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IN THIS ISSUE

Growth Regulators and *Poa annua*

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The use of growth regulators for various aspects of managing turf has increased greatly in the last 10 to 15 years. This increase has occurred as a result of an expanded number of product choices, research into potential uses, and an experience base of successes among practitioners.

Early uses

The earliest uses (1960's) of plant growth regulators on turfgrasses were primarily for growth and seedhead reduction of amenity grasses, mostly along roadsides. Sites that were hazardous to mow, waste areas, and those that only required mowing because of tall seedheads were the principal targets for growth regulator use. Early products, such as maleic hydrazide, provided good growth and seedhead suppression, but often caused reduced root growth and foliar discoloration. These undesirable side effects were often considered acceptable as the turf usually recovered and the lower level of quality could be justified by the savings realized

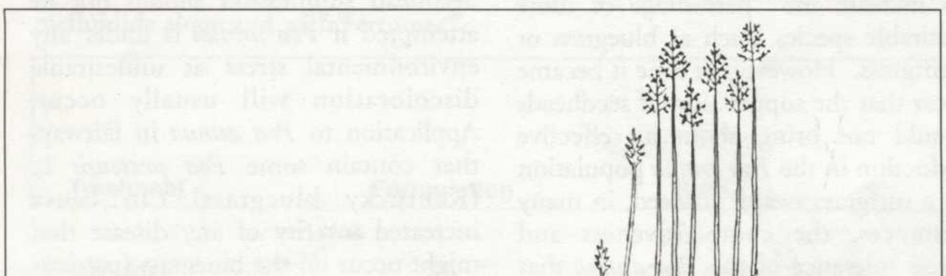

Figure 1. Timing of plant growth regulator applications.

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from the reductions in labor, equipment, and fuel for mowing. However, such undesirable side effects were not generally acceptable on most fine turf areas. It was not until the early and mid-seventies that growth regulator use on fine turf began to substantially increase. New chemistry was being introduced (chlorflurenol and mefluidide) that was less harsh, from an injury standpoint, while still providing reasonably good growth and seedhead suppression. These materials all provided growth suppression primarily through a reduction in cell division (mitotic inhibition). The reduction of cell division is the principal reason that such inhibitors can so effectively suppress seedhead production.

Fine turf applications *(Poa annua)*

Poa annua, which establishes and perpetuates itself primarily through seed production, became an early target for application of the newer mitotic inhibitors. Initially it was thought, that by significantly suppressing seedheads, *Poa annua* would eventually become less competitive and the turfgrass population could be manipulated to increase the percentage of more desirable species, such as bluegrass or bentgrass. However, in time it became clear that the suppression of seedheads would not bring about an effective reduction in the *Poa annua* population of a turfgrass sward. Indeed, in many instances, the competitiveness and stress tolerance of the *Poa annua* that had been previously treated with growth regulators increased throughout the season. This phenomenon can result in a status quo, with regard to the distribution of grass population, or even to an increase in the amount of *Poa annua* in the stand. Therefore, the use of mitotic inhibitors has evolved to the point where many golf course superintendents that are managing predominately *Poa annua* turf apply such products (primarily mefluidide) to enhance the quality of *Poa annua.*

Some roadside applications continue to be made in various states and research for such use has continued, but most recent research emphasis using mitotic inhibitors has been focused on *Poa annua* management. For the most part, the application of mitotic inhibitors to *Poa annua* is for seedhead suppression to improve turf quality. Any increased tolerance to environmental stress that might be realized is usually considered to be a bonus in the overall scheme of things.

Seedhead suppression

Successful seedhead suppression is the result of proper timing. Applications must be made after complete "green-up" in the spring (usually after the third mowing) and before the majority of seedheads have emerged (Fig. 1). If applications are made before complete "green up" there can be a delay, as new budshoot development will be suppressed. If application timing occurs after seedhead emergence has begun, poor overall suppression will result. Seedhead suppression should not be attempted if *Poa annua* is under any environmental stress as undesirable discoloration will usually occur. Application to *Poa annua* in fairways that contain some *Poa pratensis* L. (Kentucky bluegrass) can cause increased severity of any disease that might occur on the bluegrass (particularly leaf spot). If the rough is a Kentucky bluegrass/fine fescue (*Festuca* spp.) mixture, special care should be taken to avoid application to the rough, again because of the potential for worsened disease conditions. While it is highly unlikely that mitotic inhibitors predispose the turf to disease or decrease inherent resistance, the suppressed growth reduces the ability of treated turf to produce new leaves, which would be unaffected by the activity of any foliar pathogen. Properly calibrated spray equipment is critical for successful applications, and the use of foam marking systems to prevent skips and excessive overlap is recommended. When properly timed and applied, the level of seedhead suppression should equal or exceed 90% (Fig. 1).

