A PRACTICAL RESEARCH DIGEST FOR TURF MANAGERS

TURFGRASS TRENDS

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AGRONOMY

Runoff of phosphorus from simulated golf fairways

By Larry M. Shuman

Phosphorus is not an element that most turfgrass managers would associate with water quality problems. Certainly, pesticides and nitrates easily come to mind when considering possible contamination of surface water. However, recognizing water quality problems and the awareness that there are extremely high maintenance levels for golf courses, sports fields and areas led to concern about phosphorus contamination of surface waters.

Today the media bombard the public with environmental hazard information, and phosphorus has recently been highlighted as a problem, especially related to manure and wastewater applications to grassed fields. This includes concerns about fertilizer phosphorus placed on high maintenance golf courses and other areas. The number of golf courses is escalating, and they often are next to rivers or have streams running through the course. Many have ponds, which can become contaminated by nutrients.

Adding phosphorus at low amounts more often throughout the year is better than putting on a one or two year supply at one time.

In Atlanta, the U.S. Geological Survey has monitored phosphorus in watersheds that impinge on the metropolitan area. Findings show that phosphorus concentrations decreased after phosphate detergents were banned. However, now the phosphorus that is found is thought to come mostly from agricultural and urban fertilizers.

Finding phosphorus sources

The need for determining the sources of this contamination is growing, so that it can be addressed. Especially important is alleviating public concern about commercial operations including golf courses, professional lawn maintenance companies and commercial areas causing surface water pollution through fertilizer applications.

Surface water can be considered phosphorus contaminated with concentrations as little as 50 to 100 µg P /kg (parts per billion). Although algae require both nitrate and phosphorus to live and proliferate, nitrogen is not usually the limiting element.

Phosphorus runoff research has been concentrated in the area of row crop agriculture. There, much of the phosphorus that is carried from the field by rainwater is in the form of "particulate" phosphorus. That is, the phosphorus is physically or chemically bound to soil particles, which are carried off in the form of sediment. Only a portion of this phosphorus is available to algae, and it may require some time before it does become available through desorption or solubility processes. Of course, some of the phosphorus (even from cropland) is carried by the runoff water in the soluble form, which is immediately available to algae.

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Testing and analysis

Recognizing forms of phosphorus has led to the development of testing procedures to estimate the amounts of what is called "biologically available phosphorus." This is a specialized analysis attempting to measure both soluble phosphorus and the portion of the particulate phosphorus that may become available to algae. Other forms measurable in the laboratory are total and soluble phosphorus. The difference between those two forms is designated as particulate phosphorus.

Since there are many parameters that affect phosphorus runoff, it is difficult, if not impossible, to study every soil type, slope, turfgrass type, rainfall amounts, fertilizer sources and other variables that may be encountered. One way to generalize research data is to build models using existing research data on runoff and the many parameters that affect runoff and then use these to predict what will happen in other situations. Current models have been developed for cropland, but are not calibrated or even set up for turfgrass.

Thus, much more data is needed at present just to develop the models, let alone calibrate them once they are developed.

Although phosphorus is certainly needed for good plant growth, it often is added either when not needed or at rates that exceed the needs. One reason is that for fairways, agricultural fertilizer grades are often used because of economics, and are balanced (same percentages of nitrogen, phosphorus and potassium). Phosphorus fertilizer is usually added when the fairway is first seeded or sodded in order to promote good root growth. Thereafter, it is added in the spring and in the Southeast, when the warm-season turf is overseeded with ryegrass in the fall.

Nontarget areas

One situation impacting the quality of runoff water is having fertilizer remain on nontarget areas such as roads, cart paths and other hard surfaces. This fertilizer is washed directly to storm drains that usually exit into streams.

Golf courses are designed with fairly steep grades and with streams and ponds. All these features exacerbate the problem by increasing possible runoff or making runoff water move directly into surface water areas. Although there is some problem with nontarget areas receiving fertilizer in golf courses, this is more likely to be a problem with residential properties. These practices and course design factors have not been scrutinized very carefully to date to determine the risk.

This research is part of a broader project that includes both runoff and leaching of phosphorus.

Although the project emphasizes phosphorus, nitrate leaching and runoff data are also being collected. The goal of the research is to evaluate potential movement of phosphorus and nitrogen following application to golf courses and to develop best management practices to reduce potential transport to potable water systems where eutrophication may lead to reduced water quality. The objectives were to determine the amounts of phosphorus that are transported in runoff from a Southeastern Piedmont soil using various fertilizers at different rates.

Twelve identical Tifway 419 bermudagrass plots were developed on a Cecil soil that are 12 by 25 feet and have a slope of 5% back to front (Fig. 1). At the bottom of the

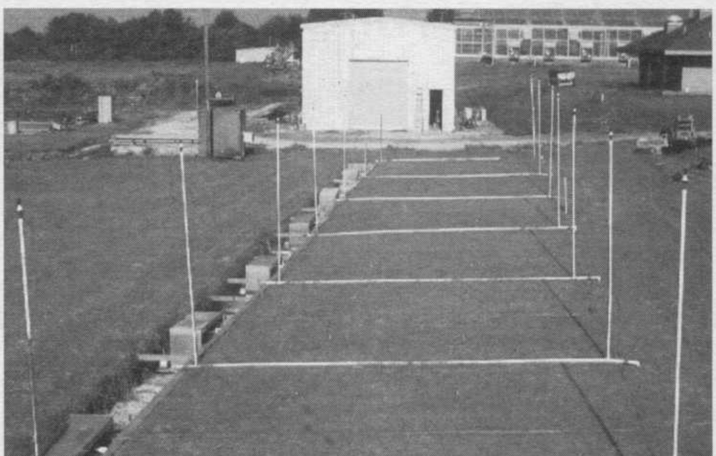

Figure 1. Simulated fairway runoff plots.

slope is a ditch wherein is a trough for each plot to collect runoff water and channel it into measuring and sampling devices. The volume of runoff is measured using tipping buckets that are instrumented with a data logger to count the tips for an individual runoff event.

A sample of the runoff water is also caught in a slit between the two buckets and run into a sample holder for laboratory analysis. The simulated rainfall was provided by overhead sprinklers especially designed for the purpose, which supplied about an inch per hour. For the experiments reported here, 0, 0.22, and 0.44 lb. P/1000 sq. ft. were added in sequential experiments using all the plots as replications. The sources were superphosphate (46% P_2O_5) and a 16-25-12 starter fertilizer.

Rainfall was simulated at the rate of two inches, four hours after treatment (4 HAT) and again two inches at 24 HAT, one inch at 72 HAT and one inch at 168 HAT. The volume was measured and soluble phosphate concentration was determined in the runoff. These are somewhat severe conditions, but not out of the question for the Southeast.

