IPM Planning Guide

reference

Pesticide Resistance Reference

GCSAA

Golf Course Superintendents Association of America

Pesticide Resistance Management

The first signs of pesticide resistance begin with the observation that pests are surviving pesticide applications, and that increased rates or frequencies of application are necessary to provide acceptable control. As more applications are made, pesticide rates must be steadily increased to maintain control of pests. And finally, after many pesticide applications, the pesticide is rendered totally ineffective, regardless of the rate used. Since the introduction, in the 1930s, of pesticides based on synthetic chemistry, the number of pests that have become resistant to pesticides has increased to an alarmingly high number (Table 1). Without good resistance management strategies in place, this number can only continue to grow. In this issue of PACE Insights, we want to explore how pesticide resistance comes about, how it affects pest management practices on golf courses, and what we can do to avoid it. We will tell you up-front, however, that there is no universal solution to the problem of pesticide resistance, partly because so little is actually understood about the complex interactions involved. But by applying the research information and practical experience that we do have, we should be able to at least slow down, if not avoid resistance development.

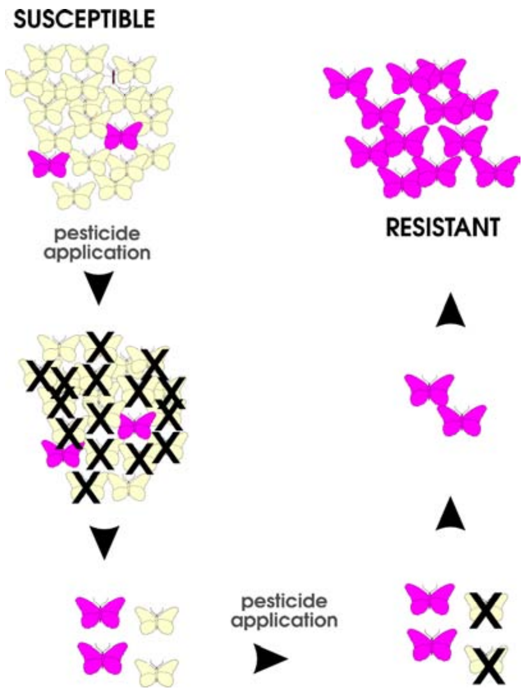
Table 1. Number of resistant pest species, as of 1986 (from Green et. al., 1990)

insects and mites	504
plant pathogens	100
weeds	48

Resistance -- a working definition: There are as many definitions of resistance as there are pesticide products, but a good working definition that we will use here is: "Resistance occurs when pests survive doses of the pesticide which would normally be lethal. This is due to a genetic change in the pest population that is caused by exposure to pesticides."

When a new pesticide is commercialized, the hope is that it will kill 100% of the pests that it is targeted against. However, this rarely occurs, partly because each individual in a pest species responds differently to the pesticide. In fact, there is a lot of variation within populations of all living organisms, whether they are human beings (note our different survival rates, different appearances, different abilities to win at "Jeopardy!") or pests. For example, within one pest species, such as the sod webworm, we see moths of different sizes, different colors, and different reproductive abilities. All of this variability is due to small differences in the DNA, or genetic material of each individual pest. With regards to pesticide sensitivity, there is great variability within each pest species as well. Keeping with the example of the sod webworm, imagine a time before the introduction of insecticides such as aldrin, when the majority of webworms were easily killed by this pesticide. However, there were a few moths that had the genetic ability to survive exposure to aldrin -- perhaps because they had enzymes that could break down and detoxify the aldrin. As a result, the aldrin -resistant individuals became more numerous after each aldrin application, while the susceptible individuals began to gradually disappear. This is the stage at which we would begin to notice that the pesticide applications were not working as well as they did originally. Eventually, all of the webworms would be resistant to aldrin, and we would have complete product failure (Figure 1).