Some golf course superintendents add wetting agents (product choice does not appear to make any significant difference) in an attempt to increase the activity of mefluidide at lower rates. The lower rate (6 oz. product/acre) plus the wetting agent at label rate can maintain a high level of seedhead suppression, but with less turf discoloration (although turf discoloration is very slight and short term when mefluidide is used alone at the label recommended rate). Seedhead suppression generally lasts approximately four weeks, after which time the turf exhibits a "rebound" effect (slightly stimulated growth and enhanced color). This effect occurs at the time when untreated *Poa annua* has flowered and set seed, and is generally exhibiting decreased quality due to slowed growth and a slight loss of color (yellowing).

In recent years (late 80's and 90's) research emphasis with mitotic inhibitors has become more focused on seedhead suppression of *Poa annua* in putting greens. Again, the objective is to improve the quality of predominately *Poa annua* greens by reducing seedheads, and thus improving smoothness and ball roll. Although not currently on the use label of mefluidide, research has shown that a reasonably high level of seedhead suppression can be attained on close cut *Poa annua*. It appears that mefluidide applied at approximately 4 oz. product/acre tank mixed with 5 oz. of Ferromec®/1000 ft^2 can produce effective suppression without any undesirable side effects (Table 1). Although higher rates provide better suppression, undesirable discoloration can occur. At the time of this writing, it is uncertain as to whether application to greens will be submitted by the manufacturer for approval by the U.S. Environmental Protection Agency as a label amendment.

Suppression via the limitation of gibberellin biosynthesis

In the 70's and early 80's, plant growth regulator chemistry expanded with the commercialization of compounds that suppressed growth primarily via the interruption of the plants ability to synthesize gibberellin (GA). GA is necessary for the normal elongation of cells; therefore, any reduction in the normal synthesis of this substance in the plant

Table 1. Percentage of Poa annua seedheads compared to the untreated check from treatments of mefluidide alone and with Ferromec®.

			Percent Suppressed	
Treatment	**Formulation**	**Rate**	**21**	**35 DAT**
Mefluidide	2S	0.05 oz/m	63	53
Mefluidide	2S	0.1 oz/m	93	90
Mefluidide	2S	0.2 oz/m	98	95
Ferromec®	---	6 oz/m	0	0
Mefluidide + Ferromec®	2S	0.05 + 6 oz/m	37	27
Mefluidide + Ferromec®	2S	0.1 + 6 oz/m	85	75
Mefluidide + Ferromec®	2S	0.2 + 6 oz/m	92	85
Untreated Check	---	---	0	0

results in suppressed growth (stunting or dwarfism). Cell division is not significantly affected; therefore, seedhead suppression is not as successfully accomplished by inhibiting GA as with the use of mitotic inhibitors. In fact, GA suppressors are used very successfully in small grains and rice production to enhance seed yield because of decreased lodging (the stalk of the seedhead grows shorter and thicker making it less susceptible to wind). Consequently, the use of GA inhibitor growth regulators for the purpose of *Poa annua* seedhead suppression is largely unsuccessful. However, GA inhibitor compounds have been found to differentially suppress the growth of *Poa annua* compared to other cool season turf species (particularly *Agrostis* spp.).

Stand conversion

Most research using GA inhibitors has targeted mixed *Poa annua*-creeping bentgrass (*Agrostis stolonifera*) stands on both golf course fairways and greens. Applications are intended to increase, over time, the percentage of creeping bentgrass over *Poa annua* without significant discoloration of the *Poa annua*. The rate of success appears to be a function of the percentage of creeping bentgrass present when treatment is initiated. There should be enough creeping bentgrass (at least 35%) in the stand to provide the plant species with a basis for conversion. If bentgrass is not present in sufficient quantity, serious consideration must be given to managing the *Poa annua* as the desired species. Otherwise, an aggressive bentgrass overseeding program must be initiated; possibly in combination with a total vegetation kill using glyphosate (Round Up®). Killing predominately *Poa annua* fairways with Round Up®, followed by bentgrass overseeding, will often result in a mixed *Poa annua*-bentgrass stand that may only slightly favor bentgrass; however, this approach usually does provide enough of a bentgrass base for a conversion program to be initiated. Regardless of the starting point, it appears that perseverance is necessary as, while the conversion is steady, it is usually slow. Two applications per year, in the spring after seedhead production and in the fall just after *Poa annua* germination, can bring about a satisfactory conversion of a mixed *Poa annua*-creeping bentgrass stand in three to five years, depending on the amount of creeping bentgrass in the stand at the beginning. The spring application is timed to follow seedhead production because *Poa annua* becomes physiologically weakened due to the production of seed; coincidentally, creeping bentgrass is entering a time of the year when it becomes vegetatively aggressive and it continues that way throughout the summer as compared to *Poa annua*. The fall application is positioned after *Poa annua* germination because seedling *Poa annua* is more sensitive to GA inhibitors than are the mature plants; this is in addition to the fact that *Poa annua* plants, regardless of age, become more competitive against creeping bentgrass in the fall.