Runoff results

As might be expected, most of the phosphorus that is transported from the simulated fairways by runoff water comes at the first simulated 2-in. rainfall just after the fertilizer is added (4 HAT). Figure 2 shows representative data for P concentrations in the runoff. Here it is for superphosphate, but a similar pattern has always been observed no matter what the phosphorus source or rate.

The volume of runoff is highest at the second simulated rainfall at 24 HAT, but it is not much larger that for the 4 HAT treatment. The 1-in. simulated rainfall events at 72 and 168 HAT yield much less runoff water volume and also much lower phosphorus concentrations as can be seen in Figure 2. These concentrations are very high compared with government guidelines for phosphorus concentrations in streams, which run in the 50 to 100 ppb range (0.050 to 0.100 mg/L in the same units as reported in Figure 2).

However, one has to consider that this phosphorus would have a great dilution before it actually would be measured in stream or pond, so the contribution to the total "load" or weight of phosphorus for the entire body of water would be small. A stepwise increase in the phosphorus concentrations due to the different rates of phosphorus added are evident for both the 4 HAT and the 24 HAT rainfall events. Thereafter, the concentrations are not much different for added phosphorus and the zero added control.

TABLE 1:

PERCENT *P* IN RUNOFF OF THAT ADDED IN FERTILIZER TREATMENTS

Phosphorus Rate	NH4NO3 - Superphosphate	6-25-12	**Mean**
(kg ha-1)	(% in runoff)	(% in runoff)	**(% in runoff)**
11	21	22	**21.5**
21	14	29	**21.5**

Calculating mass

The mass of phosphorus transported from the simulated fairways by the runoff water was calculated by multiplying the phosphorus concentration by the volume of runoff water. These values are not instructive in themselves, but can be used to calculate the percent of the added phosphorus found in runoff.

Table 1 shows that the average percent of phosphorus added that appeared in the runoff for each fertilizer source was 21.5 percent. This rate is quite high and shows the result of the severe runoff conditions imposed in these trials of high rainfall immediately following fertilizer placement. The experiments show extreme conditions that would usually not be found in actual practice.

General conclusions

Our experience in the past three years reveals several conclusions concerning phosphorus transport from golf courses to surface water.

First, leaching of phosphorus from fertilizer applications to greens and fairways does not present a problem. For greens, phosphorus can certainly leach, but in actual practice, very little phosphorus is added to greens after the initial grow-in period.

For fairways, especially in the Piedmont areas of the Southeast, the soil drains slowly and the phosphorus is adsorbed by the soil iron oxides and "fixed" by them forming iron phosphates. However, a potential problem does exist for phosphorus runoff from fairways. Under conditions like those for this experiment, 10 percent to 20 percent of the added phosphorus could be transported to surface waters. Even under less severe conditions, some phosphorus movement is likely.

To exacerbate the problem, the phosphorus that does move into surface water is in the soluble form rather than the particulate form. This form is readily available for use by algae and could contribute to algal "blooms" which deteriorate water quality.

The data generated show that phosphorus can be transported in runoff water under the right conditions of soil moisture, rainfall intensity and time of fertilizer application in relation to rainfall.

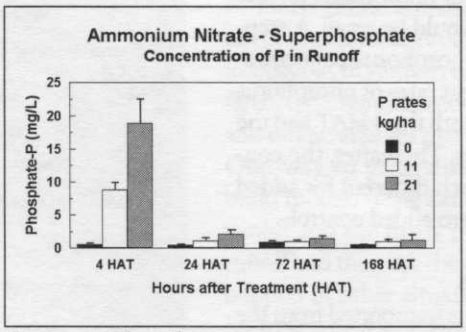

Figure 2. Phosphorus concentration on runoff from simulated fairways for three rates of ammonium nitrate-superphosphate and four rainfall events.

Under the conditions like those used in these experiments, large amounts of phosphorus can be transported from the turf areas. In actual practice, the rainfall may not be as intense or it may come more than four hours after application, but in many cases the slopes will exceed the five percent used here. Thus, expect some runoff of phosphorus added as fertilizer to fairways.

Turf management options

There are several management practices that can reduce the probability that phosphorus will be transported from fairways to surface water. Most of these are just common sense. First, add less phosphorus. Use soil tests to determine the need for extra phosphorus.

In many cases, the soil will already be at medium or high levels so that added phosphorus is not necessary. Keeping the soil pH at reasonable levels at about 5.6 or above will help to make the phosphorus in the soil more available to the turf. Acid soil pH levels tend to make iron and aluminum more soluble, thus reacting with phosphorus and making it unavailable to the plants.

Following soil test recommendations may lead to less use of balanced fertilizers. If phosphorus is not needed, then an unbalanced fertilizer with no phosphorus would be preferred. Another practice that should be followed is to add fertilizer when the soil is not saturated with water or near saturation. If the soil is relatively dry, rainfall will not be as likely to runoff as it is if the soil is very moist.

Of course, it makes sense not to fertilize if rainfall is imminent. Letting the fertilizer have a few days to react with the soil should cut down on runoff loses. If fact, this is the next aspect of management that we will be addressing in our runoff trials — that of letting giving some time between fertilizer application and the rainfall events. We also will try adding about 0.25 inch of water to wash the fertilizer into the soil. This is a practice that turf managers would be wise to follow so that the fertilizer is in contact with the soil and not sitting on the verdure or the thatch layer. If it is not in contact with the soil, it may be carried off in runoff water as fertilizer granules, dissolving in the water.

Using controlled-release fertilizers may help to reduce runoff losses, but our data show little difference between regular agricultural and slow-release sources. There is a difference between these types for leaching, but not for runoff. Lower rates of phosphorus will help, so adding it at low amounts more often through the year is better than putting on a one- or two-year supply at one time.

Avoid nontarget areas such as cart paths, roadways and other hard surfaces. Fertilizers placed there usually wash directly into storm sewers and surface water. This may mean using drop spreaders instead of cyclone or large truck spreaders. Finally, if you have ponds or streams on your course, test the water for phosphorus (and nitrate) on a regular basis to monitor changes that may be caused by fertilizer applications. If increases are found after applications, better management practices may be necessary.

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Pesticide fate in turfgrass

By Dr. David Gardner

Although there are many advantages to maintaining a stand of turfgrass, serious questions have been posed in recent years concerning the use of certain synthetic fertilizers and pesticides that have been implicated as potentially harmful to the environment. Although turfgrass management accounts for a very small percentage of total pesticide usage, it is a very intensely managed system.

Turfgrass is unique in that, except at establishment, pesticides are applied directly to the plant material. Pesticide not intercepted by the plants is instead deposited in the thatch or mat (Branham, 1994). Thatch contains high amounts of organic matter and is defined as a layer of intermingled plant material that is living or in various stages of decomposition and it lies between the green vegetation and the soil surface (Beard, 1973).