Figure 1. Pest population changes that result in development of resistance to pesticides. Susceptible insects (light colored moths) are in the majority before pesticide applications begin, and resistant insects (dark colored moths) are in the minority. As pesticide applications continue, susceptible insects are killed (insects with "X"s) and resistant insects come to dominate the population.



Exposure, exposure, exposure: With the information above in hand, it stands to reason that the way to avoid resistance is to avoid constant use of the same pesticide. This is because by reducing the exposure of the insects to the pesticide, you reduce the likelihood that susceptible (easily killed by the pesticide) pests will die and that resistant pests will survive. Reduction of exposure to pesticides is the bedrock upon which most resistance management strategies are based, and it also answers questions such as:

Why are there so many insects that are resistant to pesticides? In Table 1 above, the largest number of resistant pests are found among insects (with 504 resistant species!), with plant pathogens running a weak second place (only 100 species) and weeds even further behind. The reason? Synthetic insecticides were first introduced in the 1930s, with the development of DDT. However, it wasn't until the 1960s that the first highly effective selective fungicides (such as benomyl) were introduced, and it was even later when selective herbicides were introduced. In other words, insects have been exposed to pesticides for many years longer than pathogens or weeds have been exposed to pesticides. In addition, the early insecticides, such as DDT, had exceptionally high residual activities, with some products remaining active for years in the soil. Thus, insects were exposed to the same products on a continuous basis for long periods of time, allowing highly resistant populations to develop.

The recent introduction of highly effective, long residual products such as Heritage (azoxystrobin), Banner (propiconazole) and Merit (imidacloprid) seems to have rekindled concerns about resistance. Why is this? The fact that these products have increased residual activity (vs. other currently available fungicides and insecticides) means that pest exposure has been increased, as it was with DDT in the example above. Therefore, the risk of resistance is higher, unless strategies to decrease risk are implemented.

Why are there fewer cases of pesticide resistance on golf courses in the Western U.S.? As Table 2 illustrates below, there are relatively few cases of resistance for turfgrass pests.

Table 2. Some examples of resistant turf pests.

Pest name	Type	Pesticide
white grubs	insect	chlordane, dieldrin
chinch bugs	insect	diazinon, chlorpyrifos
black turfgrass ataenius	insect	aldrin, chlordane, dieldrin, heptachlor
sod webworms	insect	aldrin, dieldrin
dollar spot	disease	Rubigan, Bayleton, Banner, Chipco 26019, Vorlan, Benlate
Pythium	disease	Subdue
pink snow mold	disease	benomyl and dicarboximides
large crabgrass	weed	triazines
goosegrass	weed	Treflan
ann. bluegrass	weed	Diquat, Princep, Prograss

The documented cases are for the most part related to the use of chlorinated hydrocarbon insecticides (such as DDT, chlordane, dieldrin, aldrin, heptachlor) with their extremely high residual activities and high exposure levels. The remaining cases are related to diseases or weeds that are persistent pests in the Eastern U.S. and are treated for, wall-to-wall, on a frequent basis. In contrast, on Western golf courses, where pest pressures are lower, exposure to many insecticides and fungicides is limited to golf course greens only. This means that susceptible pests from acres of fairways and roughs will be unaffected by pesticide applications, and will still far outnumber any resistant populations that develop on a few acres of greens.