The scenario for conversion from predominately *Poa annua* to predominately creeping bentgrass follows the same protocol whether it is on fairways or greens. However, since greens typically have more of the perennial type of annual bluegrass (*Poa annua* var. reptans.), conversion ultimately results in a mixed creeping bentgrass-perennial annual bluegrass turf. This is the result of stoloniferous species having a competitive advantage over non-stoloniferous species when the sward is treated with GA inhibiting compounds.

Conclusion

Growth regulators, therefore, can be used to effectively enhance *Poa annua* as a turfgrass or, depending on the mechanism of action, can create significant problems for *Poa annua* with respect to its ability to compete with other species (particularly creeping bentgrass). The most important thing is to maintain consistency with respect to the direction chosen for growth regulator use.

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Maximizing Disease Control with Fungicide Applications:

The Basics of Turfgrass Fungicides Part Two: Behavior in Soil

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In the first part of this series I reviewed some of the current trends in fungicide applications. Included in that article was important information on the types of fungicides available to the turfgrass manager and how these fungicides suppress fungal pathogens in plants. In the second part of this series, I review some of the properties of fungicides that affect fungicide behavior in a turfgrass system. This information should be useful in selecting fungicides for application to particular sites and in maintaining environmentally-responsible disease management programs.

The efficacy of fungicides in turfgrass disease control can be related to their behavior in soil. An understanding of the factors that affect fungicide behavior can ultimately lead to more effective fungicide applications. This type of information is among the most important in choosing and predicting the outcome of fungicide applications, yet it is perhaps the least understood of all the aspects of turfgrass fungicide use. Unfortunately, few turfgrass managers have either had access to this type of information or have recognized this kind of information as important to their fungicide programs. Therefore, this article is an attempt to provide turfgrass managers with relevant information on the behavior of fungicides in soil, so that sound fungicide management decisions can be made and predictable fungicide performance can be routinely achieved.

Fungicide efficacy affected by soil properties

Since turfgrass pathogens are generally soil-inhabiting fungi, turfgrass fungicides must find their way to the soil or thatch for effective disease control. The soil-thatch interface under a turfgrass canopy is, without a doubt, one of the most difficult environments in which to apply fungicides successfully. There are many factors that reduce the activity of soil-applied fungicides in this zone; they can be immobilized, degraded, dissipated, and inactivated quite rapidly. This is related to a number of factors, including the degree of sorption of fungicides to organic matter and soil particles, as well as the amount of microbial and chemical degradation, photodecomposition, root absorption, and movement out of the soil profile through volatilization and leaching.

Sorption of fungicides to thatch and soil

Most turfgrass fungicides readily bind to, and are immobilized in, thatch and soil organic matter. While this is desirable in that it minimizes the movement and leaching of fungicides, it can also be detrimental in that it prevents fungicides from achieving their maximum levels of control; in particular, it prevents those fungicides applied for the control of root and crown pathogens from reaching their target. Furthermore, adsorbed fungicides are generally more persistent, thus providing greater opportunities for undesirable side-effects.

Fungicides vary in the degree to which they are adsorbed to soil particles and organic matter; it is mainly a function of the physical and chemical properties of the soil, the chemical properties of the fungicide, and the environmental conditions. The organic matter content is by far the most important determinant of fungicide adsorption. In turfgrasses, the most abundant type of organic matter is in the form of thatch. Since mature stands of some turfgrasses may have a considerable thatch layer, this can present real problems in maintaining effective fungicide treatments.

All things being equal, as the thatch layer or soil organic matter content increases, so too will the degree of fungicide adsorption. Those fungicides most likely to be immobilized in thatch include contact fungicides such as anilazene, chlorothalonil, mancozeb, chloroneb, quintozene, and etridiazole, and the penetrant fungicides propamocarb and vinclozolin (Table 1).

Table 1. Water solubility and thatch adsorption potential of turfgrass fungicides.

Fungicide	Water Solubility (ppm)	Potential for Thatch Adsorption[a]
Quintozene	0.1	High
Chlorothalonil	0.9	High
Thiophanate methyl	3	Low
Vinclozolin	3.4	High
Benomyl	4	Moderate
Mancozeb	6	High
Anilazene	8	High
Chloroneb	8	High
Flutolanil	9.6	Unknown
Iprodione	13	Moderate
Fenarimol	13.7	Moderate
Thiram	18	Moderate
Triadimefon	64	Low
Etridiazole	117	Moderate
Propiconazole	100	Moderate
Cyproconazole	140	Moderate
Metalaxyl	8400	Low
Fosetyl Al	120,000	Low
Propamocarb	1,005,000	High

[a] Low adsorption = K_{oc} values $\leq$ 300; Moderate adsorption = K_{oc} values between 300 and 1000; High adsorption: = K_{oc} values >1000.

Compiled from: Balogh, J.C., and Anderson, J.L. 1992. "Environmental impacts of turfgrass pesticides." Pages 221-353 in: *Golf Course Management and Construction: Environmental Issues,* Balogh, J.C. and Walker, W.J., Eds, Lewis Publishers, Chelsea, MI, 951 pp.