After a pesticide has been applied to a turfgrass system, it is subject to numerous biological, chemical and physical processes that will determine its fate. Many of these processes interact, complicating our ability to predict or understand pesticide fate. The study of pesticide fate is also complicated by the wide array of chemicals used on turfgrass because each pesticide is unique. Differences in soil type and climate will also affect pesticide fate.

Several processes affect the environmental fate of pesticides including volatilization, uptake of the material by turfgrass or target weeds, photolysis (degradation by sunlight) and chemical degradation. However, sorption of the pesticide to soil particles or organic matter, leaching of the material through the soil profile or runoff and degradation of the compound by soil-borne microbes are the processes most important when considering pesticide fate in a turfgrass system.

How sorption works

"Sorption" is a term used to refer to both absorption and adsorption. Absorption is the transfer of material between phases, such as a plant root and the soil solution (Kenna, 1995). Adsorption refers to the concentration of a solution component at an interface. The extent to which a pesticide is sorbed greatly influences other fate processes by determining the amount of time the pesticide is available in the soil water system and thus subject to those processes (Branham, 1994). Sorption of pesticides is controlled by pesticide properties, as well as soil properties.

Pesticide properties that influence sorption include the water solubility of the compound, its polarity, and potential to become ionized in solution. Pesticides in the soil solution can occur as cations, anions or neutral molecules. Soil particles occur predominately as negatively charged species. Thus, soils attract positively charged species and repel negatively charged species including pesticides that occur as anions, e.g. 2, 4-D. As a result, 2, 4-D is considered among the most mobile of turfgrass pesticides in the soil (Gold et al., 1988).

Pesticide properties that influence sorption include the water solubility of the compound, its polarity and potential to become ionized in solution.

Measuring potential to leach

A 1988 EPA report stated that Koc values (a constant used to describe the tendency of a pesticide to sorb to organic carbon) lower than 300 to 500 or water solubilities higher than 30 ppm indicate a particular pesticide has the potential to leach (Kenna, 1995). It is important to note that there is a wide range of reported Koc values and water solubilities for pesticides used in turfgrass (Table 1).

However, in addition to water solubility and Koc, it is necessary to consider all of the properties of a particular pesticide and how they will influence pesticide fate. As previously mentioned, 2, 4-D exists in soil as a highly water-soluble anion. It is not adsorbed to soil organic matter to any great extent in the pH range found in turfgrass soils.

But, 2, 4-D and other phenoxy herbicides are quickly broken down by photolysis and

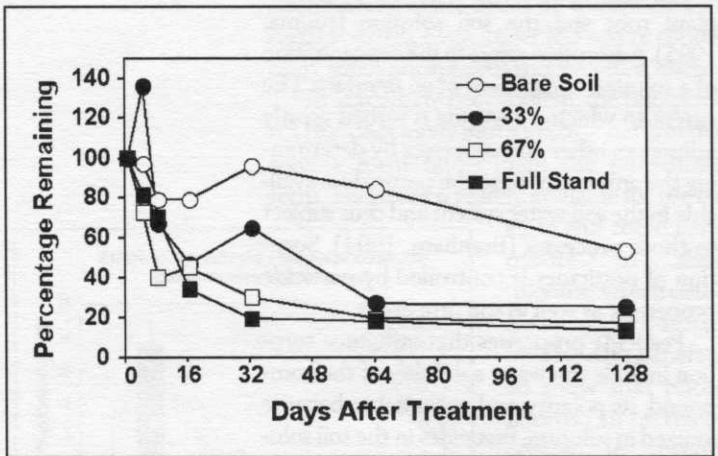

Figure 1. Percentage of cyproconazole residues remaining in each soil treatment as a function of sampling time in 1997.

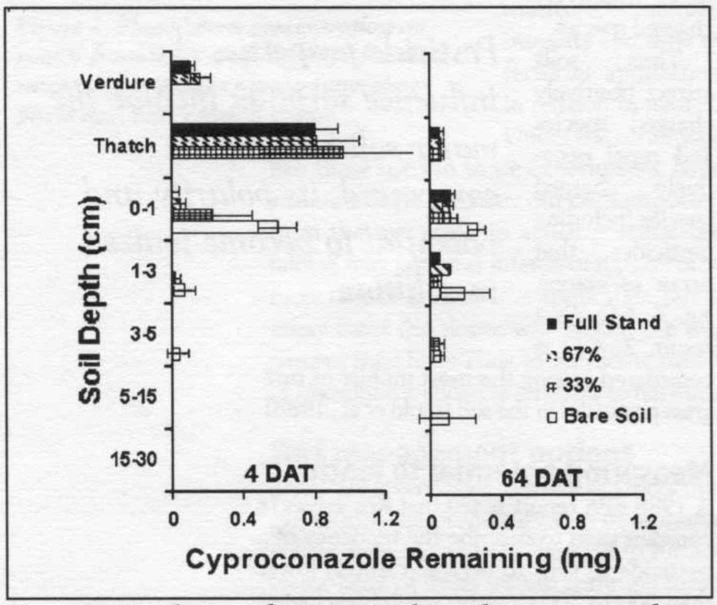

Figure 2. Distribution of cyproconazole residues among verdure, thatch and different soil depths 4 and 64 days after application (DAT). Horizontal bars represent standard error of the means.

are easily metabolized by soil microorganisms. In fact, few studies indicate that 2, 4-D has been detected to a significant extent in groundwater (Branham, 1994). Glyphosate is highly water soluble, indicating a high potential to leach. However, it has a high Koc, and is tightly sorbed to soil after application.

There is an increasing amount of literature that demonstrates the ability of thatch to retain or retard the movement of most pesticides (Branham, 1994). Research conducted by Niemczyk et al. (1988) demonstrated that turfgrass thatch strongly sorbed three commonly used insecticides.

Similar results were found in studies conducted with turfgrass fungicides (Dell et al., 1994). Stahnke et al. (1991) found that most applied pendimethalin remained in the plant tissue and thatch, and none was detected below 30 cm in the soil. Traces of pendimethalin found in leachate after heavy rainfall were attributed to gravitational displacement of soil colloids that contained adsorbed herbicide (Stahnke et al., 1991).

Leaching and runoff

Leaching and runoff of pesticides might be considered the opposite of sorption to thatch or soil. The potential for runoff and leaching of pesticides from turfgrass areas is of environmental concern (Balogh and Anderson, 1992). Leaching of pesticides through a turfgrass system is a complex process that is highly variable due to differences in soil organic matter and turfgrass cover between sites.

However, it has been suggested that pesticides are less mobile in turfgrass than in agronomic soils and this decrease in pesticide mobility is due to retention by the thatch layer. Also, the grass plants can influence pesticide fate by directly absorbing applied pesticides or they can affect the potential leachability of a pesticide by altering the flow of water in the root zone (Kenna, 1995).

Turfgrasses have extensive, fibrous root systems dominating the upper 200 to 300 mm of the soil profile, and when combined with very dense above-ground plant growth reduces runoff and allows time for infiltration of water into soil (Beard and Green, 1994).

