loss occurred during the first simulated rainfall following pesticide application (2 in./hour). It appears that wherever soils and rainfall are heavy, turf managers must consider runoff as a route of pesticide loss and probable vehicle for surface water contamination.

Several turf researchers (Kenna 1995) noted that both leaching and runoff of pesticides applied to turf was significantly less than that predicted by models designed to estimate pesticide fluxes in agricultural cropping systems. This may indicate that the GUS values and SCS rankings cited in Table 1 overestimate pesticide transport rates from turf. If so, this is undoubtedly due to the greater intensity of metabolic activity in the thatch and soil of a turf-soil ecosystem. The generally higher organic content of soils under turf promotes increased microbial activity; and this in turn speeds the metabolism of pesticides and facilitates their degradation. As a result, the potential for pesticides escaping from turf and contaminating surface or ground water is probably below that of any other managed land use.

Dr. Richard J. Hull is a professor of Plant Science and Chairman of the Plant Sciences Department at the University of Rhode Island. He has degrees in agronomy and botany from the University of Rhode Island and the University of California at Davis. His research has concentrated on nutrient use efficiency and photosynthate partitioning in turfgrasses and woody ornamental plants. He teaches applied plant physiology and plant nutrition. His most recent *TurfGrass TRENDS* article was published in the June 1995 issue.

Erratum

On page 7 of the May 1995 issue of TurfGrass TRENDS, Metalaxyl was inadvertantly included in Table 3 as increasing the severity of red thread and Rhizoctonia diseases. Metalaxyl is not known to enhance these diseases. We regret the error.

Relationships among Soil Insects, Soil Insecticides, and Soil Physical Properties

by Michael G. Villani

Insecticides are applied to the soil for the control of Japanese beetle and other scarab grub species in areas where these pests damage the roots of turfgrass and landscape ornamentals. A noted chemist researching the use of insecticides for controlling soil insects once commented that, the more we learn about the interaction of the soil environment, insect behavior, and insecticide properties, the more we recognize it is a wonder that soil insecticides are ever effective in controlling insects.

Controlling soil insects in turfgrass is especially difficult because, in contrast to agricultural and garden uses, turf insecticides are not usually incorporated directly into the soil. We must rely on the movement of insecticide down into the soil where grubs are feeding to provide sufficient coverage for control.

Although many studies have been carried out to determine how specific insecticides act in the field, there is little information available on soil-insecticide-insect interactions that accurately predict insecticide performance in controlling this pest complex.

With this rather pessimistic starting point, I would like to discuss several reasons why soil insecticides should not be expected to kill white grubs in turfgrass and suggest how turfgrass managers might mitigate the impact of these factors, thereby increasing insecticide activity. Following this, I will present a case study undertaken by Dr. Rich Cowles (Connecticut Agricultural Research Station, New Haven) and myself in which we determined the impact of soil physical properties on the performance of several turfgrass insecticides labeled for use against Japanese beetle grubs. This study was carried out in several California soils.

Breakdown on foliage and surface

Insecticides deposited on grass blades and the soil surface are exposed to heat and ultra-violet radiation from the sun, which tend to decompose and deactivate them rapidly. Liquid insecticide must be washed off the grass blades, stems, and crowns before it has the opportunity to dry. Granular insecticide must also be watered soon after application to wash the active material off the carrier (clay or corn cob particles) and down to the lower thatch. For this reason, irrigation is essential for maximum soil insecticide activity against white grubs. If irrigation is not feasible, soil insecticides should be applied just before (or during) a predicted period of light, persistent rain.

As already discussed in some detail, the movement of pesticides into the ground water has been a matter of great concern. Research with turfgrass insecticides indicates that much of the active ingredient applied tends to become trapped in the thatch zone and thus does not move deep enough to reach grubs feeding at the thatch/soil interface. This has helped reduce fears that turfgrass insecticides cause significant groundwater problems; at the same time, however, it also makes grub control much more difficult.

Two major properties affect the movement of insecticides within the soil profile: water solubility and adsorption to organic matter.

