeks of the study, ethephon-treated fine fescue produced sheaths that were 8% and 24% shorter, respectively, than untreated controls (Table 2). Conversely, ethephon increased the sheath length of perennial ryegrass and tall fescue by as much as 39% and 57%, respectively, compared to the untreated perennial ryegrass and tall fescue controls (Table 2). The application of ethephon to manilagrass did not affect sheath length (Table 2).

TABLE 2. Sheath length of eight perennial grass species as affected by application of 3.80 kg ethephon ha⁻¹. †

Week	Species							
	Bermudagrass		Creeping bentgrass		Fine fescue		Kentucky bluegrass	
	Control	Ethephon	Control	Ethephon	Control	Ethephon	Control	Ethephon
	cm							
1	1.81 a†	1.29 a	1.45 a	1.43 a	1.78 a	1.64 b	2.58 a	2.93 b
2	1.50 a	1.26 a	1.55 a	1.20 b	1.77 a	1.63 a	2.40 a	3.00 b
3	1.77 a	1.23 b	1.41 a	1.39 a	1.63 a	1.35 a	3.17 a	3.30 a
4	1.42 a	1.18 a	1.41 a	1.55 a	1.63 a	1.59 a	3.28 a	2.61 b
5	1.43 a	1.22 a	1.54 a	1.68 a	1.84 a	1.47 a	3.50 a	2.79 b
6	1.18 a	1.11 a	1.67 a	1.44 a	1.89 a	1.53 a	3.68 a	2.66 b
7	1.15 a	1.35 a	1.50 a	1.55 a	1.75 a	1.45 a	3.48 a	2.82 b
8	1.46 a	1.30 a	1.53 a	1.51 a	1.88 a	1.43 b	3.34 a	2.46 b
9	1.37 a	1.29 a	1.58 a	1.55 a	1.82 a	1.55 a	3.34 a	2.48 b
10	1.24 a	1.29 a	1.52 a	1.46 a	1.70 a	1.48 a	2.95 a	2.82 a
11	1.39 a	1.42 a	1.48 a	1.44 a	1.87 a	1.67 a	3.53 a	3.22 a
12	1.28 a	1.42 a	1.56 a	1.56 a	1.81 a	1.62 a	3.17 a	2.95 a

Week	Species							
	Manilagrass		Perennial ryegrass		Tall fescue		Zoysiagrass	
	Control	Ethephon	Control	Ethephon	Control	Ethephon	Control	Ethephon
	cm							
1	1.39 a	1.54 a	2.02 a	2.09 b	1.70 a	2.11 b	1.94 a	1.60 b
2	1.43 a	1.41 a	2.12 a	2.19 a	1.83 a	2.11 a	2.07 a	1.72 a
3	1.48 a	1.32 a	2.18 a	2.08 a	1.89 a	2.19 a	2.13 a	1.72 b
4	1.60 a	1.42 a	2.13 a	2.41 a	1.98 a	2.37 b	2.19 a	1.79 b
5	1.47 a	1.33 a	2.02 a	2.30 a	2.28 a	2.68 a	2.12 a	1.60 b
6	1.43 a	1.50 a	1.96 a	2.73 b	2.10 a	2.19 a	1.96 a	1.71 a
7	1.61 a	1.57 a	2.27 a	2.75 b	2.01 a	2.60 b	1.91 a	2.08 a
8	1.69 a	1.51 a	2.22 a	2.53 a	2.23 a	2.59 a	2.40 a	2.06 a
9	1.73 a	1.55 a	2.28 a	2.87 a	2.14 a	3.36 b	2.21 a	2.38 a
10	1.60 a	1.55 a	2.44 a	2.98 b	2.40 a	2.63 a	2.13 a	2.23 a
11	2.01 a	1.85 a	3.23 a	3.34 a	2.40 a	2.50 a	2.36 a	2.50 a
12	1.82 a	1.69 a	3.43 a	3.04 b	2.35 a	2.44 a	2.20 a	2.22 a

† Data were combined and averaged from the 1999 and 2000 studies

‡ Sheath lengths within the same species and week marked with the same letter are not significantly different at $P \leq 0.05$