Tomlin, C., 1994. *The Pesticide Manual,* 10th Edition, Crop Protection Publications, British Crop Protection Council, UK, 1341 pp.

Foster, R., Knake, E.L., McCarty, R.H., Mortvedt, J.J., and Murphy, L. 1994. *1994 Farm Chemicals Handbook,* Meister Publishing Company, Willoughby, OH, 865 pp.

Soil properties important in fungicide adsorption

Soil type can also affect the immobilization of turfgrass fungicides. As the clay content and the cation exchange capacity (CEC) increase, so too does the degree of fungicide adsorption. On golf course turf, however, high sand content growing mixes and highly-modified soils limit the clay content in the root zone, making this a relatively unimportant consideration in fungicide performance on these types of soils. However, organic amendments, as well as some types of inorganic amendments, that increase CEC (e.g., zeolites) may have significant effects on fungicide efficacy.

Soil temperature may also affect fungicide adsorption. In general, as soil temperatures increase, adsorption decreases; however, for those fungicides that have a greater potential for thatch adsorption, the effects of soil temperatures are much more pronounced.

Particularly for fungicides that are more soluble in water, wide changes in soil pH will drastically alter the degree of fungicide adsorption. For example, considerably more adsorption would be expected in alkaline (pH >7.0) soils than in acidic (pH ≤ 5.5) soils; this is not particularly important if the soil pH from site to site is relatively uniform. Soil water content will also affect fungicide adsorption insomuch as adsorption increases dramatically in very dry soils.

Fungicide properties affect adsorption

The chemical properties of the fungicides being applied are important predictors of soil or thatch adsorption. Polar or permanently charged fungicide molecules are more likely to be adsorbed than non-polar or neutral molecules. In general, polar fungicides remain more polar in alkaline, rather than in acidic, environments. With the exception of fosetyl Al, which is the most polar of them all, the majority of the turfgrass fungicides used today are quite non-polar.

Of equal importance is the water solubility of the fungicide (Table 1). As the water solubility increases, the amount of adsorption generally decreases. For the most part, many of the contact fungicides are not readily soluble in water and may be tightly adsorbed to thatch. Those fungicides that are least likely to adsorb, because of their higher water solubilities, are metalaxyl, and triadimefon. Propamocarb and fosetyl Al are unusual fungicides in that they are not only extremely water soluble, but are also highly adsorbed to organic matter; whereas, as a result of its other fungicide properties, thiophanate methyl has both low solubility and low potential for thatch adsorption.

Microbial degradation of fungicides

All turfgrass fungicides are subject to varying degrees of microbial, plant, and chemical degradation in soil. These are the only processes whereby the fungicide can actually disappear from the environment; thereby reducing the total environmental load of the fungicide. Since many soil microbes get their energy from the breakdown of carbon-containing compounds, all turfgrass fungicides have the potential to serve as a food source for microorganisms in turfgrass soils. Even if the fungicide does not directly serve as a food source, decomposition may still occur; the metabolic enzymes produced by soil microbes, during the degradation of other forms of organic material, often contribute to the decomposition of fungicides. Frequently, the active ingredient molecule is broken down into other molecules with no fungicidal or detrimental side effects. However, in a couple of cases (e.g., benomyl and triadimefon), the fungicide active ingredient is broken down into yet other fungicidal compounds that have their own behavior and efficacy in turfgrass soils.

Generally, the greater the soil microbial populations and the greater the microbial activity, the more likely a fungicide will degrade. However, studies have shown that microbial degradation of fungicides does not occur immediately after the application of the material. Rather, there is a lag period during which microbial populations shift, favoring those microbes possessing the appropriate enzyme systems to degrade the introduced fungicide. After these microbial populations acclimate to the introduced fungicide, degradation can proceed at a higher rate. Over time, the continued application of the same fungicide to the same site will very quickly result in reduced fungicide efficacy, if not from enhanced microbial degradation, then from the development of fungicide resistance. Fungicide resistance will be covered in more detail in a future chapter of this ongoing series on fungicides.

Soil properties affect microbial degradation

The rate at which turfgrass fungicides are degraded by soil microbes depends, to a large extent, on fungicide chemical properties and fungicide concentration; it also depends on a number of soil factors including moisture, pH, oxygen content, nutrient status, clay content, organic matter content, and, perhaps most importantly, the type of soil microbial community. The variety of soil microorganisms that degrade turfgrass fungicides have very specific metabolic capabilities. The population levels of these specific microbes directly affect the level of fungicide degradation. As these microbes degrade the active fungicide molecules, the degradation products further stimulate other microorganisms capable of degrading the fungicide metabolites.