Insecticides vary widely in their water solubility. The solubility of various turfgrass insecticides (technical grade) can be seen in Figure 1. Of the compounds recommended for grub control, trichlorfon (Dylox) has the highest solubility, while chlorpyrifos (Dursban) has the lowest. Solubility determines how rapidly insecticides are washed from turfgrass stems and blades, and from carrier particles. In general, in the absence of significant thatch accumulation, irrigation with at least 1/2 inch of water immediately after application should allow enough insecticide to penetrate into the upper root zone to insure adequate coverage of feeding grubs.

Thatch consists of decomposing grass blades and stems and other organic debris that accumulates between the soil surface and turfgrass foliage. Insecticides applied to turfgrass are absorbed by organic matter, preventing their movement to the soil surface. Because of their short residual activity (often less than one month), for modern soil insecticides to be effective they must move down through the thatch zone rapidly. In general, those insecticides that are least water soluble (chlorpyrifos, for example) have the greatest chance of being bound to thatch, while more soluble materials (trichlorfon, for example) are less affected. An exception to this general rule is bendiocarb (Turcam) which is relatively insoluble, but is less sensitive to thatch than are other, more soluble materials.

The propensity of turfgrass insecticides (technical grade) to bind with organic matter can be measured by determining the quantity of thatch required to bind a specified amount of insecticide. Figure 2 illustrates this. While high levels of soil organic matter or thatch will result in significant tie-up of any insecticide, chlorpyrifos has such a high affinity for organic matter that it is unsuitable for use as a grub control agent in organic soils.

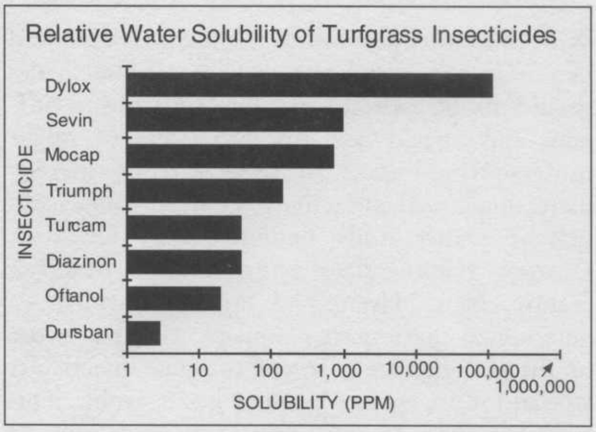

Figure 1. Relative solubility of turfgrass insecticides. Adapted from Tashiro 1987.

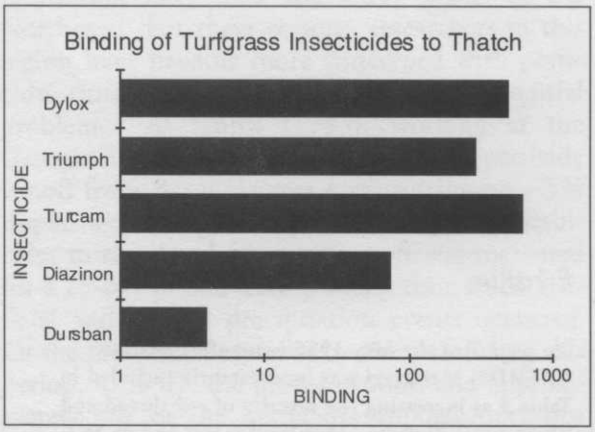

Figure 2. Binding affinity of turfgrass insecticides to thatch. Adapted from Niemczyk and Krueger. 1982.

Organic matter in soil also influences insecticide activity. Soils with organic matter levels greater than 5% can cause significant reductions in insecticide activity due to the chemical binding of insecticide molecules to soil organic matter.

