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Vertical Shoot Growth of Korean Lawngrass (*Zoysia japonica* Steud.) Influenced by Trinexapac-ethyl, Amidochlor, and Mefluidide

Kim, Kyoung-Nam* · Kim, Yong-Seon[1]

Environmental Development Division, Samsung Everland Inc., Seoul 138-160, Korea

[1]*Turfgrass & Environment Research Institute, Samsung Everland Inc., Gunpo 435-020, Korea*

*corresponding author

ABSTRACT Research was initiated to evaluate plant growth regulator effects on the vertical shoot growth of Korean lawngrass and to determine desirable growth regulator and its rate. The experiments were conducted twice at different sites in 1995. All the tested growth regulators inhibited the growth, but the inhibition period was variable among the product in Experiments I and II. During the first week after treatment, there was approximately 10 to 20% growth reduction in most of the treated plots. In the amidochlor-treated plots, growth suppression was effective for 3 to 4 weeks at low to medium rates (0.30 to 0.60 $mL \cdot m^{-2}$). A Type II growth regulator, trinexapac-ethyl exceeding the medium rate of 0.08 $mL \cdot m^{-2}$ consistently tended to suppress vertical shoot growth for 8 weeks, being above 35% reduction in both experiments. In the plots applied with mefluidide, growth suppression appeared with foliar discoloration 3 or 4 days earlier than the other growth regulators and continued to work till the 8 weeks after treatment. Suppression intensity on vertical shoot growth increased with time after treatment up to a certain period of time, depending on growth regulators. Generally, the higher the application rate, the greater the suppression intensity. Seasonal variation of activity and effectiveness of growth regulators was observed, resulting in lower suppression intensity in July than in June. It is expected to reduce mowing requirements by 30 to up to 60% for a certain period with a specific growth regulator. In low to medium maintenance of Korean lawngrass turf, a long-term suppression may be more effectively accomplished with trinexapac-ethyl rather than mefluidide and amidochlor in terms of vertical shoot growth inhibition. Therefore, turf managers will need to select proper growth regulator and determine optimum rate of application for turfgrass management, based on a defined period of mowing reduction.

Additional key words: growth suppression, mowing, plant growth regulator, plant height

Introduction

Korean lawngrass (*Zoysia japonica* Steud.) is very common in home lawns, schools, hospitals, cemetries, parks, athletic fields, and golf courses in Korea. It is the most low temperature hardy of the warm-season turfgrass species. Forbes et al. (1955) reported that it is adapted to a wide range of soil conditions and quite tolerant of drought, heat, and cold stresses. It is coarser textured, lower in shoot density, and superior in low temperature hardiness to the other two turf-type zoysia species, manilagrass [*Z. matrella* (L.) Merr.], and mascarenegrass (*Z. tenuifoila* Willd. ex Trin.). Tough and stiff nature of the leaves and stems results in the most wear tolerant of the commonly used turfgrasses when actively growing. However, this characteristic also causes difficulties for mowing in the turfgrass management.

Mowing turf was originally accomplished by grazing sheep and other domesticated animals. With the invention of the mechanical mower by Edwin Budding in 1830 (Beard, 1973), however, mechanical mowing and turf management have been linked very closely. Along with irrigation, fertilization, and pest control measures, a mechanical mowing has become one of the fundamental practices in maintaining high-quality turf. A mechanical approach has been the only practice used for cutting zoysiagrass tees, fairways, and roughs in Korea.

In rainy seasons, mechanical mowing is one of the hardest tasks on the turfgrass management. The operation of management equipment like mower should be restricted during periods of high soil moisture content to minimize turf injury, especially on fine textured soils that can be compacted easily. This is especially true of the domestic golf courses. Annual precipitation normally ranges from 1200 to 1500 mm and more than half the rainfall occurs in late June through early August (KMA, 1997), because of the characteristic of the monsoon season. During the monsoon, turf managers find it difficult to schedule mowing of tees, fairways, and roughs, resulting in poor-quality turf. Moreover, most new golf courses are built on rocky or rough terrain in mountainous areas. It means that turf managers will have a tough challenge mowing, even during the non-rainy seasons.

