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Developing Turfgrasses With Enhanced Insect Resistance

by Jennifer M. Johnson-Cicalese, Rutgers University

Great strides have been made in the development of improved turfgrasses. Turfgrass managers can now choose among many species and select an adapted cultivar with an attractive appearance, improved stress tolerance and resistance to some diseases. Improvements have also been made in resistance to insect pests, especially endophyte-enhanced resistance. This article will discuss how insect-resistant cultivars are developed and how turfgrass managers can use them.

How Insect-Resistant Cultivars are Developed

Turfgrass breeding is a young discipline with initial efforts focused primarily on improving quality. Now the emphasis has shifted towards stress tolerance, decreased maintenance needs, and improved disease and insect resistance. How does a plant breeder make these improvements to a grass cultivar? A number of methods are used, depending upon the grass species.

All breeding projects start with an extensive collection of plant material. If the goal is improving the summer stress tolerance of bentgrass, for example, then the breeder collects plants from old turfs that have been subjected to severe summer stress. This germplasm collection is then evaluated in turf plots and/or placed in crossing blocks. Seed is harvested from promising plants and the offspring are evaluated under summer stress. This cycle would be repeated for many generations until a population is developed which exhibits improved summer stress tolerance and good turf performance. This method,

Three Types of Insect Resistance

1) antixenosis (nonpreference)
2) antibiosis
3) tolerance

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called recurrent selection, has been successfully used to develop many new fescue, ryegrass, and now bentgrass cultivars.

Kentucky bluegrass, on the other hand, reproduces through apomixis, where seeds are produced asexually and offspring are genetically identical to the maternal parent. Because of apomixis, one superior plant can become a new cultivar, but production of hybrids and improvements are more difficult. With the warm-season grasses, superior clones are selected and then vegetatively reproduced. In recent years, projects to develop seeded cultivars of warm-season turfgrasses have also been initiated.

To develop a grass with insect resistance much the same methods would be used. Relatively few breeding projects, however, have had the specific goal of improving insect resistance. Instead, when natural insect infestations occur in cultivar evaluation trials, the trials are rated for insect damage. Cultivars that consistently show less damage are considered to have enhanced resistance to that pest.

Tables 1 and 2 list grasses and insect pests where differences in genetic resistance have been found. Each of these cases represents an opportunity to further improve resistance to turfgrass pests. In the warm-season grasses, no endophytic fungi have been discovered, so the resistance is due to the genetics of the grass plant. The cool-season grasses, on the other hand, have both genetic and endophyte-enhanced resistance. Table 2 shows examples of insect resistance due to the presence of endophytic fungi in the grass plant.

Working with insects presents a unique set of challenges to the turfgrass breeder. In our earlier example of improving summer stress tolerance, it was relatively easy to subject test plots to summer stress. However, natural insect infestations are unpredictable and unevenly distributed, making screening for resistance in the field difficult. Screening trials in caged plots, potted plants or laboratory dishes are used to help determine the insect resistance of grass selections. But each of these methods has its drawbacks. Insects must either be collected or reared, although with many insects there are no reliable rearing methods. Laboratory trials often do a poor job of simulating conditions in the field and results are sometimes misleading.

Once a grass is identified as having resistance to an insect, it can be used in developing a new cultivar. Thus, improvements can be made without understanding the mechanism of resistance.

However, because insects are difficult to work with it, it can be useful to learn what is causing the resistance. For example, we don't need to know why a chinch bug avoids a fescue plant in order to take advantage of that avoidance. But if we did know why, we could select plants with that characteristic and make improvements without having to work with the chinch bug. This is the case with endophyte-enhanced resistance, breeders can screen plants for the presence of endophytic fungi.

Scientists have classified three mechanisms, or types, of resistance: 1) antixenosis (or nonpreference) - the plant is not a suitable host; examples in grass include leaf blade being too narrow, plant color, or tough tissue; 2) antibiosis - the plant adversely affects the biology of the insect; such as poor digestibility, or the toxins associated with endophytes; and 3) tolerance - the plant can tolerate insect feeding without showing damage; usually due

Table 1. Examples of turfgrasses where differences in genetic resistance to insect pests have been found.

Warm-Season Grasses

Zoysiagrass -- tropical sod webworm, fall armyworm, Banks grass mite, zoysiagrass mite

St. Augustinegrass -- southern chinch bug, tropical sod webworm, Rhodesgrass mealybug

Bermudagrass -- tropical sod webworm, fall armyworm, southern and tawny mole crickets, bermudagrass scale, stunt mite, spittlebug

Buffalograss -- mealybug, eriophyid mite, chinch bug

Bahiagrass -- mole cricket

Cool-Season Grasses

Kentucky bluegrass -- billbug, hairy chinch bug, sod webworm, greenbug

Perennial ryegrass -- billbug, hairy chinch bug

Fescues -- hairy chinch bug

Creeping bentgrass -- sod webworm

to aggressiveness and ability to outgrow damage. Tolerance and endophyte-enhanced resistance are probably the most common mechanisms of resistance in turfgrass.

Genetic Insect Resistance

Turfgrass managers can select cultivars with either genetic or endophyte-enhanced resistance to insect pests. Following are a few examples of genetic resistance to insects.