Breakdown in soil

The physical and chemical components of a soil will also affect the longevity of soil insecticides. Most insecticides are extremely sensitive to high (basic or alkaline) pH. Trichlorfon (Dylox) will remain for several weeks in an acidic soil, for several days in a neutral soil, and only for several minutes in extremely basic soils. Most other grub insecticides are less sensitive to soil pH. For example, the impact of pH on the half-life (the length of time required for half of the insecticide to break down) of carbaryl (Sevin) can be seen in Figure 3. As pH increases, the insecticide decomposes much more rapidly (decreased half-life). Diazinon (Diazinon) is the only common turf insecticide that is acid-sensitive and will remain active for longer periods in slightly basic soils. High temperature, high levels of organic matter, and high clay content are other soil physical properties that tend to be associated with poor insecticide performance.

Soil is more than just a pile of dirt. Each cubic inch of soil contains millions of microscopic organisms that can break down insecticide molecules. Soils with large numbers of these microbes are termed 'aggressive,' due to the rapid rate at which some insecticides decompose in them. Although studies have suggested that a soil may be selectively aggressive (impact only a particular insecticide), other studies indicate that an aggressive soil may have the ability to break down a number of turf insecticides.

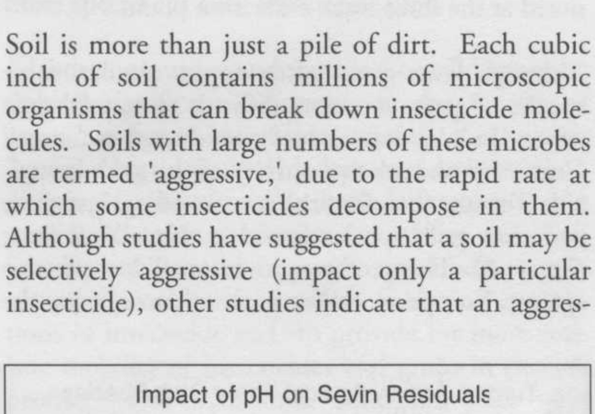

Figure 3. Relationship between pH and half-life of Sevin. Adapted from Tashiro et al. 1987.

Soil analysis for pH is the single most important tactic in reducing rapid soil insecticide decomposition. The testing of tank mixtures and irrigation water for pH levels will also reduce the chance of premature loss of insecticidal activity. Soil testing for percent organic matter and texture will also help predict if a site is predisposed to insecticide failure. There are no practical methods for deactivating an aggressive soil. Where a steady, persistent decline in a product's activity has been documented, the best alternative is to switch insecticides.

Environmental Factors

In general, insecticides are most effective at warmer temperatures. In turfgrass, this is due both to the activity of the insecticide and the activity of the insects. Improved performance of an insecticide in warmer soils can most often be traced to an increase in volatility (evolution of vapors) of the insecticide, which increases as soil temperature increases. Unfortunately, as volatilization increases, insecticide levels in the soil fall, thereby reducing the insecticide's residual impact.

Insects are cold-blooded animals. As such, their activity is directly related to the temperature at which they are living. Grubs tend to feed and move more at higher soil temperatures. Since the effectiveness of an insecticide depends in part upon the amount of toxin an insect ingests, and how much toxin is absorbed through their cuticle (skin), an actively moving and feeding grub will contact greater amounts of insecticide than will a cold, sluggish grub.

Due to the relative immobility and short residuals of modern insecticides, the location of grubs in the soil will in part determine how successful an insecticide application will be in controlling them. Research indicates that, under normal conditions, insecticides will not be found at lethal concentrations at soil depths greater than one inch (or less, depending upon thatch levels). Environmental conditions can cause some or all grubs to move below the critical one inch depth. For example, grubs will move down into the soil profile in mid- to late-fall to escape winter temperatures; they will not return to the root zone until the soil warms in the spring. Extreme summer drought can cause grubs to escape down into the soil, where cooler and wetter conditions are often found. Although grubs may move only an inch or two down into the soil to escape these dry conditions, that may take them deep enough to escape a toxic level of insecticide.

Biological factors also cause grubs to be found deeper in the soil than expected. At high densities (more than 80-100 large individuals per square foot), grubs tend to disperse in the soil, often over a depth of two to three inches. They do this to allow some space between themselves and neighboring grubs, since they bite and kill each other if they are packed too closely. Turf root growth, grub species and development stage, and soil compaction and texture all affect the vertical distribution of grubs in the soil, and indirectly, the effectiveness of grub insecticides.