It would be logical to assume that irrigation practices and rainfall events would have a major impact on leaching of pesticides. However, in turfgrass the effect of post application irrigation on mobility and dissipation of pesticides has received some attention and the results of these studies are conflicting.

Niemczyk and Krueger (1987) studied movement of isazofos as affected by various irrigation regimes consisting of 10.2 L m-2 applied immediately or 8, 24 and 36 hours after treatment. Regardless of timing, 96 percent to 99 percent of detectable residues were recovered in the thatch. The authors concluded that post treatment irrigation had little effect on insecticide movement to the soil.

Similarly, Cisar and Snyder (1996) found less than 0.1 percent of applied organophosphate insecticides in percolate water under a United States Golf Association (USGA) putting green, despite substantial variations in rainfall and total percolation. However, Niemczyk and Krause (1994) found that the mobility of pre-emergence herbicides such as pendimethalin was correlated to major rainfall events that occurred prior to sampling.

Microbial degradation

Microbial degradation is the primary process by which most pesticides are removed from soil (Wagenet and Rao, 1985). The amount of time that it takes for dissipative processes to reduce pesticide concentrations by 50 percent is called a half-life, expressed in days.

Several processes influence the rate of pesticide degradation including soil moisture, temperature, soil pH and soil mineral composition. As a result, the half-life of a given pesticide can vary considerably under different environmental conditions. Pesticides with longer half-lives are a greater threat to leach or runoff than those with short half-lives.

Generally, if the half-life of a pesticide exceeds 21 days, it is more likely that this compound will persist for a long enough time to pose a contamination risk (Kenna, 1995).

There is evidence that pesticides persist for shorter periods of time in thatch compared to soil. Mancino et al. (1993) found 40 to 1600 times as many bacteria, 500 to 600 times as many fungi, and up to 1000 times as many actinomycetes in thatch compared to soil. These organisms provide a very active system for the degradation of trapped organic chemicals and pesticides.

Horst et al. (1996) found that the half-lives of metalaxyl, pendimethalin, chlorpyrifos and isazofos applied to turfgrass were 16, 12, 10 and 7 days, respectively. This compares to published soil half-life data of 70, 34, 30 and 90 days, respectively.

Pesticide fate studies at Illinois

Regulators are using pesticide fate models when they assess pesticide exposure risk. These computer models can predict pesticide mobility and dissipation rates but they were intended for use in bare soil agronomic environments that include tillage.

A major weakness of using such models in a turfgrass environment is that they do not account for the high levels of organic carbon found in the turfgrass thatch layer. As a result, agronomic models may overestimate the amount of pesticide that is leached when applied to a turfgrass environment. Also, soil half-life data may not agree with half-lives observed in turfgrass. Therefore, the use of half-life data from soil studies may result in overestimating the leaching potential of pesticides applied to turfgrass.

Before 1985, little research had been conducted on the fate of pesticides applied to turfgrass. Recent research suggests that the mobility of pesticides applied to turfgrass is lower than in agronomic soils and that dissipation rates are faster when pesticides are applied to turfgrass than when applied to soil. While studies investigated the fate of pesticides applied to turfgrass, few attempts were made to directly compare the amount of organic carbon associated with thatch to pesticide mobility and dissipation rates.

The purpose of this research was to directly compare the fate of pesticides applied to turfgrass or bare soil. Cyproconazole was the active ingredient in Sentinel fungicide and has properties indicating the potential for some leaching through the turfgrass-soil profile. It is highly persistent, with a half-life of about 90 days in agricultural soils (Anonymous, 1991). It was introduced for use on turfgrass in 1994 but voluntarily removed by the manufacturer in 1999 due to concerns raised by the Food Quality Protection Act.

Plots were prepared that had either creeping bentgrass mowed at one-half inch or bare soil. The bare soil plots were prepared by stripping away the bentgrass with a sod cutter. Other plots with amounts of creeping bentgrass intermediate of the full stand and bare soil were prepared with a vertical mower. A hydraulic press mounted on a tractor was used to push sampling cylinders into

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the bentgrass and bare soil plots. The sampling cylinders were sections of PVC pipe.

The plots were sprayed with Sentinel at its maximum label rate. After two hours, a sampling cylinder was removed from each of the plots. The cylinder was cut open to reveal the intact soil core. The core was divided into sections (green leaf tissue, thatch and the 0 to 1; 1 to 3-; 3 to 5-; 5 to 15-; and 15 to 30- cm soil depths). Any pesticide present in the core sections was extracted and quantified. This allowed for the determination of how far the pesticide had leached and how much of the original amount applied was left. Other soil cores were removed and tested for pesticide residues at 4, 8, 16, 32, 64 and 128 days.

A major weakness of using current pesticide fate models in a turfgrass environment is that they do not account for the high levels of organic carbon that are found in the turfgrass thatch layer.

The most interesting results were the differences in pesticide persistence on creeping bentgrass. Figure 1 shows the percentage of cyproconazole remaining in each treatment. In the plots containing 33 percent, 67 percent or a full stand of bentgrass, half of the cyproconazole dissipated in 8 to 15 days. On day 128, the cyproconazole detected in the bentgrass plots was less than 20 percent of what was originally detected two hours after application (Gardner et al., 2000). But the half-life of the same product applied to bare soil was about 128 days. Why the difference?

When a pesticide is applied to turfgrass it may, depending on its characteristics, become bound to the thatch. The thatch contains a rich flora of microorganisms that break down the pesticide. These microorganisms also exist in soil, but thatch tends to contain much higher populations. Remember, degradation of pesticides by microorganisms is one of the most important avenues of pesticide fate.

The other important aspect of this research was to study the extent of leaching of the pesticide. Figure 2 shows the soil distributions of cyproconazole in the different plots 4 and 64 days after application. The horizontal bars denote the standard error. If two standard error bars overlap, then statistically, these plots are considered to have similar levels of pesticide residues. For example, the 33 percent, 67 percent and full stand plots had similar levels of cyproconazole on days 4 and 64. But on day 4, the amount detected in bare soil in the 0 to 1-cm section was different than that detected in the 33 percent, 67 percent and full stand plots.

Note the amount of cyproconazole in the soil under a full stand of creeping bentgrass was only about 1 percent of that observed in bare soil 4 days after application (Figure 2). This increased to just 11 percent by 32 days after application (Gardner et al., 2000). Remember, the pesticide had a half-life in bentgrass of 8 to15 days. Samples collected on day 32 showed only 4 half-lives of 8 days to 2

TABLE 1:

COMMON PESTICIDES USED IN TURFGRASS ALONG WITH REPORTED WATER SOLUBILITIES AND SOIL KOC VALUES

Common Name	Type	Water Solubility (PPM)	Soil Adsorption K_{oc}
Mancozeb	Fungicide	0.5†	2,000
Chlorpyrifos	Insecticide	0.4-4.8	2,500-14,800
Bensulide	Herbicide	5.6-25	740-10,000
Propiconazole	Fungicide	100-110	390-1,100
Dicamba	Herbicide	4,500-8,000	0.4-4.4
Glyphosate	Herbicide	12,000	24,000
Trichlorfon	Insecticide	12,000-154,000	2-6
Fosetyl Al	Fungicide	120,000	20
2, 4-D amine	Herbicide	2,000,000-3,000,000	0.1-136

† PESTICIDE PROPERTIES SUMMARIZED FROM INFORMATION PRESENTED IN BALOGH AND ANDERSON (1992).