Ethephon caused the internodes of fine fescue, Kentucky bluegrass, tall fescue, and perennial ryegrass to elongate during some weeks (Table 3). Internode elongation was observed in ethephon-treated fine fescue the week immediately after application. A similar response was noted in Kentucky bluegrass, although there was a three to four week time period between ethephon treatment and the formation of expanded internodes (Table 3). Treated perennial ryegrass and tall fescue at times also produced elongated internodes (Table 3). Internode elongation was not observed in any of the fine fescue, Kentucky bluegrass, perennial ryegrass or tall fescue untreated control replicates during any point in the study. During the fourth and fifth weeks after treatment with ethephon, the internode length of creeping bentgrass increased by 50% and 28%, respectively, compared with untreated controls. Ethephon caused a reduction in internode lengths of 19, 30, 33 and 15% in bermudagrass during the second, third, eighth, and tenth weeks after treatment, respectively (Table 3). Ethephon affected the internode length of manilagrass and zoysiagrass in an inconsistent manner. Ethephon-treated zoysiagrass had 15, 14 and 27% shorter internodes during the third, fifth, and eighth weeks after treatment, respectively, compared with untreated zoysiagrass controls. However, during the sixth and ninth weeks after ethephon treatment, internodes were increased by 24 and 14% compared with control plants (Table 3). Likewise, treatment of manilagrass

TABLE 3. Internode length of eight perennial grass species as affected by application of 3.80 kg ethephon ha⁻¹ ethephon. †

Week	Species							
	Bermudagrass		Creeping bentgrass		Fine fescue		Kentucky bluegrass	
	Control	Ethephon	Control	Ethephon	Control	Ethephon	Control	Ethephon
cm								
1	2.78 a‡	2.53 a	1.24 a	1.21 a	0.00 a	0.85 b	0.00 a	0.00 a
2	2.80 a	2.28 b	1.34 a	1.26 a	0.00 a	1.27 b	0.00 a	0.00 a
3	3.23 a	2.27 b	1.54 a	1.55 a	0.00 a	1.19 b	0.00 a	0.27 a
4	2.95 a	2.84 a	1.39 a	2.09 b	0.00 a	1.11 b	0.00 a	0.56 b
5	2.97 a	2.99 a	1.55 a	1.98 b	0.00 a	0.69 b	0.00 a	0.67 b
6	2.70 a	2.75 a	1.39 a	1.77 a	0.00 a	0.94 b	0.00 a	0.62 b
7	3.15 a	2.85 a	1.81 a	1.66 a	0.00 a	0.68 b	0.00 a	0.53 b
8	3.06 a	2.04 b	1.73 a	1.67 a	0.00 a	0.85 b	0.00 a	0.57 b
9	2.80 a	2.66 a	1.65 a	1.65 a	0.00 a	0.79 b	0.00 a	0.60 b
10	3.11 a	2.63 b	1.87 a	1.68 a	0.00 a	0.77 b	0.00 a	0.58 b
11	2.94 a	2.98 a	1.64 a	1.79 a	0.00 a	0.81 b	0.00 a	0.64 b
12	3.38 a	2.94 a	1.82 a	1.74 a	0.00 a	0.77 b	0.00 a	0.55 b

Week	Species							
	Manilagrass		Perennial ryegrass		Tall fescue		Zoysiagrass	
	Control	Ethephon	Control	Ethephon	Control	Ethephon	Control	Ethephon
cm								
1	1.15 a	1.51 b	0.00 a	0.00 a	0.00 a	0.00 a	2.60 a	2.62 a
2	1.34 a	1.44 a	0.00 a	0.00 a	0.00 a	0.00 a	2.28 a	2.50 a
3	1.55 a	1.48 a	0.00 a	0.00 a	0.00 a	0.00 a	2.57 a	2.18 b
4	1.59 a	1.45 a	0.00 a	0.00 a	0.00 a	0.00 a	2.50 a	2.42 a
5	1.62 a	1.27 b	0.00 a	0.07 a	0.00 a	0.47 b	2.72 a	2.34 b
6	1.66 a	1.47 a	0.00 a	0.10 b	0.00 a	0.44 b	2.55 a	3.12 b
7	1.61 a	1.33 a	0.00 a	0.23 b	0.00 a	0.39 b	2.98 a	2.95 a
8	1.49 a	1.54 a	0.00 a	0.29 a	0.00 a	0.33 a	3.10 a	2.26 b
9	1.74 a	1.49 a	0.00 a	0.15 a	0.00 a	0.42 b	2.87 a	3.27 b
10	1.47 a	1.62 a	0.00 a	0.20 a	0.00 a	0.33 a	2.93 a	3.17 a
11	1.70 a	1.46 a	0.00 a	0.28 a	0.00 a	0.55 b	2.70 a	2.93 a
12	1.68 a	1.61 a	0.00 a	0.18 a	0.00 a	0.40 a	3.10 a	3.14 a

† Data were combined and averaged from the 1999 and 2000 studies

‡ Internode lengths within the same species and week marked with the same letter are not significantly different at $P \leq 0.05$

with ethephon initially caused a 31% increase of internode length in the first week of the study and a 22% reduction of internode length in the fifth week of the study compared with untreated controls (Table 3).