Cross resistance: the "fly" in the ointment: If high levels of exposure to pesticides are the root cause of pest resistance, then it stands to reason that by reducing exposure, we avoid resistance. If this sounds too good to be true, it is. One of the first strategies developed for resistance management called for the rotation of different pesticides with one another, as a means of reducing exposure to a single pesticide. On paper, this sounds great. If we treat with pesticide A two or three times, and then switch to pesticide B for another three applications, we've reduced the exposure to pesticide A by 50% -- right? The answer is -- well, it depends. This is because <u>cross-resistance</u> frequently occurs -- that is, when a pest becomes resistant to a pesticide that it was never treated with. Cross resistance usually comes about when pests are treated with two or more products in the same <u>chemical class</u>. Products in the same chemical class are closely related to one another chemically, and for that reason also kill the pest using the same mode of action. Therefore, a pest that develops resistance to a pesticide in a given class will probably be cross-resistant to the other products in that same chemical class. **Therefore, to decrease the risk of resistance, rotation of products should occur between different classes of pesticides.** For example, for control of summer patch, Heritage, a b methoxyacrylate, could be rotated with Banner, a sterol inhibitor. To avoid a situation where cross-resistance might occur, do not rotate products in the same chemical class. For example, Banner and Bayleton, both sterol inhibitors, should not be rotated with one another. To aid you in your decision-making, classes of different pesticides and some of the turf products in each of these classes are listed in Table 3 below.

Resistance management is a preventive strategy: Resistance management strategies are based on the belief that once resistance occurs, it is too late to do anything about it. Therefore, resistance must be avoided through a variety of preventive strategies which are listed below. In our attempts to develop these strategies, it seems as though the odds are stacked against us. Almost all of the critical factors in development of resistance -- pest genetics, pest behavior and pest physiology -- are beyond our control. There are however, a few factors within our control, including 1) the type of pesticide we select, 2) the size and location of the area we spray, and 3) the timing of the pesticide application. It is upon these factors, in combination with the goal of reducing pest exposure to pesticides, that the strategies below are based.

Rely on cultural and other management practices to reduce the number of pesticide applications. There are, of course, a wide variety of reasons -- from environmental concerns to regulatory issues -- why this strategy is already being implemented at most golf courses. From the standpoint of resistance management, this strategy reduces exposure of pests to pesticides simply by decreasing the number of applications made per year. It's simple, but it makes sense.

Table 3. Chemical classes of insecticides, fungicides and herbicides.

Insecticide Class	Examples
carbamates	Sevin
chlorinated hydrocarbons	aldrin, chlordane, dieldrin, DDT, heptachlor
chloronicotinyls	Merit
diacylhydrazine	Mach 2*
organophosphates	Dylox, Dursban
pyrethroids	Tempo
spinosyns	Conserve*
Herbicide Class	**Examples**
amides	Kerb
benzoics	Banvel
dinitroanilines (DNAs)	Balan, Barricade, Pendulum, Surflan, Team, Treflan
oxadiazoles	Ronstar
phenoxys	2,4D, MCP, MCPA, MCPP, Trimec
sulfonylureas	Manage
triazines	Aatrex, Atrazine, Princep, Sencor, Simazine
unclassified	Basamid, Betasan, Prograss, Round-Up
Fungicide Class	**Examples**
b methoxyacrylates	Heritage
benzimidazoles	Cleary's 3336, Fungo
carboximides	Prostar
phenylamides	Subdue, Apron
sterol inhibitors	Banner, Bayleton, Eagle, Rubigan
dicarboximides	Chipco 26019, Curalan, Vorlan
ethylenebisdithio-carbamates	Fore, Dithane
nitriles	Daconil
phosphonates	Aliette

*have received Federal registration, but not California registration

Rotation among different pesticide classes. This strategy, already partially discussed above, has its plusses and minuses. Although rotation is the strategy most commonly recommended in university publications, on product labels and in scientific literature, there is very little real evidence that it is successful at avoiding resistance. This is probably because "rotation" is such a broad term. For example, should products be rotated every other treatment? Every other year? There is little information available to help answer this question. Rotations have also sometimes been unsuccessful in avoiding resistance, even when the products were carefully selected from different pesticide classes. This is because pests are occasionally cross-resistant to pesticides even when they are in different pesticide classes. If we could predict when this would happen, we could avoid it, but unfortunately our knowledge about cross-resistance is too sketchy right now.