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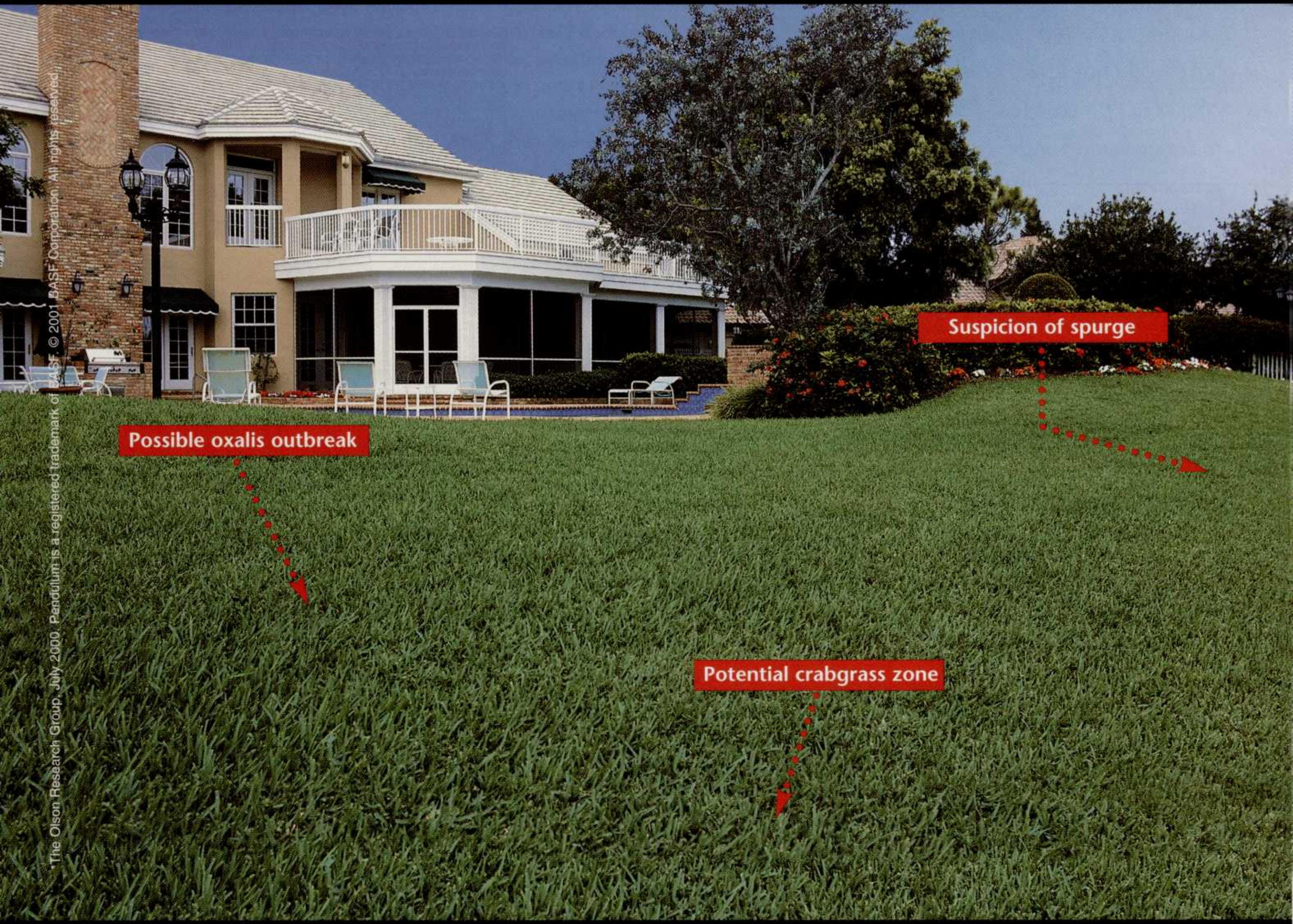

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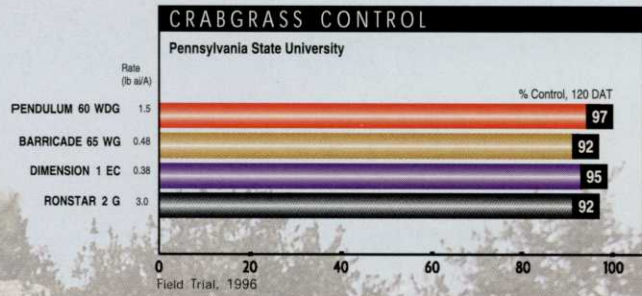

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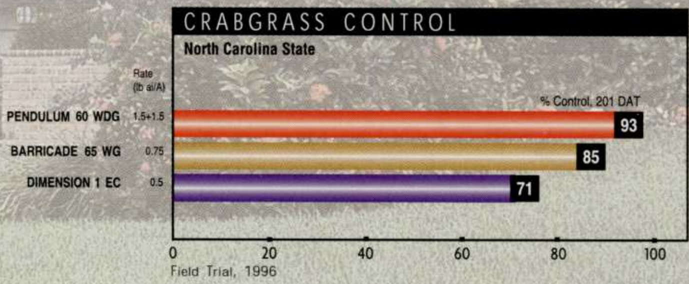

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half-lives of 15 days of the pesticide originally applied remained on the plots.

By day 64, cyproconazole applied to bare soil was detected in the 1 to 3-, 3 to 5- and 5 to 15-cm soil sections. Cyproconazole still was not detected below the 1 to 3-cm soil section in a full stand of creeping bentgrass. In other words, not much of the pesticide leached past the thatch layer and into the soil when it was applied to creeping bentgrass.

Summary

It is important to avoid drawing conclusions from the results of a single study. There are limitations to these studies that preclude making recommendations based solely on the data. First, our studies and others were conducted on one site during one year. Different locations with different soil types or conditions could affect leaching and dissipation rates. Second, the studies investigated the fate of the primary compound only. We do not know what happened to the breakdown products or if they pose more or less of a threat to the environment.

Pesticide properties influence the effect thatch has on their leaching and dissipation rates. Some behave the same in turfgrass as they do in bare soil, but many pesticides behave differently when applied to turfgrass. For the most part, pesticides applied to turfgrass do not persist or leach as much as they do when applied to bare soil.