Kentucky bluegrass and billbugs: The differences in susceptibility to billbugs among Kentucky bluegrass cultivars have been studied for a number of years. The larvae of several billbug species can do extensive damage to bluegrass, feeding on the crown and roots in mid to late summer. Studies in New Jersey and Nebraska have suggested a number of mechanisms of resistance, including females avoiding narrow-leafed cultivars for egglaying, tougher leaf tissue, and aggressive cultivars outgrowing damage. Recent trials suggest an association between resistance and heat and drought tolerance. As we learn more about this resistance it should be possible to make further improvements. In areas where billbugs are a problem, one of the resistant cultivars listed in Table 3 should be included in the seed mixture.

St. Augustinegrass and Southern chinch bugs: The Southern chinch bug does such extensive damage to St. Augustinegrass that a breeding project was initiated in Florida to identify resistant plants. In 1973, 'Floratam' was released as a resistant St. Augustinegrass and was widely planted in southern Florida. Laboratory studies showed that chinch bugs had reduced survival on resistant plants, indicating antibiosis. Unfortunately, a population of chinch bugs gradually developed that were able to survive on Floratam. A new cultivar, named FX10, has now been developed that is resistant to these chinch bugs.

Buffalograss and mealybugs: Buffalograss is a good example of a new turfgrass species that is filling a special niche of a low maintenance grass. Mealybugs, however, can cause severe damage to buffalograss. Differences in susceptibility had been observed in the field, so for my graduate work at the University of Nebraska, I chose to study this association. Many plant selections were screened by spreading infected clippings over potted plants and evaluating severity of infestation. Cultivars '609' and 'Prairie' were highly resistant and the resistance appeared to be correlated with a lack of leaf pubescence. We hypothesized that the pubescence provides a framework within which eggs are laid, or a foothold for young mealybugs. It may also catch a hold of wind-borne mealybugs, or hinder the movement of a parasitic wasp which attacks mealybugs. Unfortunately, northern adapted cultivars '315' and '378' are moderately susceptible.

Kentucky bluegrass and white grubs: Recent findings at Rutgers University show that Kentucky bluegrass cultivars vary significantly in their summer stress tolerance. Root mass measurements were taken before and after a period of summer stress from two groups of cultivars, one group that generally shows good summer stress tolerance, and one that shows poor stress tolerance. Before the stress period, no difference in root mass was found. However, after the stress the group with summer stress tolerance had a higher root mass than the intolerant group. The ability to continue producing roots under summer stress is probably very important to tolerating grub feeding. The cultivars with better summer stress tolerance were the Mid-Atlantic and Mid-West (or Common) types of Kentucky bluegrass (see Table 4). When grub damage was evaluated in another trial, the Mid-Atlantic types generally showed the least damage, even though grub counts were not significantly lower. This relationship requires further study but is a promising lead in the development of grasses with resistance to white grubs.

Endophyte-Enhanced Insect Resistance

The discovery of the significance of endophytic fungi in grasses was an important breakthrough in turfgrass science. The initial findings of endophyte-enhanced insect resistance occurred in 1981 in a New Zealand perennial ryegrass pasture being damaged by Argentine stem weevil, and then soon after in New Jersey ryegrass plots being damaged by sod webworm. Since then, considerable work has been done and many beneficial effects of endophyte have been identified, including improved stress tolerance, persistence, and dollar spot resistance. Because endophytes are transmitted through the seed, they come in a convenient package and numerous endophyte-enhanced cultivars are currently available (see Table 5).

Several species of endophytic fungi have been identified in grasses and taxonomists continue to find new species. The endophytes in turfgrasses were being called *Acremonium* but have now been renamed *Neotyphodium*. These endophytes have been found in 13 genera of grasses, including several species of fescue, ryegrass, bentgrass and bluegrass, but not in creeping bentgrass or Kentucky bluegrass. Researchers have identified 40 insect species from six different orders that are affected by endophyte-infected grasses (see Table 2 for partial list). Some insects can detect the infected grass plants and avoid feeding on them, while others are poisoned by the toxins associated with the endophyte and have reduced survival, fitness, or egglaying. Six different groups of compounds have been identified. In addition, considerable variation exists in quantity of endophyte toxins produced. For example, ergovaline in red fescue clones ranges from 300 to 2600 ppb. Unfortunately, some of these compounds can have an adverse effect on livestock, so care must be taken when selecting grasses for establishing a pasture.

White grubs: Of special interest is the effect of endophyte on white grubs. Endophytic fungi are typically found in highest concentrations in the leaf sheath, stems and seeds, with low levels in the leaf blade, and none in the roots. However, the toxins associated with endophytes are translocated and have been found in the roots, suggesting that the endophyte might have an effect on root-feeding grubs. Several laboratory studies found decreased survival and fitness, especially with very young grubs. Results in the field were mixed. Differences in grub numbers and weight were found between cultivars in a national tall fescue evaluation trial in Rhode Island. However, only grub weights correlated with endophyte level, suggesting reduced fitness of grubs. On the hand, a study in New Jersey did find fewer white grubs on the endophyte-infected tall fescue. This type of discrepancy between studies may occur because of the numerous factors which interact to affect the expression of endophyte-enhanced insect resistance. For example, concentration of toxins is affected by density of the fungal mycelium, while density of the fungus is influenced by temperature, strain of fungus and cultivar of grass.