Partly in season or in region where it is difficult to mow, a chemical application of plant growth regulator is considered as a feasible alternative over the mechanical mowing. This may improve turf quality, reduce labor costs, and relieve soil compaction. Most of the benefits will be to reduce mowing frequency and amount of grass clippings through the suppression of vertical shoot growth under the difficult-to-mow conditions (BAA, 1994). Watschke and DiPaola (1995) reported mowing requirements decreased by 50% with plant growth regulators. Growth regulator is an organic compound, natural or synthetic, that regulates turfgrass growth and development when applied in small amounts (DiPaola, 1988). Plant growth regulators have been slowly integrated into turfgrass management strategies and a better understanding is needed for the widespread uses (Kahler, 1992). Combined with a sound mowing practice, it can be a valuable tool in the management of turf shoot growth, even under conditions such as rainy weather or rough terrain.

Information is readily found on the effects of plant growth regulator on cool-season and warm-season turfgrasses (Cooper et al., 1987; Dernoeden, 1984; Fermanian, 1997; Gaul and Christians, 1988; Gaussoin and Branham, 1987; Higgins et al., 1987; Johnson and Carrow, 1989, 1993; Kageyama et al., 1989; Kim, 1998; Kim et al., 1997; King et al., 1997; Koski, 1997; Pennypacker et al., 1981; Qian and Engelke, 1998). Responses of Korean lawngrass to plant growth regulators, however, are not well established by research data and even more limited under a domestic climate condition, except for a few investigations (Kim, 1998; Kim et al., 1997). This study was initiated to evaluate growth regulator effects on the vertical shoot growth of Korean lawngrass and to determine desirable growth regulator and its optimum rate.

Materials and Methods

To evaluate plant growth regulator effects on Korean lawngrass, field experiments were conducted at the Turfgrass Research Facility, Turfgrass & Environment Research Institute in Gunpo, Kyounggi-Do. Experiments I and II were done at different sites and times in 1995. The experiments were conducted on a pure stand of Korean lawngrass turf from June through September in 1995. The turf was established by sodding and maintained under fairway conditions before the initiation of the experiments.

Plant growth regulators for Experiment I were applied on June 22, 1995 at the early stage of vigorous growth of Korean lawngrass. In the Experiment II, we applied growth regulators on July 18, 1995 at the middle stage of vigorous growth to double-check the results of Experiment I. Growth regulators used in the study were Type I growth regulators, amidochlor ('Limit'), (Monsanto Company, St. Louis, MO, USA) and mefluidide ('Embark'), (PBI Gordon Corporation, Kansas City, KS, USA) and Type II growth regulator, trinexapac-ethyl ('Primo'), (Novartis, Greensboro, NC, USA). A total of 11 treatments were comprised of the untreated control (no growth regulator application), four rates of trinexapac-ethyl, 0.02 $mL \cdot m^{-2}$ ('Primo' LL), 0.04 $mL \cdot m^{-2}$ ('Primo' L), 0.08 $mL \cdot m^{-2}$ ('Primo' M) and 0.16 $mL \cdot m^{-2}$ ('Primo' H), three rates of amidochlor, 0.30 $mL \cdot m^{-2}$ ('Limit' L), 0.60 $mL \cdot m^{-2}$ ('Limit' M) and 1.20 $mL \cdot m^{-2}$ ('Limit' H), and three rates of mefluidide, 0.60 $mL \cdot m^{-2}$ ('Embark' L), 1.20 $mL \cdot m^{-2}$ ('Embark' M) and 2.40 $mL \cdot m^{-2}$ ('Embark' H) (Table 1). Growth regulators were treated within 2 days after mowing and applied by hand sprayer capable of accurate and uniform delivery. The amount of delivery was based on 100 $mL \cdot m^{-2}$ for all treatments. The sealed mix tank was vigorously shaken prior to application. The same treatments were replicated four times in a randomized complete block design in both experiments. A plot size was 2 m × 2 m for Experiment I and 2 m × 1 m for Experiment II.

Mowing was done at a height of cut in 20 mm before growth regulator treatments. Research plots were fertilized as follows each year. The schedule for N application was 2.0 $g \cdot m^{-2}$ in April and May, and 3.5 $g \cdot m^{-2}$ in June, July, and August. Phosphorus was applied at 5.0 $g \cdot m^{-2}$ in September and K at 2.5 $g \cdot m^{-2}$ in May, June, and July. Irrigation was applied as needed to avoid wilting. Fungicides and insecticides were applied curatively.