Not all insecticides (or grubs) are created equal

Every soil insecticide has a characteristic lag period from application of the material to maximal mortality of the targeted insect. This may range from several days for trichlorfon to several weeks for a more slowly acting product such as bendiocarb. The presence of this characteristic lag period must be taken into account when choosing a grub insecticide. A fast-acting, short-residual product may not reduce grub populations to levels one expects from a longer-residual product. It also requires much greater care in timing the application to ensure eggs have hatched and young grubs are actively feeding at the thatch/soil interface. Such a product might be ideal for spot treatment of heavily infested turf, or alternatively, may be used on turf late in the fall or spring when persistence is not required, but rapid activity is. Conversely, a highly effective, long-residual, slower acting insecticide may be chosen when treating in late summer, when damage from small grubs will be minimal and increases in the grub population from unhatched eggs are possible. One should know the characteristic lag time for the various grub insecticides and use this information to help determine the most appropriate insecticide for grub control under specific management situations.

In an illustrative study, field rates of granular Turcam and Dylox were applied in early August to an irrigated golf course fairway in Syracuse, NY, that was infested with first instar Japanese beetle grubs (Figure 4). Grub counts were taken three, seven and twenty-one days after treatment to determine the specific lag time of these two products and the ultimate control achieved. Dylox provided greater initial grub reduction (three and seven days post-treatment) but short-residual activity curtailed overall grub mortality at twenty one days. By comparison, Turcam exhibited an extended lag time as seen in higher grub counts at three and seven days post-treatment. However, Turcam's longer residual activity resulted in continued grub reductions, as noted at the three-week evaluation point.

Although lawn grubs often appear similar, some species of grubs are more difficult to control than others. In a laboratory study conducted at Cornell University, the relative activity of the grub insecticide Turcam (bendiocarb) was tested against three common grub species found in New York State (Figure 5). This product proved much less effective against European chafer grubs than against the

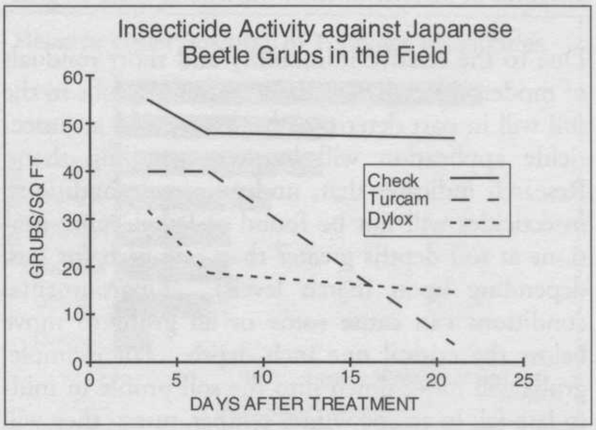

Figure 4. Field performance of Turcam and Dylox against Japanese beetle grubs. Villani, unpublished data 1992.

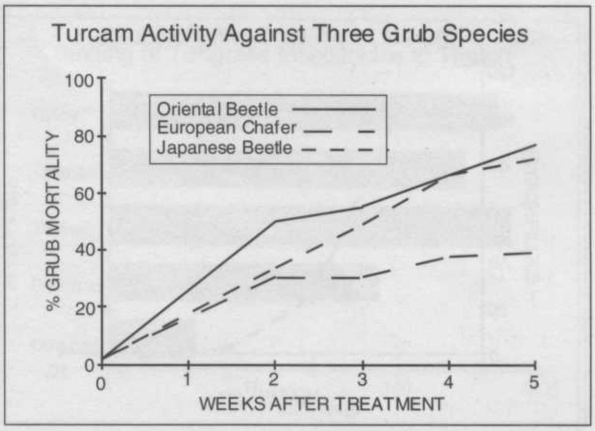

Figure 5. Relative activity of Turcam against three scarab grub species. Adapted from Villani and Wright. 1988.