No differences in the average rhizome length of fine fescue, Kentucky bluegrass, and tall fescue, or the average stolon length of bermudagrass, creeping bentgrass, manilagrass, and zoysiagrass were observed at the conclusion of the study (data not shown). In addition, no treatment effects were observed between the dry weights of ethephon-treated or untreated control plants in any of the grass species (data not shown).

DISCUSSION

The most consistent response to ethephon among the eight observed grass species was a reduction in leaf blade length. Therefore, ethephon has the potential to be utilized as a turfgrass PGR on all of the observed grass species because leaf blade length is the greatest determinant of canopy height (Diesburg and Christians, 1989). However, this reduction was variable in timing and duration among the grass species. This may limit the use of ethephon on grass stands containing several species, because the differential growth-regulating capability of ethephon could potentially disrupt the uniformity, and thus the perceived quality, of a treated sward containing a mixture of grasses.

Sheath length also can be an indicator of canopy height, although to a lesser extent than leaf blade length (Diesburg and Christians, 1989). While it is unlikely that observed increases or decreases in sheath length would cause appreciable changes in vertical growth, overall canopy height measurements were not made during this experiment and this possibility cannot be ruled out.

The most interesting turfgrass response to ethephon was the formation of elongated internodes in fine fescue, Kentucky bluegrass and, at times, perennial ryegrass and tall fescue. This change in morphology is unusual for several reasons. Ethephon historically has been generalized as a growth inhibitor in plants such as

wheat (*Triticum aestivum* L.) and oat (*Avena sativa* L.) because it effectively inhibits both leaf blade length and stem elongation (Wiersma, 1986). Nonetheless, ethephon consistently brought about an increase of internode length in these four turfgrass species that generally contain compact stacks of nonelongated internodes.

Christians (1985) and Poovaiah and Leopold (1973) have stated that as the internodes of ethephon-treated Kentucky bluegrass first elongate, upright growth is increased and then decreased as the stolon-like appendages assume a more horizontal orientation. A similar reorientation of stem tissue was observed during this study in ethephon-treated fine fescue, Kentucky bluegrass, perennial ryegrass, and tall fescue. Stimulation of internode expansion and the formation of stolon-like appendages may be beneficial, as it might allow these species to recover more rapidly from injury as a result of sports play. It also may promote a more dense, uniform, and visually appealing turf.

When treated with ethephon, the internode length of bermudagrass was reduced. This response also might serve to increase the density of treated bermudagrass, as the average stolon length of bermudagrass was unaffected by ethephon. Perhaps, the number of nodes per stolon was increased, which would allow for greater shoot density in treated bermudagrass.

At the conclusion of the 12-week study, the dry weights of all eight grass species were unchanged by ethephon. Conceivably, after the growth-regulating ability of ethephon had expired, treated plants produced a flush of growth that allowed shoot tissue production to match the untreated controls by the termination of the study. Another possible explanation is that ethephon increased the number of leaves per shoot compared with the untreated control, which would also account for the similar dry weights.

Of the species tested, ethephon has the greatest growth-regulating effect on fine fescue, Kentucky bluegrass, perennial ryegrass and tall fescue. Additional research should be performed to determine if the stolon-like appendages caused by ethephon are durable and able to withstand the rigors of normal sports play, such as foot and vehicle traffic. Further research also is warranted to identify the exact mechanism of ethephon-mediated changes in grass morphology. Such research would be beneficial in the development of new PGRs and to better understand the influence of phytohormones on the growth and development of perennial grasses.

**PART II. ETHEPHON AND TRINEXAPAC-ETHYL AFFECT THE GROWTH
AND VISUAL QUALITY OF CREEPING BENTGRASS**

INTRODUCTION

Plant growth regulators (PGRs) historically have been used by the turfgrass industry to retard the upright growth of grasses, with the main objective of reducing mowing, and therefore, maintenance costs. Many PGRs, especially older materials, produce unpredictable results and can cause significant injury to the plant. As a result, their use is limited to less-intensively managed areas, such as roadsides or ditches (Nickell, 1983). Within the last 10 to 15 years, however, newer materials have been developed that can satisfactorily reduce growth, with minimal impact on plant quality.

Trinexapac-ethyl was first released commercially in 1992 and is now one of the most widely used PGRs in the turfgrass industry (Diesburg, 1999). Trinexapac-ethyl is a Type II PGR that regulates growth by inhibiting gibberellin biosynthesis. Numerous studies have indicated that trinexapac-ethyl effectively controls the upright growth of several grass species and also may improve sward density and uniformity (Bush et al., 1998; Johnson, 1994, 1997; King et al., 1997; Lowe and Whitewell, 1999; Qian and Engelke, 1999).