Fine Fescue and Chinch Bugs: Resistance to chinch bugs has been found in endophyte-infected hard, strong creeping red fescue, and Chewings fescue. A project currently underway at Rutgers is evaluating several strains of endophyte, in several fine fescue breeding populations, for their effect on chinch bugs. Trials conducted in a dixie cup found a difference in chinch bug survival between two endophyte strains in a Chewings fescue population. When given a choice in petri-dish preference tests, chinch bugs preferred endophyte-free tillers with two of the endophyte/plant combinations, but showed no preference with the third combination.

Table 2. Examples of turfgrasses where endophyte-enhanced resistance to insect pests has been found.

Tall fescue -- greenbug and other aphids, leafhopper, fall armyworm, sod webworms, Argentine stem weevil, billbugs, Japanese beetle*, southern masked chafer, grass grub

Hard fescue -- greenbug, hairy chinch bug, fall armyworm, Japanese beetle*

Chewings fescue -- greenbug, hairy chinch bug, fall armyworm, Japanese beetle*

Strong creeping red fescue -- greenbug and other aphids, hairy chinch bug

Blue fescue -- greenbug, fall armyworm

Perennial ryegrass -- greenbug and other aphids, hairy chinch bug, fall and southern armyworm, sod and bluegrass webworms, common cutworm, black field cricket, Argentine stem weevil, billbugs, Japanese beetle*, black beetle

**Resistance to Japanese beetle is variable, primarily seen with young grubs.*

This suggests variation in endophyte/plant combinations and that turfgrass breeders may be able to improve the performance of endophyte-infected grasses by selecting the best strain of fungus and putting it in the best grass. This can be done by artificially inoculating plants with the desired fungus, or by a standard breeding procedure called backcrossing. The plants containing the 'best endophyte' (parent A) are crossed with the 'best plants' (parent B) and seed is harvested only from the endophyte-infected plants (A). The offspring (50% A, 50% B and infected with endophyte) are then crossed with the 'best plants' (B) and the seed is harvested from these offspring. The offspring (25% A, 75% B) continue to be backcrossed with the original parents (B) until the desirable characteristics of the parent are obtained and high levels of endophyte are maintained.

Utilizing these pest-resistant grasses should be an important component of any I.P.M. plan. There are many factors to consider when selecting grasses for a new stand of turf, or for overseeding. I would like to suggest that level of insect resistance be one of those factors. In many cases it will not be possible to find a suitable grass with enhanced insect resistance, but an improved, vigorous turfgrass cultivar, adapted to your area, will almost always provide better tolerance and recovery from insect feeding. The lists provided in this article provide a starting point for selecting grasses but it is also a good idea to check with your local extension office. When using endophyte-infected cultivars always use fresh seed and store the seed in a cool, dry place. When seed is stored at room temperature, the endophytic fungus in the seed will start dying out after about a year.

Future Prospects

I have discussed just a few cases of insect resistance in turfgrass. Each of the examples given in Tables 1 and 2 represent opportunities to further enhance the resistance to these pests through focused breeding efforts. Very little is know of the mecha-

Table 3. Resistance of Kentucky bluegrass cultivars to billbugs

Resistant -- Eagleton, Eclipse, Washington, Wabash, America, Adelphi, Unique, Fylking, Kenblue (Common-type)

Moderately resistant -- Midnight

Highly susceptible cultivars -- Broadway, Parade, Cheri, Sydsport, Columbia

Table 4. Kentucky bluegrass cultivars with improved summer stress tolerance.*

Mid-Atlantic Type -- Eagleton, Livingston, Monopoly, Preakness, Wabash

Mid-West or Common Type -- Huntsville, Kenblue, Park (suitable for low maintenance turfs)

** This summer stress tolerance may result in better tolerance to white grub feeding.*

Table 5. Cultivars with high levels of *Neotyphodium* endophyte-infection.*

Perennial Ryegrass -- Advent, Affinity, All*Star, APM, Assure, BrightStar, Brightstar II, Calypso II, Catalina, Citation II, Citation III, Dandy, Dasher II, Envy, Gettysburg, Legacy, Manhattan II (E), Manhattan III (E), Navajo, Omega III, Palmer II, Palmer III, Passport, Pennant, Pinnacle, Prelude II, Prelude III, Prizm, Quickstart, Regal, Repell, Repell II, Repell III, Roadrunner, Saturn, Saturn II, Secretariat, Seville, Sherwood, SR 4000, SR 4100, SR 4200, Yorktown III

Tall Fescue -- Apache II, Arid, Bonanza II, Bonsai, Bonsai Plus, Coronado, Coronado Gold, Coyote, Crossfire II, Debutante, Empress, Grande, Houndog V, Jaguar III, KY-31, Lion, Masterpiece, Pixie, Phoenix, Shenandoah, Shenandoah II, SR 8200, SR 8210, Tarheel, Titan, Titan II, Tomahawk E+, Windsor II, Wolfpack
Hard Fescue - Aurora, Discovery, Reliant, Reliant II, SR 3000, SR 3100

Chewings Fescue -- Banner II, Brittany, Jamestown II, Shadow (E), Shadow II, SR 5000, SR 5100, Tiffany, Treazure, Victory (E)

Strong Creeping Red Fescue -- Jasper (E)

Sheeps Fescue -- Bighorn

**Each cultivar listed should have at least 40% of its seeds infected with endophyte. However, seed lots may vary in percent infection, and fresh, properly stored seed must be used in order to ensure viable endophyte.*

nism or inheritance of genetic resistance and no one has studied the chemistry of these resistant grass plants. Researchers are trying to inoculate Kentucky bluegrass and creeping bentgrass with useful endophytes. Crosses are being made between infected 'wild' bluegrasses and Kentucky bluegrass and eventually these may produce useful offspring. The research reported at a Turfgrass Biotechnology Workshop last summer suggest additional areas where progress may be made. Turfgrasses being grown under tissue culture have generated clonal variants with heat tolerance and disease resistance, and gene gun technology has been used to transfer genes for herbicide and disease resistance. Perhaps these approaches will yield new sources of insect resistance also.