Those fungicides more resistant to microbial degradation are those that are less available in the soil solution. For example, those fungicides that more readily bind to thatch, that are not very water soluble, and are known to persist in soil for appreciable periods of time, will be less prone to microbial degradation. This persistence in soil is usually expressed as the half-life of the fungicide, which is the time it takes for half of the original applied fungicide to degrade (Table 2). Fungicides such as anilazene, thiram, and vinclozolin are rapidly degraded in soils, whereas propiconazole, cyproconazole, and benomyl are quite persistent.

Volatilization of fungicides

Volatilization refers to the evaporation of fungicides from the spray, the turfgrass foliage, and the soil surface into the atmosphere. Volatile losses of fungicides are significant from two different perspectives: first, volatile losses remove the fungicide from the target site, thus reducing the effectiveness of the fungicide; second, volatile losses increase the inhalation hazard to applicators and others who come into contact with treated turf. Efforts, therefore, should always be made to minimize these losses where possible.

The degree of volatilization of a given turfgrass fungicide is related not only to the inherent vapor pressure of the fungicide at a given temperature (Table 3), but also to environmental factors and chemical processes at the soil-air-water interface. For example, volatilization may be affected by the soil water content and bulk density. Generally, as soil water content increases, volatilization decreases; however, in very dry soil, volatilization is also reduced as increased adsorptive processes limit the amount of fungicide free in the soil solution. Increases in bulk density tend to reduce the diffusion of the fungicide to the soil surface and further increase fungicide adsorption.

Precipitation and irrigation will also reduce the amount of volatilization by transporting fungicides away from the turfgrass foliage and soil surface, where the greatest amount of volatilization occurs, and by increasing the soil water content. The frequency of rainfall or irrigation can also indirectly affect volatilization by affecting the degree of water evaporation. Water evaporation will transport most fungicides to the soil surface where volatilization can occur; therefore, the greater the frequency of irrigation or rainfall, the lower the potential for volatilization losses.

Wind speed also indirectly increases volatile losses of fungicides by increasing water evaporation rates. Generally, wind serves to mix the stagnant layer of air adjacent to the turfgrass foliage, thereby increasing the overall evaporation rates and the volatilization potential of turfgrass fungicides. Those fungicides that adsorb more tightly to thatch and soil will be unaffected by evaporative processes, but those that are normally free in the soil solution will have considerable increases in volatilization losses.

Table 2. Half-life and persistence of turfgrass fungicides in soil[a].

Fungicide	Half-Life in Soil	Persistence Classification
Fosetyl Al	20 Min. – 1.5 Hr	Very short
Anilazene	0.5 – 1 Days	Very short
Thiram	0.5 – 15 Days	Short
Vinclozolin	1 – 31 Days	Moderately short
Chlorothalonil	5 – 90 Days	Moderately short
Mancozeb	6 – 139 Days	Moderately persistent
Triadimefon	6 – 28 Days	Short
Iprodione	7 – 160 Days	Moderately short
Propamocarb	10 – 27 Days	Short
Chloroneb	10 – 180 Days	Moderately Short
Thiophanate methyl	10 – 28 Days	Short
Etridiazole	20 Days	Short
Fenarimol	20 – 365 Days	Highly persistent
Quintozene	21 – 434 Days	Highly persistent
Flutolanil	40 – 60 Days	Moderately short
Propiconazole	40 – 123 Days	Highly persistent
Metalaxyl	70 – 160 Days	Moderately short
Cyproconazole	80 – 100 Days	Moderately persistent
Benomyl	90 – 360 Days	Highly persistent

[a] Fungicides ranked from the shortest half-life to the longest.

Compiled from: Balogh, J.C., and Anderson, J.L. 1992. "Environmental impacts of turfgrass pesticides." Pages 221-353 in: *Golf Course Management and Construction: Environmental Issues*, Balogh, J.C. and Walker, W.J., Eds, Lewis Publishers, Chelsea, MI, 951 pp.

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Kenna, M.P. 1995. "What happens to pesticides applied to golf courses?" *USGA Greens Section Record* 33(1): 1-9.

Tomlin, C., 1994. *The Pesticide Manual*, 10th Edition, Crop Protection Publications, British Crop Protection Council, UK, 1341 pp.

Table 3. Vapor pressures of turfgrass fungicides and their potential for volatilization.

Fungicide	Vapor Pressure[a] (mPa), 20-25°C	Potential for Volatile Losses
Chloroneb	400.0	High
Etridiazole	19.0	High
Quintozene	12.7	High
Thiram	2.3	Moderately High
Flutolanil	1.77	Moderately High
Propamocarb	0.800	Moderate
Metalaxyl	0.75	Moderate
Chlorothalonil	0.076	Low
Fenarimol	0.065	Low
Triadimefon	0.06	Low
Vinclozolin	0.016	Low
Fosetyl Al	0.013	Low
Thiophanate methyl	0.0095	Very Low
Propiconazole	0.0056	Very Low
Benomyl	0.0049	Very Low
Cyproconazole	0.00346	Very Low
Anilazene	0.0000008	Very Low
Iprodione	0.0000005	Very Low
Mancozeb	negligible @ 20°C	Very Low

[a] Fungicides ranked from most volatile to least volatile.