The most recent PGR to be labeled for use on turfgrasses is ethephon. Ethephon is an ethylene-evolving compound that has dramatic effects on the growth and morphology of some grass species. Grass plants treated with ethephon generally

exhibit reduced leaf blade length, and in some instances, expanded internodes (Christians, 1985; Dernoeden, 1984; Diesburg and Christians, 1989; Diesburg and Christians, 1993; Fry, 1991; Nittler and Kenny, 1976; Poovaiah and Leopold, 1973; Shatters et al., 1998; van Andel, 1973; van Andel and Verkerke, 1978; Wu et al., 1976). Moreover, studies also have indicated that ethephon may promote a more horizontal growth habit (Christians, 1985; Poovaiah and Leopold, 1973). The promotion of a more horizontal growth habit would be beneficial because it would increase the recuperative ability of a grass sward and create a more dense and appealing turf stand.

The primary purpose of this study was to determine the efficacy of ethephon as a PGR for use on creeping bentgrass. To be considered an ideal PGR, several conditions must be met. The material must suppress the vertical growth of a grass plant without causing severe discoloration or phytotoxicity. The PGR should consistently control plant growth for a period of at least three to four weeks. The PGR should not cause unusual growth effects, such as an initial burst of growth after application of the chemical or a flush of growth after the regulating activity of the chemical has elapsed. An ideal PGR also will allow for continued horizontal growth, as constant renewal of leaf blades, tillers, rhizomes, and stolons is essential to maintain sward visual quality and stress tolerance (Nickell, 1983).

In this study, ethephon was compared to trinexapac-ethyl to evaluate its effects on color, density, uniformity, and growth suppression of creeping bentgrass (*Agrostis palustris* Huds. cv. SR 1020). The respective manufacturers of ethephon (Aventis Environmental Science USA LP, Montvale, NJ) and trinexapac-ethyl (Novartis Crop Protection, Inc., Greensboro, NC) recommend that their products be applied every four weeks to actively growing creeping bentgrass to achieve the greatest degree of growth regulating efficacy. Often, it is not feasible to apply chemicals on such a regular basis due to unfavorable weather conditions. Therefore, ethephon and trinexapac-ethyl were applied at label rates every six-weeks to determine their ability to regulate growth beyond their recommended application interval.

In addition, turfgrass professionals often apply trinexapac-ethyl more frequently and at lower rates than recommended by the manufacturer. This PGR application program arose for several reasons, most notably as a means to reduce phytotoxicity or discoloration (Diesburg, 2000). Research performed by Wiecko and Couillard (1997) and Han et al. (1998) indicated that such an application schedule can lessen the severity of phytotoxicity, without affecting the growth-regulating capability of trinexapac-ethyl. Darker color and improved quality also may result from such an application program (Diesburg, 2000). For these reasons, this study also examined

the efficacy of ethephon and trinexapac-ethyl when applied at lower rates and more frequent application timing.

MATERIALS AND METHODS

An established stand of 'SR 1020' creeping bentgrass at the Iowa State University Horticulture Research Station was used for this study. The grass was maintained at a height of 1.28 cm and watered as necessary to facilitate normal growth. The grass stand was grown on a modified Nicollet (fine-loamy mixed, mesic, Aquic Hapludoll) soil containing equal parts of soil, sand and peat.

The trial was organized as a completely randomized block design with three replications per treatment, and five treatments were utilized. Ethephon was applied at two- and at six-week intervals, trinexapac-ethyl applied at two- and at six-week intervals and an untreated control. Ethephon two-week interval treatments were made at a rate of 1.90 kg a.i. ha⁻¹ and six-week interval treatments were applied at a rate of 3.80 kg a.i. ha⁻¹. Trinexapac-ethyl two-week treatments were applied at a rate of 0.05 kg a.i. ha⁻¹, and the six-week treatments were made at 0.10 kg a.i. ha⁻¹.

Treatment applications began 10 May 2000, with subsequent applications occurring at either two or six-week intervals over the duration of the 18-week study. A total of nine two-week PGR treatments and three six-week PGR treatments were made for both ethephon and trinexapac-ethyl. Plant growth regulator applications were made to square 2.32 m² plots by using a CO₂-powered backpack sprayer.

Turf evaluations of color, density, uniformity, and clipping yield were performed on a weekly basis for the duration of the 18-week study following initial chemical treatment. Visual quality ratings of color, density and uniformity were determined by using a 9 to 1 scale, with 9 being best quality, 6 being lowest acceptable quality, and 1 being worst quality. The plots were mowed three times a week to 1.28 cm. Once a week, during the normal mowing schedule, fresh clipping weights were measured and recorded as a percentage of the untreated control.