Plant resistance is an important alternative to pesticides and many opportunities exist for researchers to further develop insect resistant turfgrasses. A cooperative effort between breeders and entomologists would greatly facilitate this work. In the meantime, turf managers can select endophyte-infected grasses and grasses which exhibit genetic resistance to insects and enhanced stress tolerance.

Dr. Jennifer Johnson-Cicalese received a master's degree from Rutgers University. In 1995, she received a Ph.D. from the University of Nebraska. Jennifer is back at Rutgers with the Turfgrass Breeding Program.

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Insecticide Series: Part V
Insecticides and Environmental Issues

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Pesticides are often in the news - and seldom are presented in a positive light. The news media present stories, often in the spring when many homeowners are beginning to think about planting gardens and about pesticides and their purported effects on the environment. However, many of these news "reports" present half truths or misleading information, and make some assumptions which may or may not be accurate. In particular, pesticides applied to turfgrass settings normally behave very differently than do the same pesticides applied to agricultural (or even backyard vegetable garden) settings, but the news media often do not point out the benefits of turfgrass or the way in which turfgrasses often minimize the effect of a pesticide on its environment.

A pesticide can be introduced into the environment through a properly conducted application. In such cases, assuming that label restrictions and guidelines were followed, effects on the environment normally are minimal. The Environmental Protection Agency requires information about the fate of a pesticide under normal application conditions before the agency considers labelling that material. The EPA does not support the labelling of materials which are likely to have detrimental effects under normal use patterns.

In addition, however, there are several activities which might introduce a pesticide into the environment unwittingly or inappropriately, and might result in adverse effects - either to unintended insect targets, such as bees or predatory beetles, or to vertebrates or plants. For example, improper disposal of pesticide containers or a spill during the mixing process could result in a pesticide reaching groundwater. Various misapplications - treatments made at the wrong rate of application or when the wind is blowing or at the wrong time of year or without following instructions about post-application water - can lead to unexpected or unintended results.

This article will focus on some of the environmental fates of insecticides. Keep in mind that the concepts discussed here hold true for all kinds of pesticides, including insecticides, fungicides, herbicides, and plant growth regulators.

Fate Processes

When an insecticide (or other pesticide) is applied to a turfgrass setting, one of three things can happen. The insecticide might undergo adsorption, which refers to a process which binds the insecticide to soil particles. The insecticide could transfer, or move away from the original site of application. Finally, the insecticide can undergo degradation, or breakdown from its original form into another form. The breakdown product could be more toxic or less toxic than the original material, depending on the chemical reaction involved. The likelihood that a given insecticide will move or degrade or be adsorbed depends on the chemical properties of the material as well as such things as soil properties. For example, texture, temperature, moisture, climate, and application practices.

Some "fate processes" are beneficial. For example, with recent concerns about pesticides contaminating water supplies, some people have suggested

Risk Factors of Groundwater and Surface Water Contamination

Chemical
high solubility
low soil adsorption (Koc)
long half-life
low volatility

Soil
sandy or porous
low organic matter

Site
shallow water table
steep slopes or low spots
near surface water
thin turf stand
sink holes/fractured soils
uncapped wells nearby

Management
misapplication
overirrigation

that any new pesticides should be virtually immobile in soil (adsorbed onto soil particles rapidly or essentially insoluble in water). This would seem to reduce the likelihood that such materials would move laterally to surface water or vertically to ground water. However, it would be very difficult to get those kinds of materials to the root zone of turfgrass plants. As a result, herbicides would not reach the roots (to be taken up systemically) and soil insecticides would never travel deep enough to reach the target insects.

Natural degradation of insecticides is critical - if these materials did not eventually break down naturally, residues would accumulate in the soil and plant tissue. So, a certain amount of natural degradation, whether chemical or biological, is generally considered to be a good feature of an insecticide.

If a turf manager fails to take into account the characteristics of the insecticide he or she is using, that manager might encounter some detrimental effects. For example, chemical or microbial degradation of an insecticide can occur rapidly enough, under some circumstances to result in a significant reduction in the effectiveness of the compound. In addition, if an insecticide moves from the point of application, the material could injure non-target insects or arthropods or earthworms. Finally, insecticides which make their way into groundwater or surface water can cause environmental damage as well.

Chemical Properties of Insecticides

The degree to which a given insecticide might breakdown or move from the original point of application depends on several physical or chemical properties of the insecticide. The **vapor pressure** of an insecticide measures the ability of a compound to volatilize, or transform from the liquid or solid state to the gas phase. Compounds which have high vapor pressures are more volatile, which means they are more likely to change to the gaseous phase after application and to move from the point of application. Compounds which have low vapor pressures are more likely to remain in their original state (liquid or solid) and to remain at or near the original point of application.