Compiled from: Tomlin, C., 1994. *The Pesticide Manual*, 10th Edition, Crop Protection Publications, British Crop Protection Council, UK, 1341 pp.

As mentioned earlier, volatilization losses have important implications on human health. In this regard, there are a number of important factors to consider. First, it is important to note that the greatest volatilization losses occur during, and within a few hours after, application. Furthermore, volatilization losses are greater at warmer temperatures, particularly during the middle to latter part of the day. Therefore, if the fungicide being applied is particularly prone to volatilization losses, precautions should be taken to adjust application schedules to avoid the warmer times of day and to wear the proper protective clothing to avoid inhalation dangers during, and the hours immediately following, applications. Second, the concentration of the applied fungicide affects the degree of volatilization: the greater the fungicide concentration, the greater its vapor concentration. Therefore, reducing application rates, or increasing the amount of water in which the fungicide is applied, will help to minimize volatile losses of fungicides and reduce the risk of unnecessary exposures.

It is also important to recognize that the formulation of the fungicide will affect its degree of volatilization. Wettable powder and granular formulations generally have a greater volatilization potential, following application, due to either a thin film remaining on the turfgrass foliage, or the granular particles remaining on the soil surface. Some studies have linked volatile losses with the degree of dislodged fungicide residues; therefore, the greater the degree of soil incorporation of the fungicide, the lower will be the volatilization of the fungicide.

Fungicide leaching

Fungicide leaching occurs whenever the applied fungicide is not taken up by the plant, degraded by soil microbes, broken down by chemical reactions in soil, decomposed by light, adsorbed to thatch and clay particles, or volatilized. The leaching of pesticides in turfgrass systems has been discussed in considerable detail in a previous issue of *TurfGrass TRENDS* (September 1995) and will not be discussed at any length here.

Keep in mind that all of the factors discussed in this article will affect fungicide leaching. Turfgrass fungicides, as a group, however, are not particularly susceptible to significant amounts of leaching when applied to mature stands of turf grown on soils with some level of organic matter or clay. Leaching usually becomes a problem when fungicides are applied to immature stands of turf on high sand content soils and when applications at high rates are followed by considerable amounts of rainfall or irrigation. Of all the turfgrass fungicides, fenarimol, metalaxyl, propiconazole, and triadimefon have the highest potential for leaching; however, these fungicides pose little or no reason for concern under normal climatic conditions and operating procedures. Furthermore, by making simple adjustments in cultural management and application techniques, any potential leaching problem can be easily avoided.

Management recommendations

The importance of understanding the behavior of fungicides in soil should now be quite apparent. These properties should be used as a guide in making decisions about the application of specific fungicides to specific sites for specific disease problems. It is important to recognize that while the fungicides applied to turfgrasses do not normally move about or disappear from a turfgrass system to any significant degree, their presence alone does not insure efficacy since they are rapidly transformed or inactivated. For these reasons and others pointed out in Part I of this series, fungicides fail from time to time.

Much of the behavior of the fungicide being applied can be predicted from a limited amount of knowledge of the soil properties and the environmental conditions at the site. For example, if faced with the decision of what fungicide to apply to a golf green with brown patch symptoms, you could choose from a vast number of products and formulations all labeled for brown patch control. If the green to which you were applying the fungicide was a native soil green with a high clay and organic matter content, you may want to choose a fungicide such as cyproconazole or propiconazole. Both have higher water solubilities, and lower potential for adsorption to clay and organic matter, than do many other brown patch fungicides. On the other hand, if the green was a high sand content green in an exposed sunny area, you may want to choose a fungicide such as iprodione that has a relatively short half life in soil and is relatively non-persistent. This would avoid any potential leaching losses. Furthermore, on this type of a green, soil temperatures and evaporation rates would be expected to reach relatively high levels, increasing the chances of volatilization losses. Since iprodione has a very low volatilization potential, a short persistence, and only moderate potential for adsorption, this would be an ideal choice for that site.

Aside from choosing a fungicide based on its inherent properties and the soil conditions, making small adjustments in application rates, timing, formulation, and post application irrigation schedules will help to maintain the maximum amount of fungicidal activity with the least amount of undesirable side effects. Furthermore, thatch management is critical to maintaining minimal immobilization and maximum efficacy.

In the coming months, I will continue the discussion of turfgrass fungicides, covering some of the plant and pathogen factors that affect fungicide efficacy, handling, applying and monitoring fungicides, record keeping, human and environmental health considerations, and how to interpret fungicide test results. Stay tuned!

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Terms to Know

Acclimate - To adapt to a new chemical, physical, or biological environment.

Adsorption - The retention of solids, liquids, or gasses at an interface.

Bulk density - The weight of soil per unit volume.

Cation exchange capacity (CEC) - The sum total of all exchangeable positively charged ions, such as sodium, magnesium and potassium, that a soil can adsorb. Expressed as milliequivalents per gram of soil.