In the experiments plant height was evaluated on a weekly basis over the 8 weeks during the study. A total of 30 measurements were made from each plot. Data were analyzed as a randomized complete block design with analysis of variance, using the General Linear Model procedures and the Statistical Analysis System (SAS Institute, 1990). Means were separated using least significant differences at the 0.05 probability level (Steel and Torrie, 1980). Plant height data in the plots of growth regulators were reported in a comparison with that of the untreated control plots as a contrasting value, being 100% of no suppression in vertical shoot growth.

Results and Discussion

All the tested growth regulators inhibited the growth of Korean lawngrass, but the inhibition period was variable among the products in both experiments. In the Experiment I treated on June 22, 1995, a vertical shoot growth was progressively suppressed with time after growth regulator application (Fig. 1). Vertical shoot growth suppression varied with growth regulator and its rate, especially 1 week after treatment. With amidochlor treatments, vertical shoot growth was inhibited for only about 3 weeks at low to medium rates (0.30 to 0.60 $mL \cdot m^{-2}$), but the suppression continued to work over the 8 weeks of the experiment at high rate of 1.20 $mL \cdot m^{-2}$ when compared to the untreated control. Trinexapac-ethyl and mefluidide suppressed plant growth of Korean lawngrass at all rates for 8 weeks.

In the Experiment II initiated on July 18, 1995, vertical shoot growth responses were similar to those in the Experiment I. As found in the Experiment I, growth suppression differed in growth regulator in use and its rate of application, especially 1 week after treatment (Fig. 2). Among the products tested, trinexapac-ethyl and mefluidide were effective at any application rate for 8 weeks. Amidochlor treatment suppressed vertical shoot growth for only 3 weeks after application, but the degree of suppression was variable with rate and time.

To find a difference of suppression intensity of vertical shoot growth, data for plant height were compared with that of the untreated control plots as a contrasting value. The suppression intensity

Table 1. The treatments and rates of plant growth regulators used in the study.

Treatment	Common name	Rates[z] ($mL \cdot m^{-2}$)	Manufacturer
1. Control	No plant growth regulator applied		
2. Primo LL	Trinexapac-ethyl	0.02	Novartis
3. Primo L	Trinexapac-ethyl	0.04	Greensboro, NC, USA
4. Primo M	Trinexapac-ethyl	0.08	
5. Primo H	Trinexapac-ethyl	0.16	
6. Limit L	Amidochlor	0.30	Monsanto Company
7. Limit M	Amidochlor	0.60	St. Louis, MO, USA
8. Limit H	Amidochlor	1.20	
9. Embark L	Mefluidide	0.60	PBI Gordon Corporation
10. Embark M	Mefluidide	1.20	Kansas City, KS, USA
11. Embark H	Mefluidide	2.40	

[z]The amount of delivery was based on 100 $mL \cdot m^{-2}$ for all treatments.