Solubility in water is another important chemical characteristic of insecticides. Materials which are highly soluble in water will be "dissolved" in that water more readily, and will be much more likely to be moved in water from the point of application. According to Balogh and Anderson (1992), insecticides that have a water solubility of 30 parts per million (ppm) or more are more likely to be involved in groundwater or surface water contamination than less soluble insecticides.

Sorption indicates the tendency of a material to bind on soil surfaces (adsorption) or to penetrate (absorption) into soil particles or plant tissue. An insecticide which has been adsorbed or absorbed is sometimes referred to as "bound residue" and is usually unavailable to the target insect and is not as likely to be broken down by microorganisms.

The partition coefficient (Koc) represents the relative amount of a pesticide that will bind (adsorb) to soil particles. A high Koc value indicates that much of a pesticide will bind to soil, while a low Koc value suggests that a pesticide will be more "available" and perhaps more likely to leach or run-off. Adsorption depends on the chemical characteristics of the insecticide, as well as the physical characteristics of the soil. For example, soils which have high levels of organic matter or clay adsorb insecticides much more quickly than coarse, sandy soils. The Koc takes into account some of the soil characteristics. According to Balogh and Anderson (1992), pesticdes with a Koc of less than about 400 are more likely to be involved in groundwater or surface water contamination.

Persistence indicates how long an insecticide remains in its original, "active" form. Researchers often refer to the "half life" of a compound. For example, if an insecticide has a half life of 10 days, one would expect that 10 days after application half of the material would have broken down to another form. Compounds which have long half lives are more persistent than compounds with short half lives. Pesticides that are relatively persistent remain in their "active" form longer, and thus are more likely to be involved in surface water or groundwater contamination. (Materials which are less persistent are more likely to have broken down to different forms before they are moved by run-off or leaching.) Several kinds of half-lives are mentioned in the literature, including "hydrolysis half-life" (breakdown in water), "photolysis half-life" (breakdown in sunlight), and "soil half-life" (natural breakdown in soil). According to Balogh and Anderson (1992), pesticides which have a hydrolysis half-life of more than 175 days, a photolysis half-life of more than 7 days, or a soil half-life of more than 21 days are more likely to be involved in groundwater or surface water contamination than pesticides with shorter half-lives.

Adsorption

As was mentioned earlier, adsorption refers to the process by which an insecticide is bound to soil particles, similar to paper clips clinging to a magnet. The degree of adsorption will depend on the chemical characteristics of the insecticide and physical characteristics of the soil. Soils which have a high clay content will adsorb pesticides more readily and more strongly than sandy soils, in part because clay particles are much smaller than sand particles and thus have a larger surface area available for binding. In addition clay particles tend to be negatively charged and will adsorb positively charged insecticides very readily. In addition, soil moisture affects adsorption. Wet soils usually do not adsorb pesticides as readily as dry soils because water molecules compete with the pesticide for binding sites on the soil particles.

Insecticides which are adsorbed readily are not as available to the target insect as insecticides which are not highly adsorbed. However, strongly adsorbed insecticides are also much less likely to move from the point of application, which is normally considered to be an advantage relative to environmental concerns.

Insecticide Transfer

There are several ways that insecticides can transfer, or move, from the original point of application. This movement may occur as a result of drift, volatilization, run-off, leaching, plant uptake, or crop removal.

Drift refers to the movement of an insecticide away from the intended target plants at the time of application. Normally drift occurs as a result of wind which blows particles of the material away from the target plant. Air currents move molecules of the insecticide downstream to unintended targets, such as plants, animals, bodies of water, or structures. Loss of insecticides as a result of drift can be minimized by applying materials when the wind is not blowing (often at dawn or dusk), using larger droplet sizes (larger nozzle orifices) or lower pressures, or using skirted sprayers.

Volatilization refers to the transformation of an insecticide from a solid or liquid phase to a gaseous state. Evaporation of water is an example of volatilization. Once a compound has volatilized, it can move in air currents away from the original point of application. Insecticides with high vapor pressures are more likely to volatilize, while compounds which are tightly adsorbed to soil particles are less likely to volatilize.

Conditions which favor volatilization are the same as those in which people are more likely to sweat - high air temperatures, low relative humidity, and moderate winds. Loss of insecticides as a result of volatilization can be minimized by avoiding applications when air temperatures are high, relative humidity is low, winds are moderate, or soil moistures are relatively high. In addition, sub-surface application techniques (high pressure liquid injection or slicing) place the insecticide beneath the surface, where it is much less likely to volatilize.

Run-off refers to the lateral movement of water on the surface, and occurs when water is applied (through rainfall or irrigation) to an area faster than it can enter the soil. Water which "runs off" may carry insecticides which have dissolved in the water or are carried in or on soil particles that are moving in the water (erosion). Run-off is of concern because materials which are carried in the water eventually make their way to surface water - streams, rivers, ponds, or lakes. Pesticides which reach surface water may have unintended effects on the plant and animal life in those bodies of water.

The severity of run-off depends on several factors. For example, steep slopes are more likely to experience run-off than gradual slopes because water moves more rapidly along those steep slopes.

Sandy soils are more able to absorb water and thus are less likely to be sensitive to run-off. A thick and healthy stand of turfgrass usually REDUCES the rate of run-off, because the vegetation acts as a sponge and absorbs the surface water while it is moving, allowing it time to penetrate the soil profile. Highly soluble insecticides are most likely to be moved by run-off, while strongly adsorbed materials are less likely to run-off. Obviously, heavy rainfall or overirrigation also lead to run-off.