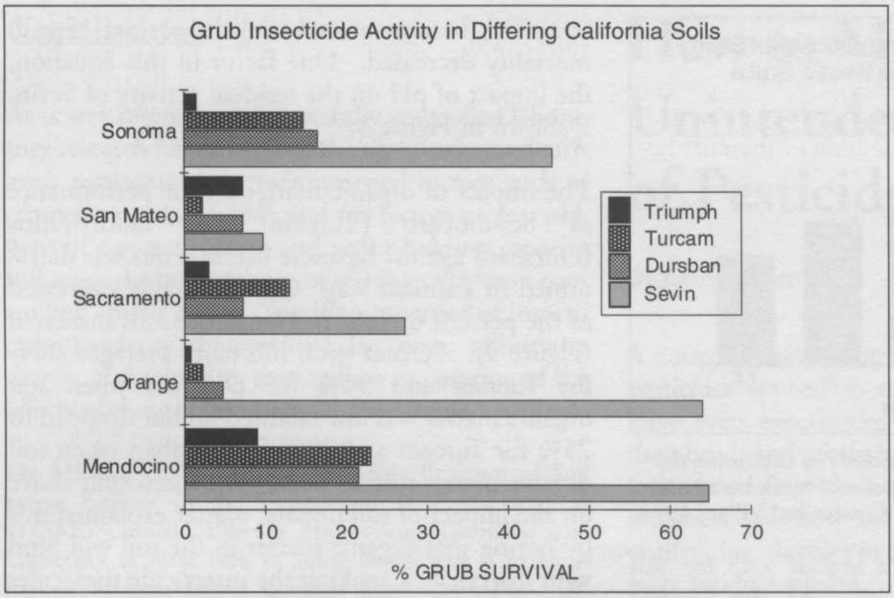

Figure 6. Results of Cornell University study that evaluated the performance of labeled turfgrass insecticides to control third instar Japanese beetle grubs in five California soils. Adapted from Cowles and Villani 1994.

other two grub species. Knowing which grub species you are dealing with will often lead to improved pest control. The rate of mortality for each grub species can also be measured, and is an indication of the specific lag time against each of those species for each insecticide used.

A laboratory study conducted at Cornell University showed significant differences in the activity of several turfgrass insecticides against third instar Japanese beetle grubs (14 days post-treatment) in differing California soils. Small laboratory arenas provided data on the interaction of five soils with four insecticides and a parasitic nematode. Larger arenas allowed us to simulate field-type applications of insecticide and to provide for more realistic mobility of insecticides and grubs in the soil profile. Five California collection sites were chosen, based on risk of Japanese beetle infestation. At all of these sites, turf, thatch, and weeds were scalped off the surface and shipped to the New York state Agricultural Experiment Station for soil analysis and grub bioassay. The Japanese beetle grubs were field-collected from a golf course rough in central New York.

Our initial evaluation of insecticide activity indicated that the various insecticides differed in activity across soil types. It also indicated that soil-related factors accounted for significant differences in activity of all insecticides from one soil to another. Figure 6 shows how three of these factors compared in each of the five soils.

Regardless of the soil in question, there were clear differences in the grub-controlling performance of the several insecticides. Triumph proved the most effective and Sevin the least effective in this particular study. Remember, an insecticide may not provide acceptable control of an insect pest, even where environmental conditions for insecticide performance are ideal. For all insecticides tested, however, grub survival was much poorer in some soils than in others. The performance of all insecticides in the Mendocino soil was generally poor; the performance of all in the San Mateo soil was significantly better.

Standard soil testing procedures were employed to help determine the contribution of specific soil properties to the differing activity of the insecticides in differing soils. The variables examined included soil pH, water holding capacity (soil with low water holding capacity tends to allow more rapid movement of water into the soil profile), and percent organic matter (Figure 7).