Color, density, uniformity, and clipping yield data were analyzed using the General Linear Model (GLM) procedure of the Statistical Analysis System software (1996), and Fisher's LSD test was used to separate significant treatment means.

RESULTS

Trinexapac-ethyl applied at both two- and six-week intervals improved the color ratings of creeping bentgrass compared with the control. The trinexapac-ethyl two-week (TE2WK) treatment consistently produced the best color, resulting in color ratings that were as much as 13% greater than the control (Table 1). The trinexapac-ethyl six-week (TE6WK) treatment also increased color ratings as much as 13% over the control, although not as frequently as the TE2WK treatment (Table 1).

Ethephon applied at either two- or six-week intervals caused a small, but acceptable, reduction in color. This response was consistent for ethephon applied at both intervals throughout the 18 weeks of the study. Ethephon-treated creeping bentgrass generally acquired a uniform light green-yellow color, and both application intervals reduced the color ratings below the control by as much as 13% (Table 1).

Both ethephon treatments enhanced the density of creeping bentgrass. Changes in density associated with ethephon first appeared during the third week after the initial PGR application and continued throughout the remainder of the study. The ethephon two-week (ET2WK) treatment resulted in the most consistent improvement, increasing density by as much as 29% compared with the control (Table 2). The ethephon six-week (ET6WK) treatment produced similar

TABLE 1. Color ratings of 'SR 1020' creeping bentgrass as affected by applications of ethephon and trinexapac-ethyl at two- or six-week intervals.†

Weeks after initial treatment									
Treatment‡	1	2	3	4	5	6	7	8	9
Control	7.0	8.0	8.7	7.7	8.0	8.0	8.0	8.0	8.0
ET2WK	7.0	8.0	8.0	8.0	8.0	8.0	7.3	8.0	7.3
ET6WK	7.0	8.0	7.7	7.7	7.7	8.0	7.0	7.0	7.0
TE2WK	7.0	9.0	9.0	9.0	8.7	9.0	9.0	9.0	8.7
TE6WK	7.0	9.0	9.0	9.0	8.7	8.3	8.0	6.7	8.3
LSD _{0.05} §	ns	0.1	0.6	0.7	ns	0.5	0.5	0.5	0.9

Weeks after initial treatment									
Treatment	10	11	12	13	14	15	16	17	18
Control	8.0	8.0	8.0	8.0	8.0	8.3	8.3	8.0	8.0
ET2WK	7.7	8.0	7.0	7.0	7.0	7.0	7.0	7.3	7.0
ET6WK	7.7	7.0	7.7	7.0	7.0	7.7	8.0	8.0	7.3
TE2WK	9.0	9.0	8.7	9.0	9.0	9.0	8.7	9.0	9.0
TE6WK	9.0	9.0	8.0	8.0	8.0	8.3	8.7	9.0	8.3
LSD _{0.05}	0.7	0.1	ns	0.1	0.1	0.9	ns	0.5	0.7

† Ratings are based on a 9 to 1 scale, with 9 being best quality, 6 being lowest acceptable quality, and 1 being worst quality.

‡ Treatment abbreviations are as follows: ET2WK = ethephon applied every 2 wks at 1.90 kg a.i. ha⁻¹; ET6WK = ethephon applied every 6 wks at 3.80 kg a.i. ha⁻¹; TE2WK = trinexapac-ethyl applied every 2 wks at 0.05 kg a.i. ha⁻¹; TE6WK = trinexapac-ethyl applied every 6 wks at 0.10 kg a.i. ha⁻¹.

§ LSD_{0.05} values indicate differences between means at $\alpha = 0.05$.

results, as density also was increased by as much as 29% over the control, although this response was not as consistent as the ET2WK treatment (Table 2). Trinexapac-ethyl also improved density, but not to the same extent as the ethephon treatments. The TE2WK treatment improved density by as much as 14%, whereas the TE6WK treatment improved density by as much as 19% (Table 2).

The uniformity of creeping bentgrass also was influenced by the PGRs.