Turf managers can do several things to reduce insecticide run-off into bodies of water. For example, managers can use less soluble insecticides where available. They should avoid applications before heavy or extended rainfall, avoid overirrigating the treated area, and avoid making applications to areas with steep slopes. In addition they can avoid applications near bodies of water (leave an untreated buffer zone surrounding the body of water) and use spreader-stickers, which increase the amount of insecticide which sticks on the foliage. Finally, sub-surface application technology moves the insecticide off the surface, which means it is much less likely to run-off.

Leaching refers to the vertical movement of water through the soil profile and eventually to the water table. Like run-off, it occurs when water is applied (through rainfall or irrigation) to an area faster than it can be absorbed within the root system. Water which leaches may carry pesticides or fertilizers which were applied in the vicinity and have dissolved in the water. Leaching of pesticides has implications for water quality, because occasionally a pesticide which has been applied according to label directions will move vertically through natural processes and reach the water table (or groundwater). The drinking water supply for a large portion of the population of the United States comes from groundwater sources (wells, natural aquifers), so the potential for contamination of these underground reservoirs is of great concern.

The likelihood that an insecticide will leach depends on several factors. Sandy soils are more vulnerable to leaching because water molecules can find their way through the large pore spaces in the soil. Conversely, heavy soils are less subject to leaching because water does not percolate through those soils as quickly Areas which have vertical fractures in the underlying bedrock would experience more rapid rates of leaching than locations which do not have fractures. Surface burrows of insects and small animals may increase the initial rate of penetration of water into the soil profile. Low lying areas are more subject to leaching than are slopes, because water which falls on slopes may run off horizontally as well as move vertically, while water which accumulates in low areas will not move laterally.

As with run-off, areas which have vigorous stands of turfgrass usually are less vulnerable to leaching, because the vegetation acts as a sponge and allows more time for the root system to absorb water. Heavy rainfall or overirrigation can lead to leaching. Finally, the depth of the local water table is critical - areas with a shallow water table are much more likely to be exposed to pesticides or fertilizers than are locations with a deep water table. This is because most pesticides and fertilizers degrade over time and if the water table is deep, it will take longer for the material to reach that groundwater, thus allowing more time for breakdown to occur.

The chemical characteristics of the insecticide also have a direct bearing on its potential to leach. Highly soluble (mobile) insecticides are more likely to be moved by leaching water than insoluble (immobile) insecticides. Insecticides which tend to adsorb to soil particles are less available and less likely to leach. Persistent insecticides (ones with long half lives) are more likely to reach groundwater, simply because they will remain in their active form longer, allowing more time to reach the water table.

Turf managers can do several things to reduce the potential for pesticides or fertilizers to leach to groundwater. First, they should be familiar with local conditions and select less mobile (less soluble) and less persistent materials when possible, particularly if they are working in sensitive areas (sandy soils, shallow water table, fractured soils). They should avoid applications to open soil and avoid applying pesticides before heavy or extended rainfall. They should manage the irrigation cycle carefully, to avoid overirrigation and to avoid puddling on the surface. And of course they should be careful to calibrate application equipment to ensure that applications are made at the proper rate.

Absorption refers to the movement of pesticides into plants or animals. In this case, plant uptake may occur through the foliage or the roots. Some insecticides are absorbed into plant tissue and then move through the vascular tissue of the plant to other parts of that plant. Such insecticides are called systemic insecticides. The process of uptake may "move" an insecticide into the tissue or alter the flow of water within the root zone. For example, turfgrass species which have a higher rate of evapotranspiration will absorb moisture from the root zone and, at the same time, insecticides in that micro-environment. This can reduce the rate of leaching of relatively soluble materials. However, when plants are not growing actively, this process is curtailed and leaching is more likely to occur.

Turf managers can use **plant uptake** to their advantage by using systemic insecticides (ones which are designed to be absorbed and subsequently translocated within a plant). They can try to make applications of sensitive (soluble and/or persistent) materials when the turfgrass is growing vigorously and, thus, is more likely to take up more of the material.

Crop removal is yet another way in which a pesticide and its breakdown products can move from the original point of application. Many pesticides cannot be applied to food crops within a certain number of days of harvest because residues from the pesticide remain on the plant for a period of time, and would still be on the plant at the time of harvest. However, people tend to forget that some pesticides may remain on the surface of turf plants for several days after application. While food commodities can be washed or processed in other ways to remove or reduce pesticide residues, turfgrass is a perennial crop and cannot be "cleaned". Turfgrass managers must keep in mind that clippings may contain residues, so disposal of clippings may not be a trivial matter. Turfgrass clippings probably should not be used as a mulch if they have recently been treated with an herbicide. Mulching mowers, which return clippings to the turfgrass, should be considered where appropriate.

Degradation of Insecticides

Insecticides are complex chemical molecules which break down into simpler compounds over time. Chemical, biological, or physical processes operate on the original compound to degrade it. These processes normally are considered to be beneficial because they change pesticide residues to compounds which are less toxic than the original compound (note that there are a few exceptions, where the degradation product is more acutely toxic than the parent compound.) Degradation may be a disadvantage, however, if the insecticide is destroyed before it has had an opportunity to attack the target insect.