Half-life - The time required for half of the original amount of applied fungicide to disappear.

Immobilization - The reduction in movement of fungicides.

Leaching - The removal of fungicides dissolved in water from upper soil layers to the ground water.

Metabolites - Products of microbial metabolism.

Microbial community - Interacting populations of microorganisms.

Non-polar molecules - Molecules with no electrical charge.

Polar molecules - Molecules possessing two equal and opposite electrical charges.

Vapor pressure - The pressure exerted by a fungicide in its gaseous state in equilibrium with that in the liquid state. A measure of the potential of a fungicide to convert to a gas.

Volatilization - The conversion of a fungicide from a liquid to a gaseous state and its subsequent escape from the soil.

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Poa annua Management

by Bridget Ruemmele

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Poa annua, or annual bluegrass, is regarded as either a help, a hindrance, or purely a frustration, depending on your particular situation. This grass is often described as a light green to yellow green annual plant with boat-shaped leaf tips. It usually germinates in the fall and flowers profusely, even at mowing heights as low as those found on golf greens. Unlike Kentucky bluegrass, annual bluegrass tolerates shade; however, survival can be poor during hot, dry summers, such as those some of us experienced in 1993 and 1995.

Growth characteristics

The most common identifying characteristics associated with annual bluegrass are its light green color, annual growth habit, and profuse flowering. In cool humid areas of the country, like New England, annual bluegrass may be found in various forms, ranging from that described above to dark green perennial types that seldom flower. A number of people have detailed annual bluegrass variability (Adams and Bryan, 1977; Gibeault, 1971; Law *et al.*, 1977; Warwick and Briggs, 1978a; Warwick and Briggs, 1978b; and Youngner, 1959). This variability is what may induce frustration in managing your site to remove annual bluegrass; what works at someone else's site may not be successful at yours.

Annual bluegrass is a colonizer, which means it readily establishes on new sites. It is extremely adaptable to harsh environments as well as to the desirable conditions in which most turfgrasses thrive. Since annual bluegrass can survive on shallow rooting, it can even tolerate compacted soil such as is found in high traffic areas.

Annual bluegrass is pervasive throughout much of the world and can be found in just about any site; often establishing bare areas where other grasses will not grow. It is not usually found in wooded areas; however, since its seed is so readily spread, it does not take long for it to be introduced into any cleared area.

Poa annua seed can survive several years in soil before germinating, which compounds the frustration in controlling this plant. A single plant can be a prolific seed producer. While working with numerous types of annual/perennial bluegrass at the University of Minnesota, I found that a single seedhead could contain 200 or more seeds, most of which were viable. Coupled with this high seed count, a single plant may produce many flower heads; it is, therefore, easy to see why a population can become so extensive.

Controlling *Poa annua*

Controlling *Poa annua* may include both pre- and post-emergent procedures. Both cultural and chemical methods will be described.

As turf managers know, the first line of defense in any weed control is a dense, healthy turf. Since many weedy plants, such as annual bluegrass, germinate most readily when exposed to light, heavily shaded ground can reduce germination significantly. Whenever an established turfgrass area thins out or becomes bare, it is important to find and correct whatever condition led to the grass' demise; it is also important to replace the turf with seed or sod as soon as possible in order to reduce weed, especially annual bluegrass, encroachment.

Cultural methods

There are several cultural practices that may discourage *Poa annua* invasion. Unfortunately, while a single plant or two can be pulled or dug out, by the time the problem is recognized, the site may contain too many plants to eradicate by hand.
Compacted soils, inadequate drainage, excessive close mowing, high nitrogen, adequate water through natural rainfall or supplemental irrigation, and mild summers all favor annual bluegrass growth. While the weather is beyond anyone's control, you can aerify to decrease soil compaction, if that is a problem. Correcting any drainage problems and raising the mower height above one inch, if possible, will further discourage *Poa annua* encroachment. Reducing nitrogen and irrigation frequency, to favor more desirable turfgrasses over *Poa annua*, as well as limiting phosphorus applications will also decrease annual bluegrass populations.

Reducing pH, as well as occasionally withholding water, can also encourage preferred turfgrass growth. This control, however, may not be practical on intensely utilized sites, since desired grasses may be too severely stressed by these actions.

Annual bluegrass is highly susceptible to a number of diseases, including anthracnose, dollar spot, brown patch, pythium, and snow mold. It is possible to let disease decimate the population, but you should then be prepared to replant the area to prevent the re-establishment of annual bluegrass from seed. This process would be undesirable if preferred grasses, which also may be susceptible to these diseases, are present.

Extensive ice cover can be detrimental to *Poa annua* survival. Repeated thawing and freezing may also

Table 1. *Poa annua* control strategies.