Ethephon and trinexapac-ethyl treatments produced uniform grass stands with more consistent color, density, and texture than the untreated controls. The ET2WK

TABLE 2. Density ratings of 'SR 1020' creeping bentgrass as affected by applications of ethephon and trinexapac-ethyl at two- or six-week intervals.†

Treatment‡	Weeks after initial treatment								
	1	2	3	4	5	6	7	8	9
Control	7.0	7.0	8.0	8.0	7.3	7.0	7.3	7.7	8.0
ET2WK	7.0	7.0	9.0	9.0	9.0	9.0	8.3	8.7	9.0
ET6WK	7.0	7.0	9.0	9.0	9.0	8.0	9.0	9.0	8.0
TE2WK	7.0	7.0	8.3	8.0	7.7	8.0	8.0	8.0	8.0
TE6WK	7.0	7.0	8.0	8.0	7.7	8.0	8.0	7.7	8.0
LSD _{0.05} §	ns	ns	0.5	0.1	0.7	0.1	ns	ns	0.1

Treatment	Weeks after initial treatment								
	10	11	12	13	14	15	16	17	18
Control	7.0	7.0	7.3	7.3	7.0	7.0	7.0	7.0	7.7
ET2WK	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0
ET6WK	9.0	9.0	9.0	8.0	9.0	9.0	8.3	9.0	9.0
TE2WK	8.0	8.0	8.0	7.0	8.0	7.0	8.0	8.0	8.0
TE6WK	8.0	8.0	7.7	7.0	8.0	7.3	8.3	8.0	7.7
LSD _{0.05}	0.1	0.1	0.8	0.5	0.1	0.5	0.7	0.1	0.7

† Ratings are based on a 9 to 1 scale, with 9 being best quality, 6 being lowest acceptable quality, and 1 being worst quality.

‡ Treatment abbreviations are as follows: ET2WK = ethephon applied every 2 wks at 1.90 kg a.i. ha⁻¹; ET6WK = ethephon applied every 6 wks at 3.80 kg a.i. ha⁻¹; TE2WK = trinexapac-ethyl applied every 2 wks at 0.05 kg a.i. ha⁻¹; TE6WK = trinexapac-ethyl applied every 6 wks at 0.10 kg a.i. ha⁻¹.

§ LSD_{0.05} values indicate differences between means at $\alpha = 0.05$.

treatments frequently produced the greatest uniformity ratings, improving uniformity over the control by as much as 29% (Table 3). Uniformity was increased by the ET6WK treatments by as much as 29% compared with the control (Table 3).

The trinexapac-ethyl treatments did not increase sward uniformity to the same degree as ethephon treatments and occasionally resulted in lowered uniformity ratings in comparison to the control. The TE2WK and TE6WK treatments resulted in uniformity ratings as much as 14% and 19%, respectively, greater than the

TABLE 3. Uniformity ratings of 'SR 1020' creeping bentgrass as affected by applications of ethephon and trinexapac-ethyl at two- or six-week intervals.†

Treatment‡	Weeks after initial treatment								
	1	2	3	4	5	6	7	8	9
Control	7.0	7.0	8.0	8.0	7.3	7.3	8.0	7.7	8.0
ET2WK	7.0	7.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0
ET6WK	7.0	7.0	8.7	8.7	8.7	8.0	9.0	9.0	9.0
TE2WK	7.0	7.0	8.3	8.0	7.0	7.7	7.0	7.0	9.0
TE6WK	7.0	7.0	8.0	8.3	7.3	7.7	7.7	7.0	8.0
LSD _{0.05} §	ns	ns	0.6	ns	0.7	0.9	0.5	0.5	0.1

Treatment	Weeks after initial treatment								
	10	11	12	13	14	15	16	17	18
Control	7.0	7.0	7.3	7.3	7.0	7.3	7.0	7.0	7.7
ET2WK	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0
ET6WK	8.7	9.0	9.0	8.7	9.0	9.0	8.3	9.0	9.0
TE2WK	8.0	8.0	8.0	7.0	8.0	8.0	8.0	8.0	8.0
TE6WK	8.0	8.0	7.7	7.0	7.0	8.0	8.3	8.0	7.7
LSD _{0.05}	0.5	0.1	0.8	0.6	0.1	ns	0.7	0.1	0.7

† Ratings are based on a 9 to 1 scale, with 9 being best quality, 6 being lowest acceptable quality, and 1 being worst quality.

‡ Treatment abbreviations are as follows: ET2WK = ethephon applied every 2 wks at 1.90 kg a.i. ha⁻¹; ET6WK = ethephon applied every 6 wks at 3.80 kg a.i. ha⁻¹; TE2WK = trinexapac-ethyl applied every 2 wks at 0.05 kg a.i. ha⁻¹; TE6WK = trinexapac-ethyl applied every 6 wks at 0.10 kg a.i. ha⁻¹.

§ LSD_{0.05} values indicate differences between means at $\alpha = 0.05$.

untreated control, although during the eighth week of the study both the TE2WK and TE6WK treatments reduced uniformity by 9% compared to the control (Table 3).