Chemical degradation occurs when an insecticide breaks down by processes that do not involve living organisms. Chemical and physical properties of the original molecule will have a direct affect on the rate at which the compound degrades. Some insecticides are quite stable in a variety of conditions - chemically, this means that the molecular structure is stable and the bonds within that molecule remain intact. Other insecticides are not very stable - the bonds are relatively weak and can be broken quite easily. When those bonds break, the molecule loses its original structure and "degrades". The "breakdown product" may look very similar to the original molecule (it may have lost one or two atoms) or it may split into two separate and smaller molecules. Usually the breakdown product is less toxic than the parent compound, but occasionally the breakdown product is more toxic than the parent compound.

Insecticides which break down quickly are the ones in which the chemical reactions take place rapidly. The rate of reaction depends on the chemistry of the molecule itself, as well as ambient temperature, soil moisture and pH, presence of water and its pH, and the rate of adsorption of the compound. Normally chemical reactions occur more rapidly at higher temperatures, so most insecticides break down more rapidly in summer settings than in the spring or autumn (note that some of the synthetic pyrethroids, particularly the earlier materials like resmethrin, are quite sensitive and break down quite quickly at *high temperatures*). The availability of water often speeds a reaction, so adequate *soil moisture* (such that the turf is not wilting) or light irrigation following an application can be enough to initiate the breakdown process.

One of the most common chemical degradation processes which affects insecticides is *hydrolysis,* which occurs when the insecticide reacts with water and some of the bonds in the molecule are broken. Chemists have developed a system which measures how acidic or basic (the opposite of acid) a compound is. By definition, a material with a pH rating of 7.0 is considered to be neutral (neither acidic nor basic), while a material with a pH of less than 7.0 is acid and one with a pH greater than 7.0 is basic. The pH of water varies widely (from 2 to 11), depending on impurities in the water.

Many organophosphate and carbamate insecticides are especially vulnerable to *alkaline hydrolysis* (breakdown in alkaline or basic water). This becomes significant in certain parts of the country, where the natural water supply tends to be alkaline. For example, some of the older cities in the Northeast still have lead pipes as part of the delivery system. Officials intentionally raise the pH of the water in these systems because the lead will not dissolve into the water supply as quickly at higher pHs. In addition, the fluoridation process tends to raise the pH of a water supply as well. In some parts of the country (particularly where native soil or bedrock is alkaline) well water or surface water supplies will be alkaline.

Some insecticides will breakdown to inactive forms in less than two hours if the pH of the water in the tank is higher than 8.5. Acephate, isazophos, and trichlorfon are particularly sensitive to alkaline conditions. However, many formulations of these and other insecticides already include a buffering agent, which functionally adjusts the pH so that the insecticide is not as vulnerable to breakdown.

If turf managers experience a "failure" with an insecticide, particularly with one which is known to be sensitive to pH, they should double check the pH of the water at the time of application. In fact, turf managers should get into the habit of checking the water pH each time they fill a spray tank - and include this information in their normal record keeping.

The pH can be measured by using color coded strips of paper which change color according to the pH, or by using a pH meter, which is more accurate but also more expensive. If the pH of the water is found to be higher than 8.0, the turf manager probably should add a buffering agent to the tank to minimize the likelihood of hydrolysis. Check with your supplier - there are several compounds available commercially.

Note that some pesticide labels specifically warn against tank mixes with certain materials, such as fertilizers or other pesticides. Often this restriction is on the label because the combination will interfere with the pH of the final mix and will result in a more rapid rate of breakdown of the active ingredient. So, as always, read and adhere to the restrictions on the label - they are there for a reason!

Biological degradation occurs when an insecticide is broken down by living organisms. This form of degradation is often called microbial degradation because most of the organisms which break down the material are fungi, bacteria, or other microscopic organisms. These microbes use the insecticide as a food source, breaking down the molecule into forms of carbon and hydrogen which they can process and use.

The soil and thatch are very complex communities, with a host of organisms thriving - including bacteria, fungi, protozoa, nematodes, predatory insects, and earthworms, among other things. Several soil and environmental factors affect the rate at which the "*degradation organisms*" will attack insecticides. Some of these factors are: organic matter content, soil oxygen, soil moisture, temperature, and pH.

Carbon and other nutrients which are found in soil organic matter often provide the primary food source for soil microbes. In fact the population of those soil microbes is often directly related to the amount of carbon (essentially determined by the organic matter content) available in the soil. High levels of organic matter can cause higher levels of adsorption of insecticides. Finally, the presence of a vigorous thatch sometimes increases the rate of degradation of insecticides (and other pesticides) because a healthy thatch provides conditions which are often ideal for microbes to thrive.

The *availability of oxygen* in the soil and the thatch also plays a critical role in microbial degradation of insecticides. Some microbes operate best when there is plenty of oxygen available (aerobic conditions), and may be more active in aerified turf, since aerification usually increases air flow within the soil. Other microbes prefer conditions with low levels of oxygen (anaerobic conditions). Some insecticides are broken down more quickly in aerobic conditions because some of the aerobic bacteria are particularly well suited to those compounds, while others are broken down more quickly in anaerobic conditions. Normally degradation occurs more quickly under aerobic conditions, but there are some exceptions.

Soil moisture is another critical factor. The microorganisms which degrade insecticides must have water to grow, but if soil moisture is too high, the soil oxygen content will be reduced. The optimum moisture level for many aerobic organisms in the soil and thatch usually is from 50-75%. In addition, insecticides are more likely to be adsorbed on soil particles in low soil moisture conditions, which means those molecules are less readily available for microbes to attack.