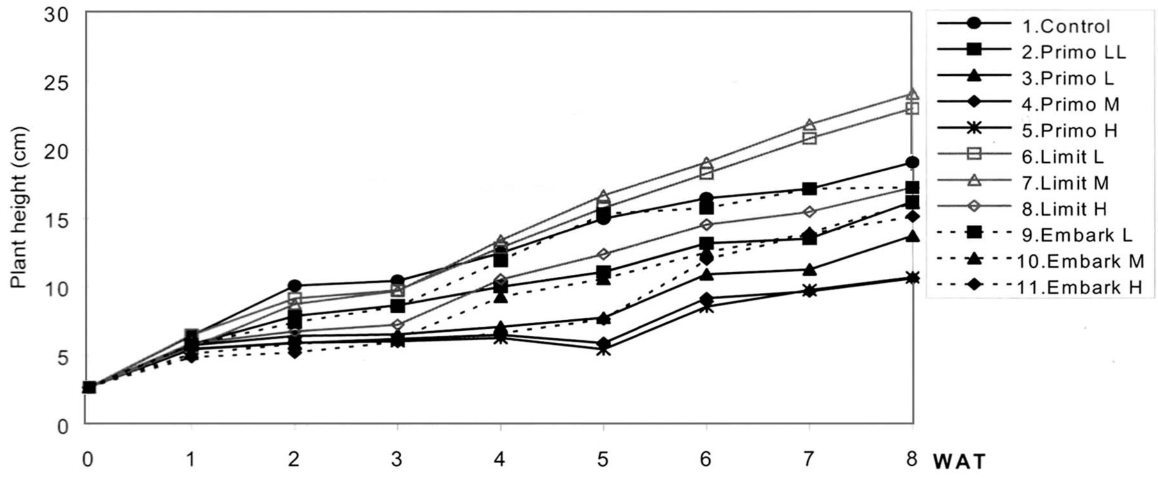

Fig. 1. Changes in plant height of *Zoysia japonica* Steud. treated with trinexapac-ethyl ('Primo'), amidochlor ('Limit'), and mefluidide ('Embark') on June 22, 1955 by week after treatment (WAT).

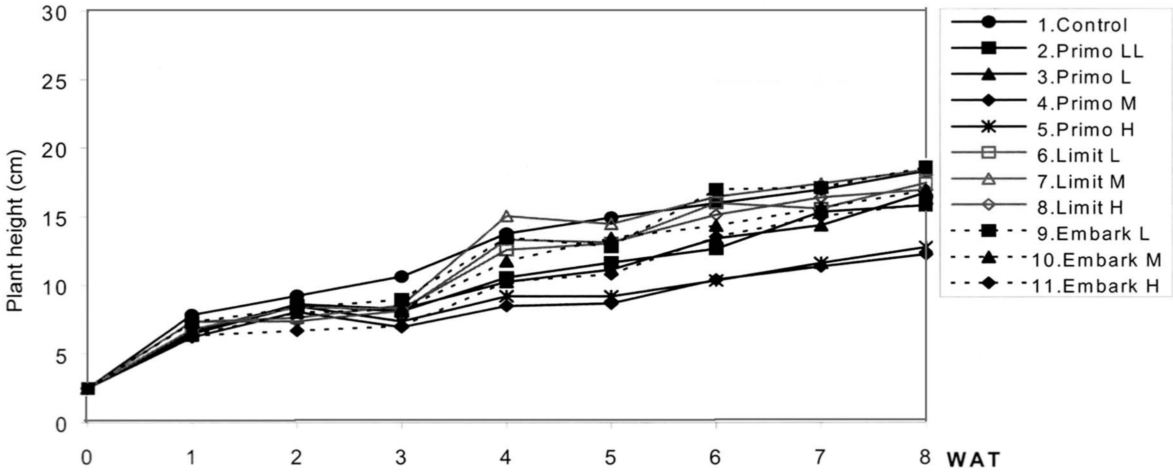

Fig. 2. Changes in plant height of *Zoysia japonica* Steud. treated with trinexapac-ethyl('Primo'), amidochlor('Limit'), and mefluidide ('Embark') on July 18, 1955 by week after treatment (WAT).

generally increased with time after application in both experiments. During the first week after treatment, there was approximately 10 to 20% growth reduction in most of the treated plots (Fig. 3 and 4). Mefluidide at high rate of 2.40 mL · m^{-2} produced the highest suppression by 22% in Experiment I and by 20% in Experiment II. In the amidochlor-treated plots, however, suppression intensity was generally lower than that in the plots of the other growth regulators. In the Experiment I, growth reduction was only 10% at medium to high rates (0.60 to 1.20 mL · m^{-2}), without suppression at low rate of 0.30 mL · m^{-2} (Fig. 3). Lower suppression with amidochlor treatment was considered due to different mode of action of growth regulators.

Plant growth regulators are categorized according to how they reduce growth. By the modes of action and activity of the products, researchers have divided the growth regulators as Types I and II (Kaufmann, 1986; Watschke, 1985). Type I growth regulators such as maleic hydrazide, chlorflurenol, mefluidide and amidochlor are primarily foliar absorbed, except amidochlor ('Limit'), and can inhibit or suppress growth and development through stopping cell division and differentiation in meristematic regions, while Type II growth regulators such as flurprimidol, paclobutrazol, and trinexapac-ethyl suppress turfgrass growth through the interference of gibberellin biosynthesis, thus reducing cell elongation and subsequent plant organ expansion. A Type I growth regulator, amidochlor is a root-absorbed chemical, allowing some growth at reduced rate to occur until it reaches the roots (Danneberger and Street, 1990; Watschke and DiPaola, 1995). Therefore, growth suppression would delay until xylem will transport it elsewhere in the plant.