Refugia: A refuge, or a non-treated area, provides a breeding ground for pests, the majority of which will be susceptible to pesticides (because they have never been exposed to pesticides). If pests from the refuge are mobile (i.e., flying insects, wind-dispersed weeds, pathogens transported by mowers and foot traffic), then pests from the refuge can breed with and numerically overwhelm any resistant pests that develop on treated areas of the golf course. As mentioned above, golf courses in the Western U.S. have already been utilizing this strategy. In other words, by restricting pesticide treatments almost exclusively to greens, the tees, fairways and roughs have become huge refugia, harboring susceptible pests that it is not necessary to treat for, because they cause little or no damage. Looking at an even bigger picture, the parks and home lawns and gardens near golf courses are also excellent refuges for development of susceptible pests. The only down-side to this concept is that not all pests are mobile, and there is so little known about turfgrass pest behavior, that we just don't how mobile many of our pests are. For example, we know that the black turfgrass ataenius adult beetle can fly fairly long distances, and we therefore assume that this pest is mobile. However, we have observed that ataenius grub infestations develop in the same spot year after year, possibly because the populations become localized. In other words, even though they can fly, they choose to stay in one area to feed and reproduce and therefore become effectively non-mobile. At this point, we don't have enough information to know whether ataenius are mobile or not. Without this type of knowledge, we can only guess at how effective refuges will be for resistance avoidance on golf courses. More basic research on pest behavior is the only way we can get these answers.

Mixtures of pesticides: In theory, this strategy makes the most sense, but in practice, it is the most difficult to implement. The theory is that by mixing pesticides of two different classes, you are almost guaranteed to kill all targeted pests --whether resistant or not. This is because even if a pest is resistant to one pesticide, it will still be killed by exposure to the second pesticide in the mixture. The pests that are resistant to both pesticides in the mixture will be extremely rare, and should be outnumbered by susceptible pests from refugia (see above). However, there are many requirements that must be fulfilled for this strategy to work. First, as for rotations, pests cannot be cross-resistant to the two pesticides in the mixture. Second, the two pesticides must be equally toxic, and have equal residual activity against the target pest. If this requirement is not fulfilled, then the more toxic or higher residual product will kill all of the pests, making the presence of the second pesticide redundant. Finally, immigration of pests from the untreated refuge must occur. Unfortunately, in most cases, we do not have enough information to know whether we are meeting these requirements or not. For this reason, mixtures, although frequently used for other reasons (i.e., to target two or more different pests with the same application) are infrequently used as a resistance management strategy.

Practical recommendations: As many of you have commented, explorations into technical areas sometimes result in more questions than answers, and resistance management may be such a case. However, we can derive, from the scientific literature, from our own experiences and also from good common sense, a list of practical recommendations:

- To reduce pest exposure to pesticides, continue efforts to avoid unnecessary pesticide applications and use cultural control methods whenever possible
- View your untreated fairways and roughs as a resource, full of susceptible pests which can breed with and overwhelm any resistant pests that develop on greens; wherever possible, avoid treating fairways and roughs with pesticides
- When pesticide applications are necessary, use Table 3 above and rotate among chemical classes, to avoid development of resistance, and also to: 1) avoid deleterious effects of repeated applications with the same product, such as phytotoxicity; 2) comply with newer product labels which now contain restrictions on the number of times a product can be applied sequentially
- If pesticide mixtures are used as a resistance strategy, make sure that there is scientific data available demonstrating that the mixture will be effective, and that the requirements listed above for successful mixtures are fulfilled.

References

Denholm, I. and M.W. Rowland. 1992. Tactics for managing pesticide resistance in arthropods: Theory and practice. Annu. Rev. Entomol. 37:91-112.

Green, M.B., LeBaron, H.M. and W.K. Moberg. 1990. Managing resistance to agrochemicals: From fundamental research to practical strategies. American Chemical Society Symposium Series number 421. American Chemical Society, Washington, D.C. 496 pp.

Vargas, J.M. 1994. Management of Turfgrass Diseases. Lewis Publishers, Boca Raton, FL. 294 pp.