Each microbe has a range of temperatures and pH levels within which it will be most active. When temperatures are above or below that optimum range, degradation will occur more slowly. Also, most microorganisms grow in a limited pH range. Most of the soil bacteria found in turf settings prefer pHes between 6 and 8 (very near neutral, neither acidic nor basic). Some of the actinomycetes prefer alkaline conditions, but other fungi seem to tolerate a relatively wide range of pHs. Soil pH also plays a role in determining how much of a pesticide can be adsorbed by soil.

Microbial Degradation Case Study

Many turf managers will remember that isofenphos (Oftanol™) became available for use in turf in the early 1980s. When it first came on the market, it appeared to give season-long control of certain turf insects, such as white grubs. The same active ingredient had also been released for use on corn rootworms in the Midwest (under a different trade name), and appeared to work very well the first year or two in a given location. However, growers noticed that the effectiveness of the material declined with subsequent applications. An application which provided good control one year barely affected the rootworm population the next year. A series of studies eventually showed that the compound was quite sensitive to microbial degradation - naturally occuring microbes in the treated areas thrived on the material and broke it down quite quickly. The first year that the material was applied, the microbes which were present grew and reproduced rapidly, so there were even more microbes in the soil the next year when the material was applied. Each year the material was applied, the population of degradation microbes increased until eventually the population of microbes was high enough that it could break down the insecticide before it came in contact with the target insect.

While the phenomenon of microbial degradation of isofenphos does not appear to have been as widespread in the turf world as in the world of field corn, it has been suspected to have been a factor in some of the "failures" of Oftanol™ which were reported in the 1980s. In addition some other insecticides seem to be vulnerable to microbial degradation, as well. In some cases, the microbial action appears to occur on several insecticides within a chemical class, so the field result (reduced effectiveness of an insecticide) looks like resistance.

Turf managers can minimize the likelihood of experiencing microbial degradation by using common sense and incorporating the same approaches which are used to delay the development of resistance. Apply insecticides only when necessary and only in the affected areas. Never use the same material several times in one year (several turf insecticides now include a statement cautioning that the material should be applied only once per growing season) or more than two or three consecutive years. Finally, alternate chemical classes and formulations to minimize the likelihood of microbial degradation.

Photodegradation normally occurs when an insecticide is broken down in sunlight. Ultraviolet rays and other parts of the light spectrum can disrupt chemical bonds of certain molecules, resulting in their breakdown. Photodegradation can affect insecticide molecules in the air (from drift or volatilization), on foliage, or on the soil surface. Several factors influence the severity of photodegradation, including the intensity and duration of sunlight, application method, and chemical properties of the insecticide.

A turf manager can minimize the breakdown of insecticides in sunlight by using common sense. Whenever possible, avoid applying insecticides in the middle of the day (for example, between 10 am and 2 pm), particularly on hot, sunny days. Many materials will be markedly more effective if applied late in the day, especially when the target insect is nocturnal. Often watering a treated area immediately after application will move much of the material off the leaf blades and into the thatch, where it will be slightly less vulnerable to photodegradation. Finally, subsurface application technology places materials at the thatch-soil interface or deeper, so it is much less sensitive to the action of sunlight.

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Terms to Know

ABSORPTION - the taking up of a compound (actual penetration) by another compound

ADSORPTION - the binding of an insecticide to a soil particle

ALKALINE HYDROLYIS - breakdown of an insecticide in alkaline (ph above 7.0) conditions

BUFFERING AGENT - a material which makes an insecticide less vulnerable to alkaline hydrolysis

CHEMICAL DEGRADATION - breakdown of the molecular structure of an insecticide by chemical processes such as hydrolysis

DEGRADATION - breakdown of an insecticide from its original molecular structure to a less complex structure (may be biological, chemical, or physical)

DRIFT - the movement of an insecticide away from the original point of application, usually by wind

HALF LIFE - the time required for one half of a given material to undergo chemical reaction (usually break down)

HYDROLYSIS - decomposition (breakdown) of a substance by water

Koc - partition coefficient, indicates the relative amount of a pesticide which will bind (adsorb) to soil particles

LEACHING - the vertical movement of water (and insecticides or other materials which have been dissolved in the water) through the soil profile

MICROBIAL DEGRADATION - breakdown of an insecticide by microscopic organisms in the soil and thatch

PERSISTENCE - a measure of how long an insecticide remains in its original "active" form

PHOTODEGRADATION - breakdown of a substance by light (usually sunlight)

RUN-OFF - the lateral movement of water (and insecticides or other materials which have been dissolved in the water) along the surface

SOLUBILITY - the ability of a substance to form a solution with another substance

SOLUTION - a homogeneous liquid (or solid or gas phase) that is a mixture in which all the components are uniformly distributed throughout the mixture

SORPTION - the tendency of an insecticide to bind on soil particles (adsorption) or to penetrate (absorption) into soil particles or plant tissue

SYSTEMIC INSECTICIDE - an insecticide which is absorbed into a plant and subsequently translocated from the original point of penetration to other parts of the plant

TRANSFER - the movement of an insecticide from its original point of application to another site

VAPOR PRESSURE - a characteristic of an insecticide which measures its ability to volatilize

VOLATILIZE (also volatilization) - to transform from a liquid or solid phase to a gas phase

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