In the Experiment I, at the second week after treatment, trinexapac-ethyl applications suppressed the turf by 22 to 41% compared to the untreated control with greater suppression occurring at higher rates (Fig. 3). Amidochlor reduced the vertical shoot growth 9 to 33%, depending upon rates. Mefluidide suppressed growth at 27 to 48% with greater inhibition at higher rates. In the Experiment II, vertical shoot growth was reduced by 22 to 36% with trinexapac-ethyl application (Fig. 4). The shoot growth was suppressed at 20% or so with amidochlor treatments. Mefluidide reduced growth more as application rates increased. At the lowest rate of 0.60 mL · m^{-2}, the growth suppression was 16%, but 34% at the highest rate of 2.40 mL · m^{-2}.

In 4 weeks after treatment, trinexapac-ethyl suppressed the vertical shoot growth by 20 to 50% in the Experiment I and by 24 to 38% in the Experiment II, with greater inhibition occurring at higher rates (Figs. 3 and 4). Mefluidide suppressed the growth at 5 to 48% and at 1 to 25% in Experiments I and II, respectively, depending upon application rates. In plots applied with amidochlor, however, the effectiveness of plant growth regulator was nearly ineffective. Growth suppression was observed by 16% with Experiment I and 4% with Experiment II, only at the highest rate of 1.20 mL · m^{-2}.

In the study conducted with three growth regulators, the higher the application rate, the greater the suppression intensity of vertical shoot growth. Duration of growth suppression, however, was variable with growth regulators. Among the products, in 2 weeks, the greatest suppression in the Experiment I was 48% in the mefluidide-treated plots at high rate of 2.40 mL · m^{-2} (Fig. 3). By 8 weeks after treatment, the greatest suppression was found with trinexapac-ethyl at medium to high rates (0.08 to 0.16 mL · m^{-2}), being 44% reduction, when compared with the untreated control. There were no statistically significant differences among the treatments of trinexapac-ethyl M and H. Similar responses were also observed with Experiment II, but intensity of growth suppression differed in that of Experiment I. In the Experiment II initiated on July 18, 1995, growth suppression was 36% with trinexapac-ethyl at medium rate of 0.08 mL · m^{-2} and 34% with mefluidide at high rate of 2.40 mL · m^{-2} at the time of 2 weeks (Fig. 4). By 8 weeks, the greatest suppression was associated with trinexapac-ethyl at medium rate of 0.08 mL · m^{-2}, being 35% reduction when compared to the untreated control.

Overall duration of growth suppression was for only 3 to 4 weeks in plots treated with amidochlor (Figs. 3 and 4). In the mefluidide-treated plots, the retardation began to appear 3 or 4 days earlier than in the plots of the other growth regulators, and continued to work untill the 8 weeks after treatment. However, serious foliar discoloration was observed for 2 or 3 weeks, depending on rates. Unlike trinexapac-ethyl and amidochlor, mefluidide is a foliar absorbed, growth-inhibiting compound. It can rapidly stop cell division and differentiation in meristematic areas and thus inhibit or stop growth and development (Kaufmann, 1986; Watschke, 1985). Therefore, turfgrass plants in the mefluidide-treated plots were considered to be immediate in response to suppression, compared to the other growth regulators. Turf managers should be aware of the risk of foliar discoloration at higher rates of mefluidide application on the Korean lawngrass turf.