Research continues today using computers and knowledge of pesticide behavior and soil physics to predict pesticide fate. Based on what we learned so far, the use of certain pesticides may not pose as much of a threat to the environment as was once feared. However, responsible management practices and proper usage always will continue to be important.

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REFERENCES

Anonymous. 1991. Cyproconazole, A1032/Aug. 91. The Agrochemicals Handbook. The Royal Society of Chemistry. Cambridge, England.

Balogh, J. C., and J. L. Anderson. 1992. Environmental impacts of turfgrass pesticides. In J. C. Balogh and W. J. Walker (ed.) Golf course management and construction: Environmental issues. Lewis Publ., Boca Raton, FL.

Beard, J. B., and R. L. Green. 1994. The role of turfgrasses in environmental protection andtheir benefits to humans. J. Environ. Qual. 23:452-460.

Beard, J. B. 1973. Turfgrass: Science and culture. Prentice-Hall, Inc., Englewood Cliffs, NJ.

Branham, B. E. 1994. Herbicide Fate in Turf. p. 109-151. In Turf weeds and their control. American Society of Agronomy and Crop Science Society of America, Madison, WI.

Cisar, J. L. and G. H. Snyder. 1996. Mobility and persistence of pesticides applied to a USGA green. III: Organophosphate recovery in clippings, thatch, soil, and percolate. Crop Sci.36:1433-1438.

Dell, C. J., C. S. Throssell, M. Bischoff, and R. F. Turco. 1994. Estimation of sorption coefficients for fungicides in soil and turfgrass thatch. J. Environ. Qual. 23:92-96.

Gardner, D. S., B. E. Branham, and D. L. Lickfeldt. 2000. Effect of turfgrass on leaching and dissipation of cyproconazole. Crop Sci. 40:1333-1339.

Gold, A. J., T. G. Morton, W. M. Sullivan, and J. McClory. 1988. Leaching of 2, 4-D and Dicamba from home lawns. Water, Air, and Soil Pollution. 37:121-129.

Horst, G. L., P. J. Shea, N. Christians, D. R. Miller, C. Stuefer-Powell, and S. K. Starrett. 1996. Pesticide dissipation under golf course fairway conditions. Crop Sci. 36:362-370.

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

Mancino, C. F., M. Barakat, and A. Maricic. 1993. Soil and thatch microbial populations in an 80% sand:20 % peat creeping bentgrass putting green. Hortsci. 28(3):189-191.

Niemczyk, H. D. and A. Krause. 1994. Behaviour and mobility of pre-emergence herbicides in turfgrass: A field study. J. Environ Sci. Health. B29(3):507-539.

Niemczyk, H. D., Z. Filary, and H. Krueger. 1988. Movement of insecticides residues in turfgrass thatch and soil. Golf Course Management. February. p. 22-23.

Stahnke, G. K., P. J. Shea, D. R. Tupy, and R. N. Stougaard. 1991. Pendimethalin dissipation in Kentucky bluegrass turf. Weed Sci. 39:97-103.

Reusing clippings to improve turfgrass health and performance

By Janet Hartin, Mike Henry and Ali Harivandi, Ph.D.
University of California Cooperative Extension

Many states have passed waste diversion acts. California's Integrated Waste Management Act, enacted from Assembly Bill 939 legislation, mandates a 50 percent diversion of landfill wastes that each county and city generates by the end of the year 2000, based on 1990 levels. If such legislation has not yet hit your state, be assured it likely will be under consideration soon.

Grasscycling, composting and mulching offer valuable alternatives to depositing grass clippings in landfills, and promote the growth of healthy landscape plants. Studies indicate that an average California lawn generates 300 to 400 pounds of grass clippings per 1,000 square feet annually, which equates to as much as eight tons per acre each year.

Grass clippings historically have comprised half of the yard trimmings deposited in California landfills, and yard trimmings make up the largest single component of California's municipal waste. The situation is likely to be similar elsewhere.

Grasscycling

In grasscycling, clippings are simply left on the turf area as it is mowed to decompose, rather than bagged.

Grasscycling is an excellent method of recycling a valuable organic resource in lawns and large public and commercial turfgrass plantings such as parks, cemeteries, school grounds and portions of golf courses.

In situations where prolonged wet weather, mechanical breakdown of mowers, or infrequent mowing result in large amounts of clippings, the cut turfgrass should be bagged and composted or dried for use as mulch. Besides diverting organic matter from landfills, grasscycling supplies valuable organic material and nutrients to the soil.

Grass clippings decompose quickly. They typically contain about four percent nitrogen, 0.5 percent phosphorus, and two percent potassium, which reduce fertilizer requirements by approximately 20 percent. Grasscycling also reduces mowing time and disposal costs.

TABLE 1:

RECOMMENDED TURFGRASS MOWING HEIGHTS

Turfgrass Type	Mower Setting (inches)	Mow When Grass Reaches This Height(inches)
Bermudagrass (common)	1 to 1-1/2	1-1/2 to 2-1/4
Bermudagrass (hybrid)	1/2 to 1 inch	3/4 to 1-1/2
Buffalograss	1 to 2	1-1/2 to 3
Kentucky Bluegrass	1-1/2 to 2-1/2	2-1/4 to 3-3/4
Kikuyugrass	1 to 1-1/2	1-1/2 to 2-1/4
Perennial Ryegrass	1-1/2 to 2-1/2	2-1/4 to 3-3/4
St. Augustinegrass	1 to 2	1-1/2 to 3
Tall Fescue	1-1/2 to 3	2-1/4 to 4-1/2
Zoysiagrass	1/2 to 1-1/2	3/4 to 2-1/4

Golf course putting greens, sod farms, and major league sports fields are not as adapted to grasscycling due to their requirements for exceptionally uniform playing surfaces.

Mowing basics

It is often usually necessary to mow at least weekly during the active growing season when grasscycling to avoid a build-up of excess clippings. Turfgrass that is not cut frequently enough when grasscycling may produce a "hay-like" look that can be unsightly. Maintaining turfgrass at the recommended mowing height is also important. Follow the 1/3 rule; mow often enough so that no more than one-third of the length of the grass blade needs to be removed during any single mowing. This allows short clippings to work their way through the canopy to decompose, without covering the surface.

It is important to use sharp mower blades and mow when the surface is dry. Table 1 lists recommended mowing heights for several species of turfgrass. Studies have shown that there are benefits to maintaining a relatively high mowing height to encourage the development of deeper roots, which can improve drought resistance and reduce stress. (See Table 1)

Options for mowing

Many types of mowers adapt to grasscycling. Mowers with a safety flap covering the opening where the bag fits into the chute offer the option of simply removing the bag. Mowers without a flap, or a plug for the chute, may be adapted to retrofitting. Contact a reputable dealer to inquire about the availability of purchasing a retrofit kit.