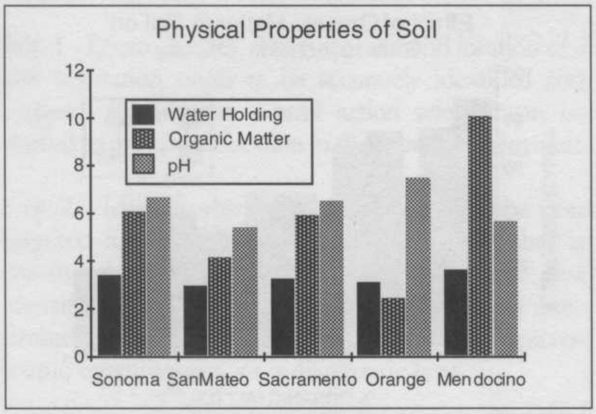

Figure 7. Determination of the water holding capacity, percent organic matter and pH of soils in California study. Adapted from Cowles and Villani 1994.

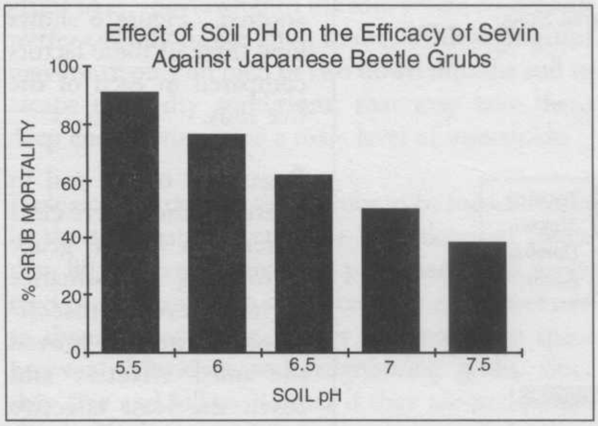

Figure 8. Results of regression analysis to determine the effect of soil pH on the performance of Sevin based on California study. Adapted from Cowles and Villani 1994.

Observed pH ranged from a low of 5.43 for San Mateo (acidic) to a high of 7.47 for Orange (neutral/basic). Water holding capacity ranged from a low of 2.98 for San Mateo to a high of 3.62 for Mendocino. Percent organic matter ranged from a low of 2.43 for Orange to a high of 10.07 for Mendocino.

Taken together, these variations help us begin to understand how specific soil properties can interact to cause performance differences in insecticides in field soils. It is also possible to determine how individual soil properties, taken separately, affected grub mortality and contributed to the overall performance of a given insecticide in a given soil.

An example is our determination of the impact of soil pH on the activity of Sevin (carbaryl) against Japanese beetle grubs (Figure 8). As soil pH increased (became more basic) the percent of grub mortality decreased. One factor in this equation, the impact of pH on the residual activity of Sevin, is shown in Figure 3.

The impact of organic matter on the performance of bendiocarb (Turcam) and chlorpyrifos (Dursban) against Japanese beetle grubs was determined In a similar way. Grub mortality decreased as the percent organic matter in the soils increased (Figure 9). Percent grub mortality averaged 96% for Turcam and 94% for Dursban when soil organic matter was low (about 3%) but dropped to 75% for Turcam and 80% for Dursban when soil organic matter rose to 10%. The discussion above on the impact of soil organic matter explained this by noting that organic matter in the soil will bind with insecticides, making the insecticide molecules unavailable for grub control.

The impact of two simulated irrigation regimes on the activity against Japanese beetle grubs of two turf-grass insecticides and an entomogenous nematode (S. glaseri) was also determined (Figure 10). In each treatment, grub mortality was higher at the higher irrigation level (1 in. equivalent) than in the lower irrigation regime (1/8 in. equivalent). Improved insecticide activity at the higher irrigation rate can be assumed to be the result of better overlap of insecticides and grubs — i.e., deeper penetration of insecticides — in the soil profile. This improved overlap can be due to increased movement of control agents down into the root zone, movement of grubs up to the thatch/soil interface, and increased grub feeding at the interface.