Time	Control Measure
New planting	soil sterilants
Pre-emergence	benefin (Balan®) bensulide (Betasan®) oxadiazon (Ronstar®) prodiamine (Barricade®) ethofumesate (Prograss®) pendimethalin (Pre-M®)[1] DCPA (Dacthal®)[1] isoxaben (Gallery®) [2]
Post-emergence	ethofumesate (Prograss®)
Seedhead suppression[3]	Maleic hydrazide chlorfluorenol mefluidide (Embark®) Paclobutrazol (Scott's TGR®)

[1] May require a second application or higher rates for control.
[2] May only provide suppression or partial control.
[3] Variability within *Poa annua* causes varied and unpredictable responses to growth regulators.

hydrate and kill plant crowns. Unfortunately, favored grasses may also succumb to this problem.

Chemical methods

Before using any chemical control, make sure your state allows its use on *Poa annua.* Find out whether its use is restricted (requiring a pesticide applicator license), and familiarize yourself with the safe, proper application procedures and timing.

New sites may be treated with soil sterilants to stop annual bluegrass seed germination; however, this only provides short-term control and, due to their being taken off the market, soil fumigant options are decreasing.

Pre-emergent grass control chemicals are useful in preventing, or at least greatly reducing, annual bluegrass germination. Post-emergent products, on the other hand, are somewhat successful in controlling established populations. A word of caution—some of the products listed in Table 1 may also harm desirable turfgrasses. Be sure to check the herbicide label for turfgrasses which could be affected adversely.

Timing is most critical with pre-emergent weed control. Make sure you follow label instructions to ensure the product is applied at the correct time (just before germination) and in the prescribed manner to activate the chemical. Pre-emergent herbicides often block germination by forming a chemical barricade in the soil. Although the greatest annual bluegrass germination typically occurs in fall, seed may germinate at any time conditions are suitable; as a result, repeat pre-emergent herbicide applications during the same growing season may be needed to control *Poa annua.*

Several pre-emergent herbicides that are effective on weedy grasses will control annual bluegrass. An extensive list of chemicals and their product names is available in the January 1995 issue of *Grounds Maintenance* magazine. Examples include benefin (Balan®), bensulide (Betasan®), oxadiazon (Ronstar®), and prodiamine (Barricade®). Some products, like pendimethalin (Pre-M®) or DCPA (Dacthal®), may require either higher rates or a second application for control. Other chemicals, such as isoxaben (Gallery®), may only provide suppression or partial control.

Fewer post-emergent herbicidal controls are effective for annual bluegrass. Most products listed in the 1995 *Grounds Maintenance* article do not indicate cool-season turfgrass tolerance to the herbicides. Kentucky bluegrass, perennial ryegrass, fine fescues, and bentgrass fit this classification.

Post-emergent annual bluegrass management includes using growth regulators, to suppress flowering and the resulting seed production, as well as herbicides, to kill the plants, hopefully before they flower. Since pollination and fertilization leading to seed development may occur even as the flowers emerge from the plants, timing is critical in controlling *Poa annua.*

Several growth regulators have been tested for suppression of annual bluegrass flowering with varying degrees of success (Cooper *et al.*, 1987 and Danneberger *et al.*, 1987). Unfortunately, the variability within this weed species causes varied and unpredictable responses to growth regulators.

Maleic hydrazide, chlorfluorenol, and mefluidide (Embark®) all successfully inhibit flowering by *Poa annua.* Paclobutrazol (Scott's TGR®), which stunts seedheads, has been used to convert *Poa annua* sites to desirable turfgrasses. I found a range of seedhead control with mefluidide in tests conducted at the University of Minnesota. Some *Poa annua* selections had excellent seedhead suppression, while others showed little effect. The length of suppression also varied depending on the plant selections. Thus, what works for one person may not be as successful for someone with different strains of annual bluegrass. This is not to discourage you from trying growth regulators—just be aware that the product may or may not perform well in your situation.

A relatively new product, ethofumesate (Prograss®), provides both pre- and post-emergent control. Effective control has been demonstrated in many situations on several strains of annual bluegrass, although I do know some sod growers in New England who have been frustrated in their attempts to use this product. Lack of control could be due to improper timing of applications or resistant genotypes of *Poa annua,* rather than the product itself. Some states have not registered this product or have placed restrictions on its use. Check the label before using it.

You may find one or more of these cultural and chemical controls useful in managing annual bluegrass. Do not be surprised if it takes a combination of methods. The battle will likely be long-term and result in reduced populations rather than total elimination.

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Conditions Favoring *Poa annua* Invasion

* Compacted soils
* Inadequate drainage
* Excessive close mowing
* High nitrogen
* Adequate water
  (natural rainfall or supplemental irrigation)
* Mild summers

Cultural Controls for *Poa annua*

* Aerify to decrease soil compaction.
* Correct drainage problems.
* Raise mower height above one inch, if possible.
* Reduce nitrogen frequency.
* Reduce irrigation frequency.
* Limit phosphorus applications.
* Reduce pH, and occasionally withhold water.
  (Note: This control may not be practical on intensely utilized sites, since desired grasses may be too severely stressed by these actions.)

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