Growth regulator treatments also affected clipping yield, although the extent and persistence was variable and treatment-dependent. The TE6WK treatment reduced clipping yield by as much as 70% compared with the control after each PGR application, but after four weeks, there was an equally dramatic postinhibition stimulation of growth that lasted for two weeks until the next chemical application. Relative clipping yield increased by as much as 43% compared with the control after

TABLE 4. Clipping yield of 'SR 1020' creeping bentgrass as affected by applications of ethephon and trinexapac-ethyl at two- or six-week intervals.†

Treatment	Weeks after initial treatment								
	1	2	3	4	5	6	7	8	9
	Clipping yield (g fresh weight, % of control)								
Control	100	100	100	100	100	100	100	100	100
ET2WK	124	167	97	92	96	53	70	81	117
ET6WK	122	87	76	70	67	69	53	72	87
TE2WK	95	77	58	74	49	54	65	66	57
TE6WK	101	67	83	102	143	114	55	41	75
LSD _{0.05}	ns	35	21	22	ns	36	24	28	35

Treatment	Weeks after initial treatment								
	10	11	12	13	14	15	16	17	18
	Clipping yield (g fresh weight, % of control)								
Control	100	100	100	100	100	100	100	100	100
ET2WK	92	90	63	54	38	76	88	79	92
ET6WK	97	86	75	80	43	57	89	72	66
TE2WK	58	51	74	58	80	52	114	67	60
TE6WK	98	114	144	54	30	84	85	107	117
LSD _{0.05}	21	ns	36	ns	32	ns	ns	22	ns

† Fresh weight of clippings from the treatment plots relative to the untreated control.

‡ Treatment abbreviations are as follows: ET2WK = ethephon applied every 2 wks at 1.90 kg a.i. ha⁻¹; ET6WK = ethephon applied every 6 wks at 3.80 kg a.i. ha⁻¹; TE2WK = trinexapac-ethyl applied every 2 wks at 0.05 kg a.i. ha⁻¹; TE6WK = trinexapac-ethyl applied every 6 wks at 0.10 kg a.i. ha⁻¹.

§ LSD_{0.05} values indicate differences between means at $\alpha = 0.05$.

the growth-regulating activity of the TE6WK treatment had expired (Table 4). The TE2WK treatment produced the most reliable reductions in clipping yield of all the PGR treatments, reducing clipping yield as much as 51% below that of the control. The TE2WK treatment did not exhibit the postinhibition growth response associated with the TE6WK treatment (Table 4).

Both ethephon treatments resulted in an initial flush of growth following the first chemical application. The growth flush lasted one week in the ET6WK treatment,

increasing clipping yield 22% compared with the control (Table 4). The ET2WK treatment caused a flush of growth for two weeks after the initial chemical application and did not produce a satisfactory reduction in relative clipping yield until the sixth week of the study. In the two weeks following the initial chemical application, the ET2WK treatment increased clipping yield by 24% and 67% compared with the control. The largest reduction in clipping yield caused by the ET2WK treatment was observed during the fourteenth week, when clipping yield was decreased by 62% compared with the control (Table 4).

DISCUSSION

Trinexapac-ethyl and ethephon were both successful in reducing the vertical growth of creeping bentgrass, despite fluctuations in clipping yield. A dramatic growth enhancement was observed in the TE6WK treatment during the fifth and sixth weeks after each sequential chemical application. This growth enhancement was not desirable and reinforces the importance of following the manufacturer-specified four-week application interval.

The most consistent regulation of creeping bentgrass vertical growth was achieved by the TE2WK treatment. The TE2WK treatment regularly resulted in the largest clipping yield reduction compared the untreated control and was not susceptible to the postinhibition growth flush observed in the TE6WK treatment.

A flush of growth occurred after the initial application of ethephon at both treatment intervals. The growth surge lasted one week in the ET6WK treatment and two weeks in the ET2WK treatment. This initial increase in clipping yield is most likely attributable to a gibberellin-mediated increase in internode elongation, similar to that previously observed in Kentucky bluegrass (Christians, 1985; Dernoeden, 1984; Diesburg and Christians, 1989; Diesburg and Christians, 1993; Nittler and Kenny, 1976; Poovaiah and Leopold, 1973; van Andel, 1973; van Andel and Verkerke, 1978). It has been noted that as the internodes first elongate, vertical

growth is increased and then decreases as the stems assume a more horizontal orientation (Christians, 1985; Poovaiah and Leopold, 1973). The ET2WK treatment often did not produce satisfactory reductions in clipping yield, and despite large improvements in sward density and uniformity, this treatment application program cannot be recommended. The ET6WK treatment did not exhibit the post-inhibition flush of growth evident in the TE6WK treatment, and resulted in a more subtle, long-term reduction in clipping yield.