Major lawnmower manufacturers now offer mulching or recycling mowers which cut grass blades into small pieces before reapplying them to the turfgrass. Horsepower rating is very important when purchasing a mulching mower; a model supplying at least 4 or 5-hp is recommended. Convertible mulching mowers should have blades that can conveniently be changed. Otherwise, they may end up being used for only one purpose, defeating its intended dual use. Studies indicate that seasonal mowing time can be reduced by 50 percent or more when mulching or recycling mowers are used compared to conventional bagging and disposal operations. Additionally, the potential for back strains and injuries is reduced, which can equate to significant savings on health care costs and workers compensation.

In some cases, grasscycling is not appropriate. Examples are instances when the grass is too wet or when it has not been regularly mowed and is too tall. Options such as composting and mulching are viable alternatives to grasscycling in these cases.

Role of thatch

Thatch is comprised of lignin-containing roots, stems, rhizomes, crowns and stolons, and decomposes relatively slowly.

Since turfgrass clippings are approximately 80 percent water and contain only small amounts of lignin, they decompose rapidly. Research conducted in California indicates that grasscycling only slightly increases the amount of thatch buildup, and the benefits outweigh the disadvantages in most situations.

Bermudagrass, Kentucky bluegrass and kikuyugrass produce more thatch than most other turfgrasses, and require regular dethatching whether the site is grasscycled or not. A one-half inch layer of thatch provides insulation to roots, reduces soil water evaporation, cushions playing surfaces, and may prevent soil compaction.

Fertilization

Proper fertilization is important to insure healthy, safe turfgrass sites. Over-fertilization should be avoided to prevent excessive shoot growth and weak turfgrass, and the need for frequent mowing.

For moderate, even growth, a combination of fast acting fertilizers (ammonium nitrate, ammonium sulfate, or urea) and slow release nitrogen sources (sulfur-coated urea, urea formaldehyde, IBDU and organic materials) should be used.

While turfgrasses differ in their fertility requirements, it is usually better for the grass and the environment to apply smaller quantities of fertilizer more frequently, concentrating on the active growing season, rather than applying larger amounts less often.

Grasscycling supplies about 20 percent of the fertilizer requirements of most turfgrasses.

Irrigation's impact

Correctly irrigating is always a high priority when maintaining turfgrass plantings, but is particularly important when grasscycling. Applying too much water is wasteful and can increase growth, requiring more frequent mowing. Not applying enough water may lead to unhealthy, slow-growing grass vulnerable to disease and insect pests. In general, deep irrigation leads to deep root systems, which increases drought resistance and reduces stress.

Turfgrasses vary in their need for water. Warm-season turfgrasses (Bermudagrass, zoysiagrass, buffalograss, and St. Augustinegrass) are more drought resistant than cool-season turfgrasses (tall fescue, bluegrass, annual and perennial ryegrass) and require about 20 percent less water.

There is an increasing amount of literature that demonstrates the ability of thatch to retain or retard the movement of most pesticides.

Irrigating according to a local weather station network using ETo (reference evapotranspiration) can be a highly effective method of reducing water waste and improving turfgrass health and performance Irrigating until runoff just begins is the preferred length of an individual irrigation. In cases where soil has a slow infiltration rate or the irrigation precipitation rate is high, water cycling is necessary. To accomplish cycling effectively, irrigate until runoff just begins, turn the system off, and repeat the process in 10 or 15 minutes before the soil surface dries out.

To determine the precipitation rate, conduct 'can tests' by setting out small, empty straight-sided containers every 10 to 15 feet between sprinkler heads irrigated by the same valve, and run the system for 15 minutes. There are a wide array of cans that work well for this purpose, including clean empty tuna and cat food cans. (If cups or other non-straight sided cans are used, volumetric measurements need to be taken, which increases the amount of time required for this task.)

Measure the amount of water in each can with a ruler, and determine the average amount of water per can. Multiply this average by four to determine the precipitation rate per hour. Conducting 'can tests' regularly is useful for determining how evenly irrigation water is distributed over the area (distribution uniformity), allowing sprinkler head misalignments and other mechanical problems to be corrected. The best time to irrigate is early in the morning, because less water is lost to evaporation, and water pressure is at its peak. Irrigating in the afternoon is wasteful due to high evaporation rates, and prolonged damp conditions in the evening may encourage disease development.

Benefit to composting

Turfgrass clippings are an excellent addition to a compost pile. Since grass clippings contain higher levels of nitrogen than other organic landscape materials contain, they help balance the carbon to nitrogen (C:N) ratio. While tree leaves alone will decompose, leaves mixed with turfgrass clippings decompose faster and more completely.

Because turfgrass clippings are small and herbaceous, they will decompose readily and can be added 'as is' to a compost pile without further chopping or cutting. Grass clippings should not be composted alone; unfavorable conditions resulting from low levels of oxygen will develop. Large amounts of wet clippings should be dried before they are added to a compost pile.

There are numerous physical benefits derived from amending planting beds for annuals and perennials with compost, as long as the material is well decomposed and is mixed evenly and deeply into the soil. Studies show that established lawns may benefit from a shallow (less than 1/2 inch) layer of compost topdressing, applied four times

REFERENCES

California Environmental Protection Agency, Integrated Waste Management Board. 1996. Grasscycling: Send Your Grass Back to its Roots: Publication #500-94-007.

Harivandi, A. and V.A. Gibeault. 1999. Mowing Your Lawn and Grasscycling. UC DANR Leaflet 2587.

Harivandi, Ali, V.A. Gibeault, and Trevor O'Shaughnessy. 1996. Grasscycling in California, California Turfgrass Culture. Volume 46, Nos 1, and 2, 1996.

Hartin, J.S. and V.A. Gibeault. 1997. Maintaining Bermudagrass Athletic Fields in Los Angeles County. (UC Cooperative Extension Publication available from Los Angeles and San Bernardino County offices.

Hartin, J. S. Reusing Turfgrass Clippings. 1996. NorCal/San Bernardino, Inc., San Bernardino County Waste System Division publication.

Hartin, J.S., V.A. Gibeault and J.L. Meyer. 1995. Scheduling Turfgrass Irrigations. Turf Tales Magazine. Spring Issue.

a year. In addition to nutritional benefits, a light compost topdressing can improve soil microbial activity, aiding in soil aeration and overall health of the turfgrass planting.

Mulching methods

Dried turfgrass clippings applied as a mulch aid in weed control and prevent moisture loss in ornamental planting beds. While a three to four inch layer of mulch is necessary to reduce weed infestations, adding too much mulch prevents oxygen movement into the soil.

Mulches used around tree trunks should not come in contact with the trunk. Mulching with Bermudagrass clippings should be avoided due to its invasiveness, as should mulching with clippings receiving recent or regular herbicide applications. Turfgrass clippings should be thoroughly leached before being dried and used as mulch if questions exist pertaining to any chemicals that may have been applied.