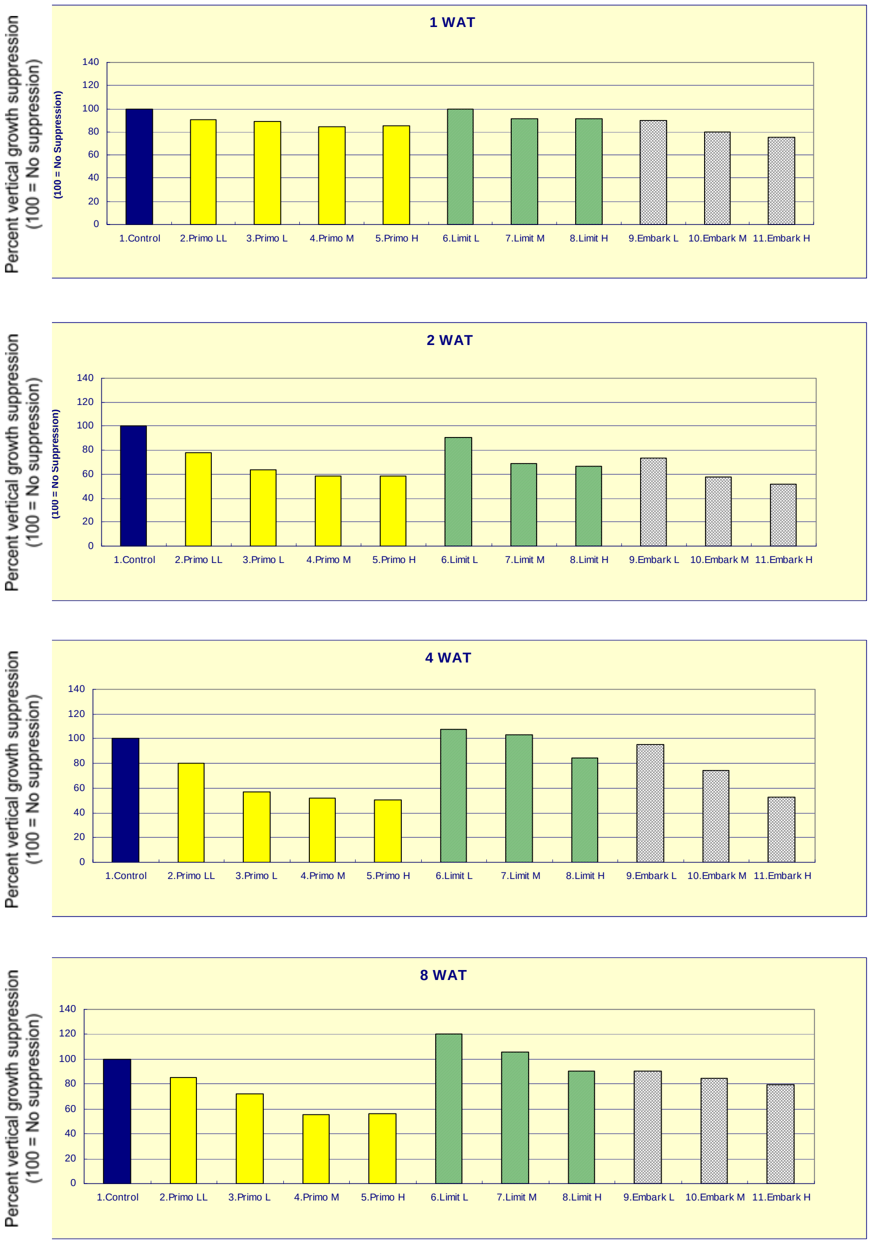

Fig. 3. Vertical shoot growth suppression of *Zoysia japonica* Steud. affected by trinexapac-ethyl ('Primo'), amidochlor ('Limit'), and mefluidide ('Embark') treated on June 22, 1995.

In the trinexapac-ethyl-treated plots exceeding medium rate of 0.08 mL · m^{-2}, growth suppression was consistent and effective over the 8 weeks in both experiments with above 35% growth reduction. These results suggest a long-term suppression may be more effective with trinexapac-ethyl rather than mefluidide and amidochlor growth regulators in terms of vertical shoot growth inhibition. For all growth regulators tested, we observed lower intensity of suppression with Experiment II, when compared with Experiment I. This demonstrates that seasonal variation of activity and effectiveness of growth regulators occur, depending upon circumstances. Kaufmann (1994) noted seasonal growth patterns of turfgrasses must be understood in relation to proper application timing of growth regulators. Korean lawngrass has an optimum temperature of 27 to 35℃ (Beard, 1973) and thereby can grow more vigorously in July than in June here in Korea. We considered that seasonal variable responses to growth regula-

Fig. 4. Vertical shoot growth suppression of *Zoysia japonica* Steud. affected by trinexapac-ethyl ('Primo'), amidochlor ('Limit'), and mefluidide ('Embark') treated on July 18, 1995.

tors were associated with difference in plant vigor by season. Kim (1998) reported climate was one of the important factors to consider for the application of growth regulators. Turf managers will need properly to select growth regulator and determine appropriate rate of application for turfgrass management, based on a defined period of mowing reduction.