Both of the PGR studied reduced creeping bentgrass clipping yield without severe reductions in sward visual quality. In fact, PGR treatments at times improved grass visual quality. Whereas trinexapac-ethyl readily improved the color of treated turf, ethephon improved the density and uniformity of creeping bentgrass. Improvement in overall turf quality as a result of increased density and uniformity is an important benefit of ethephon. Even though ethephon did cause some slight yellowing of the turf and a flush of growth after the initial application, the increased density and uniformity and the general reduction in clipping yield improved the overall appearance of the treated grass swards.

Future research should address ways to mask or reduce the effect of ethephon on sward color, such as addition of supplemental nitrogen, iron, or magnesium. Wiecko and Couillard (1997) have demonstrated the benefits of adding iron with

trinexapac-ethyl to reduce any yellowing of the turf caused by trinexapac-ethyl, and perhaps ethephon also may benefit from supplemental iron applications.

Additionally, more research is warranted to identify ways to reduce or eliminate the initial growth stimulation caused by ethephon. It may be possible to limit the initial growth flush by applying a Type II PGR, a gibberellin biosynthesis inhibitor, in conjunction with ethephon. The growth flush is most likely the result of either increased production of and/or sensitivity of grass tissue to gibberellic acid. Addition of a Type II plant growth regulator could potentially counteract the ethephon-induced stimulation of internode cell elongation and limit the initial growth flush.

GENERAL CONCLUSIONS

Applying chemical growth regulators to modify plant growth and development is not new. However, there has been a renewed interest in the use of PGRs in the last several years. The development of new PGR materials that result in a more consistent response and are not as phytotoxic as older materials is the primary reason for this. Ethephon is the newest PGR to be labeled for use on grass species.

The results included in this thesis demonstrate the unique changes ethephon causes in the morphology, growth rate, and visual quality of several grass species. In general, ethephon reduced the leaf blade length of bermudagrass, creeping bentgrass, fine fescue, Kentucky bluegrass, manilagrass, perennial ryegrass, tall fescue, and zoysiagrass. Leaf blade reduction was most pronounced in fine fescue and Kentucky bluegrass, in which leaf blade lengths were reduced by as much as 72% and 55%, respectively, compared with controls. This response indicates that ethephon can have significant effects on the vertical growth of established stands of the aforementioned grass species, as leaf blade length is the largest determinant of sward canopy height (Diesburg and Christians, 1989).

Perhaps the most unusual morphological response among the eight turfgrass species was the elongation in internodes in fine fescue, Kentucky bluegrass, tall fescue, and perennial ryegrass and the formation of stolon-like appendages. This

response was curious given that these species generally contain a stack of nonelongated internodes. Ethephon-induced internode expansion has been described previously in Kentucky bluegrass by Christians (1985), Diesburg and Christians (1989), and van Andel (1973) and in fine fescue by Dernoeden (1984) and Christians and Nau (1984). In addition to increasing the visual density of treated plants, ethephon-induced internode elongation also may increase the recuperative potential of a grass stand and make it more resistant to wear.

Results from the field study indicated that ethephon-mediated changes in grass morphology result in reduced clipping yields of creeping bentgrass, with minimal adverse effects on sward visual quality. In comparison with the TE6WK treatment, the ET6WK treatment had more subtle, long-term effects on clipping yield. In the week following PGR application, the TE6WK treatment generally produced a decrease in clipping yield, as much as 46% compared with the untreated control; whereas there was a delay of a week after initial PGR application before ethephon caused a reduction in clipping yield. The growth-regulating effects of trinexapac-ethyl generally lasted four weeks after each subsequent PGR application. Clipping yield was increased above the control by as much as 44% the fifth and sixth weeks after each TE6WK treatment application. Ethephon produced a much longer inhibition of clipping yield, as the growth-regulating effects of ethephon never

diminished substantially between PGR treatment applications. The ET6WK treatment produced reductions in clipping yield that ranged between 3% and 57% of the control.

Grass quality is of great importance to turfgrass professionals. In the field study, trinexapac-ethyl produced the greatest color quality, whereas grass treated with ethephon consistently acquired a green-yellow color, and thus, the lowest color ratings. Density and uniformity, however, were increased by ethephon compared with the control and trinexapac-ethyl. Ethephon-treated grass stands appeared much more uniform, with consistent color, density, and texture, when compared with trinexapac-ethyl-treated grass stands and untreated controls.

These results indicate that ethephon may be an effective PGR for use on bermudagrass, creeping bentgrass, fine fescue, Kentucky bluegrass, manilagrass, perennial ryegrass, tall fescue, and zoysiagrass to reduce overall canopy height and mowing expenditures.

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