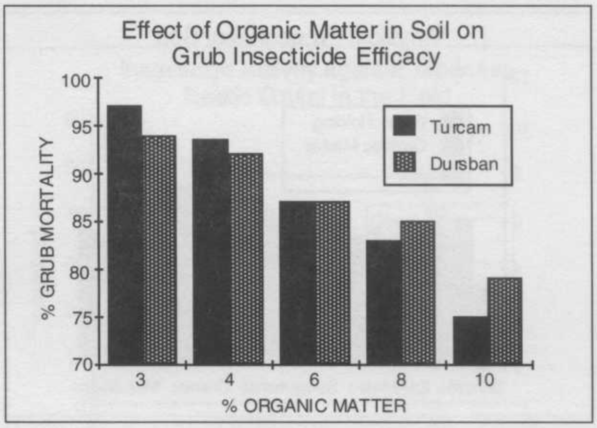

Figure 9. Results of regression analysis to determine the effect of soil organic matter content on the activity of Turcam and Dursban. Adapted from Cowles and Villani 1994.

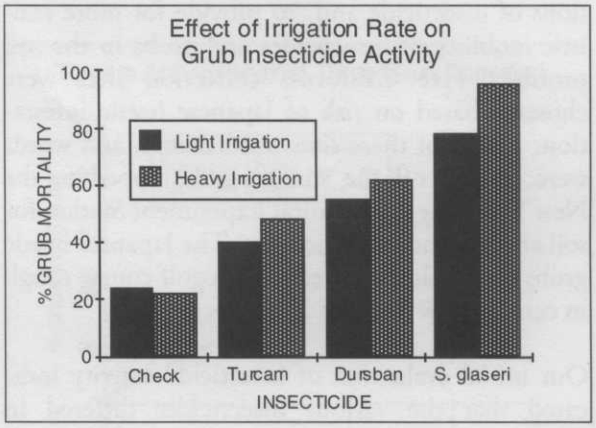

Figure 10. Impact of irrigation on the performance of turfgrass insecticides. Adapted from Cowles and Villani 1994.

Conclusions

As is very often the case, carefully controlled laboratory research has reinforced the observations of turfgrass managers that environmental factors such as temperature and rainfall, and soil factors such as pH, percent organic matter, and water holding capacity influence the performance of soil insecticides in controlling scarab grubs. Specific properties of insecticides, such as characteristic lag time, affinity to thatch, and solubility then reduce or compound the effects of these environmental conditions.

Dr. Michael G. Villani is an Associate Professor of Soil Insect Ecology in the Department of Entomology at NYSAES/Cornell University. He has degrees from the State University of New York at Stony Brook and -- in entomology -- from North Carolina State University. Dr. Villani, who is active in both research and extension work, concentrates on the interrelationships between soil insects, their host plants, and the soil environment. His most recent contribution to *TurfGrass TRENDS* appeared in the June 1995 issue.

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How to Minimize Unintended Movement of Pesticides

by Christopher Sann

A cursory examination of all the factors involved in pesticides applied to turfgrass moving off-site can leave even experienced turfgrass managers shaking their heads and muttering "Where do you start?" The task of deciding which pesticide to use, in what formulation, and how and when to apply it, is already challenging. It pales in comparison to having to consider product solubility, affinity for adsorption, persistence, vapor pressure, and runoff and leaching potential — not to mention site environment, host condition, topography, and soil characteristics.

The only way turfgrass managers can deal with all the data and processes in keeping pesticides from moving to undesired locations, is to develop and use a conscious decision-making process. The following discussion "walks" the reader through much of what must be considered. This framework can be used "as is," or modified to correspond to your needs.

No matter how this framework is configured, there are some universals that need to be addressed. These universals apply to decide on control action, regardless of whether or not movement off-site is a serious consideration.

Action 1 - Decide if control action is required

Step 1 - Locate the pest: The full extent and location of a pest infestation needs to be accurately identified and mapped, so that the control action selected can be applied to the proper location in the appropriate manner.

Step 2 - Identify the pest: Make sure that the pest targeted for your action is in fact the pest that is causing the problem. At sites where multiple pest identifications are likely, have your diagnosis confirmed by a "second opinion," by off-site microscopic examination, or a diagnostic lab.

Step 3 - Determine the development stage of the pest, then determine the growth stage of the insect or weed pest, or how far a disease has progressed.