In conclusion, vertical shoot growth suppression varied with growth regulators and its application rate, especially from the first week after treatment. Generally, the higher the application rate and the greater the intensity of vertical shoot growth suppression, but the inhibition period was variable among the products. With amidochlor applications, a vertical shoot growth was effectively suppressed for only 3 to 4 weeks after treatment, but the growth in the plots of trinexapac-ethyl and mefluidide was inhibited for 8 weeks. Plant growth regulators can be successfully used to make mowing easier and less time consuming. They also minimize clipping management difficulties by suppressing turfgrass shoot growth. It was reported that plant growth regulators reduced the mowing requirements by up to 50% (Fermanian, 1997; Watschke and DiPaola, 1995). In the study we consider it is feasible to decrease mowing frequencies by 30 to up to 60% in Korean lawngrass for a defined period with a specific growth regulator. Combined with a sound mowing practice, chemical mowing with growth regulators is potentially cost effective in managing vertical shoot growth, even under the hard-to-mow circumstances. But it is also strongly needed the selection of plant growth regulator and its rate should be determined in order to optimize turf quality and performance at the management intensity intended. It was suggested the seasonal aspects of turfgrass growth and development and relative management intensities should be integrated for the proper use of the various growth regulators (Kaufmann, 1994; Kim, 1998).

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Trinexapac-ethyl, Amidochlor 및 Mefluidide가 들잔디 직립생장에 미치는 효과

김경남* · 김용선[1]

삼성에버랜드(주) 환경개발사업부

[1]삼성에버랜드(주) 잔디 · 환경연구소

초 록

여러 가지 생장조절제가 들잔디 직립생장에 미치는 영향을 규명함으로써 예초관리에 적절한 생장조절제 종류 및 적용수준을 파악하고자 본 연구를 수행하였다. 실험은 페어웨이 수준으로 유지되고 있는 들잔디 연구포장에서 1995년 2회에 걸쳐 각각 다른 장소에서 실시하였다. 공시한 3종류 생장조절제 모두 들잔디 생장을 억제하였지만, 억제기간은 종류에 따라 다르게 나타났다. 처리 1주 후 대부분의 생장조절제 처리구에서 약 10%에서 20% 정도의 억제효과가 있었다. Amidochlor 처리구는 $0.30mL \cdot m^{-2}$에서 $0.60mL \cdot m^{-2}$ 사이까지 3, 4주 정도 효과가 지속되었고, $0.08mL \cdot m^{-2}$ 이상의 trinexapac-ethyl 처리구에서는 8주까지 약 35% 정도의 억제효과가 관찰되었다. 다른 생장조절제에 비해 생장억제가 3, 4일 정도 빨리 나타난 mefluidide 처리구도 8주 정도 억제효과가 있었지만, 엽색 퇴화도 동시에 관찰되었다. 직립생장 억제 관점에서 관리 정도가 낮게 유지되는 한국잔디에서 장기간 효과는 trinexapac-ethyl 처리가 amidochlor 및 mefluidide 보다 더 효과적인 것으로 사료되었다. 계절에 따라 생장조절제의 효과차이가 다르게 나타났는데, 들잔디 생육왕성기인 7월 처리에 비해 6월 처리시 직립경 생장억제 정도가 높게 나타났다. 본 연구를 통해 잔디 관리시 생장조절제 종류에 따라 30%에서 60% 정도 예초 회수를 감소시킬 수 있는 것으로 나타났으나, 예초 관리와 관련하여 기대하는 생장억제 기간에 따라 생장조절제 종류 및 적용 수준을 선택하는 것이 필요하다.

추가 주요어 : 생장억제, 예초, 식물생장조절제, 초장