Janet Hartin, Mike Henry and Ali Harivandi, Ph.D are all members of the University California's Cooperative Extension Service. They are located, respectively, at San Bernardino and Los Angeles Counties; Riverside and Orange Counties; and Alameda, Contra Costa, and Santa Clara Counties.

Letter to the Editor

DEAR EDITOR,

I subscribe to TurfGrass Trends *to try to stay current with the "state-of-the-art" in a variety of areas that influence turfgrass management practices. When I read the articles and commentaries by your scientific experts, I ascribe a high degree of credibility to their accuracy because I assume they are experts in their fields.*

I was shocked and disappointed, therefore, when I read Dr. Richard Hull's response to the question, "How efficient is foliar feeding?" in the July 2000 issue of TurfGrass Trends. *Not only is it neither clear nor accurate but it also ignores the current state-of-the-art in foliar technology. That's unfortunate.*

It's unfortunate for us because we manufacture true foliar fertilizers and micronutrients and it's "our ox that's being gored." It's unfortunate for you because it doesn't advance your reputation as a publication on the "cutting edge" of turfgrass technology and science. And it's unfortunate for those readers who are field practitioners and who might benefit from the appropriate use of true foliar materials but won't because of the impression created by Dr. Hull's answer to this question.

I would appreciate it if you would make some good faith attempt to present a more clear, accurate and balanced answer to the question "How efficient is foliar feeding?" in some future issues.

As a suggestion, it would be helpful to begin by defining what a true foliar fertilizer is. Liquids, water solubles and foliars are distinctly different. Most liquids and almost all water solubles are not foliars at all; they are designed for root uptake. They contain the same large macro molecules that granulars do but deliver them in a liquid or water soluble form.

True foliars are not designed for root uptake (although they can be taken-up by the roots). Rather, they are formulated to penetrate the leaf cuticle and be absorbed directly into the foliage of the plant. So while it is true that all foliars are liquids, it is not true that all liquids are foliars.

What defines a true foliar fertilizer is the size of the molecules. The size of the micropores in the surface of the leaf determines the size of the molecules that can penetrate the leaf. If the fertilizer molecules are too big, they can't penetrate. It's *like trying to stuff basketballs into holes the size of golf balls. So true foliars are formulated with molecular miniaturization in mind.*

True foliar fertilizers are designed specifically to overcome the inherent limitations of any root uptake dependent fertilizer (granular, liquid or water soluble). Their efficacy depends on such highly variable factors as soil moisture, microbiological activity and temperature.

In essence, true foliars are designed to bypass the root system to give the practitioner a degree of control over his or her fertility program that is available in no other way.

Sincerely,

William D. Middleton
President
Emerald Isle, Ltd./ Ann Arbor, MI

DEAR MR. MIDDLETON:

I am sorry you found my response to the question on the efficiency of foliar feeding disturbing (*TurfGrass Trends*, July 2000). I must admit that in responding to the question I was not thinking of sophisticated applications using materials specifically designed for foliar absorption.

Rather, I addressed my response to the claims made by some lawn care companies who argue their liquid fertilizer applications are superior to granular because they have the advantage of foliar uptake. I also was thinking of the turf manager who mixes common soluble fertilizer materials in solution and sprays it on turf in the belief that direct foliar application is somehow better than soil treatments.

I have no argument with what you say and I probably could have avoided some confusion by restricting my comments to the above situations. However, as a general rule, there is no way foliar applied materials can be as efficient as the same quantity of nutrient applied through the roots. The physics of nutrient penetration through a leaf cuticle, the cuticular efflux of water especially during daylight hours and the relatively high concentration of nutrient ions within the leaf cell walls all work against efficient foliar uptake. Add to this the limited redistribution potential of calcium and several micronutrients within a plant and the frequent partial defoliation inherent in turf management, and it becomes obvious why leaves are not the preferred route for nutrient acquisition. Given the high cost per pound of nutrient furnished as a foliar fertilizer, it is difficult for me to see any advantage of foliar fertilization over root feeding when there is nothing restricting root absorption.

However, as I believe I mentioned in my response, there are many situations in turf management when root function is restricted (nutrient fixing soils, dry soil, summer root decline, root predation by insects and cold soils) when a foliar application would not only be beneficial but the only practical way to apply nutrients. Because turf is managed so as to maintain constant vegetative growth (an unnatural condition for any perennial plant) there will be times when root function simply is not adequate. Thus, foliar feeding plays an important role in fine turf management and products, such as those marketed by Emerald Isle, very likely are much superior to ordinary fertilizers. The more intensively turf is managed, the more likely foliar feeding will play an important role in the fertilization strategy.

Thus, I do not believe we disagree on the basic issues of turfgrass fertilization and the role foliar fertilizers can play. It would be much appreciated if you, or someone in your company, could prepare an article for *TurfGrass Trends* on the new foliar fertilizers and supply data showing conditions when they are superior to normal root feeding. I have been unable to find much published information on these materials and I believe many readers, myself included, would find such an article extremely useful.

In any event, I hope this addresses your concerns.

Yours sincerely,

Dr. Richard Hull, University of Rhode Island

EPA requires diazinon phase out

Curt Harler
Managing Editor

By Curt Harler/Managing Editor

On December 5, 2000, the U.S. Environmental Protection Agency (EPA) announced a plan to phase out diazinon for all lawn, garden and turf uses by December 2003. The phase-out for indoor uses begins this March.

Anyone who got into this industry in the past couple of decades grew up with diazinon as a standard recommendation for control of insects and grubs. It is the most widely used pesticide by homeowners on lawns and is one of the most widely used ingredients for application around homes and gardens.

Diazinon is an organophosphate that is widely used on turf, agricultural crops and for residential control of various insects indoors and outdoors. Its manufacturers, Syngenta and Makhteshim Agan, agreed to a plan which will eliminate 75 percent of the use of the material which totals about 11 million pounds annually.

Syngenta (www.syngenta.com) is the result of the merger of Novartis and Zeneca Ag Products. The manufacturers say that doing the additional studies the EPA would require would go beyond revenues the product would provide.

Diazinon is probably the last widely-used chemical in its class to be taken off the market by the EPA. The Agency, citing health risks to children as its reason for the action, already removed several other materials in the same class from the market.

"The Clinton-Gore Administration continues to aggressively target for elimination those pesticides that pose the greatest risk to human health and the environment, and especially those posing the greatest risk to children," said former EPA Administrator Carol Browner in December.

"The action will significantly eliminate the vast majority of organophosphate insecticide products in and around the home, and by implementing this phase-out, it will help encourage consumers to move to safer pest control practice," she said.

For turf, lawn and garden uses, manufacturing stops June 2003. Sales and distribution to retailers ends August 2003. In addition, there will be a ratcheting-down for turf uses.

For more information, check www.epa.gov/pesticides.

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