The disease triangle is a familiar concept to horticulturists who manage infectious plant diseases. It is the simple concept that infectious disease is a process, involving three facets — a virulent pathogen, a susceptible host plant, and an environment conducive to disease.

A standard test question for pesticide certification always lists these three and asks which of them is necessary for disease to develop. The answer is, of course, all three. If the disease is rose black spot, for disease to occur, there must be the fungal pathogen *Diplocarpon rosae*, a susceptible type of rose, and the right numbers of hours of leaf wetness.

The true power of the triangle, though, is to realize and train yourself and your employees to put this triangle truism to practice when considering how to control disease. For example, when considering how to control rose black spot, do not simply default to the squirt-gun botany solution of which fungicides are labeled. Broaden your consideration of all three facets of the triangle when deciding how to control black spot.

- Which roses have better genetic resistance to black spot?
- How can you limit the hours of leaf wetness by your choice of irrigation type and timing?
- How can you use sanitation to limit fungal inoculum in the planting?
- Finally, how can fungicides be best used to prevent infection?

Let’s look at how we can harness the power of the triangle concept by looking at each facet of the triangle and using some specific diseases to illustrate the points. Let’s also take a look at extending the concept, by looking at modifications such as the pest triangle, and finally — the horticultural triangle.

### The Host Plant

Yogi Berra once said that “It ain’t over till its over” and he might just as well have said, “A good place to start is at the beginning.” The beginning for plant disease management is with proper plant selection.

Prevention is the key to disease control and, whenever possible, prevention starts with selecting plants with good genetic resistance to key disease problems. If you find yourself each year getting call after
call about why the leaves are falling off the crabapples you installed and you are muttering that “it is the same darn thing over and over again,” break the cycle.

Learn which crabapples in your part of the country have good genetic resistance to apple scab. Then combine this information with which crabapple fulfills your landscape design needs. Fortunately, with crabapples, there is a good collection of scab-resistant taxa over a wide spectrum of horticultural features.


It is also important to know what works in your area. Sometimes scab resistance is not a big factor in your part of the country. ‘Royalty’ and ‘Radiant’ are scab dogs in many areas, but where scab pressure is low and spring conditions are dry, these crabapples can be good choices.

It is also important to remember that disease resistance is not necessarily forever. While horticulturists are busily involved in plant breeding and in making superior selections, plant pathogens are also busily mutating and genetically recombining.

A rose that exhibits great genetic resistance to black spot in one part of the country or in times past may not do so elsewhere or over the years because of new strains of the pathogen that develop. ‘Indian Magic’ crabapple was listed with good scab resistance in the early days of the International Ornamental Crabapple Society trials; it now is listed as being quite susceptible.

This does not negate, however, the importance of first considering what your options are relative to host resistance. If horticultural desires mandate planting a ‘Peace’ rose even though it has susceptibility to rose black spot, at least do not choose all black-spot-susceptible roses for a public rose garden. Don’t make it easy for Diplocarpon rosae to feast at a veritable training table of its favorite foods. Mix things up a bit.

When Verticillium wilt recurs again and again on your Japanese maples, switch to dogwoods or birches. When you grow weary of powdery mildew on your beebalms and zinnias, consider planting the ‘Petite Delight’ series of beebalm and the ‘Profusion’ series of zinnias.

The Pathogen

There is a great quote from more than a century ago from the Russian plant pathologist Antonin Woronin, who declared: “The only cure for cabbage hernia is fire!”

Until recently cabbage was generally not considered an ornamental plant, but Woronin’s point still applies to us in the green industry. He was talking about a disease now known as club root of cabbage, caused by a primitive organism known as Plasmodiophora brassicae.

What he meant was that they had no cabbages with good genetic resistance to “cabbage hernia,” no pesticides to control
it, and no way to seriously modify the environment conducive to disease.

But they could control it by sanitation — by getting rid of the pathogen — in this case by burning the infested fields after harvesting whatever they could each year. By burning the remaining herniated cabbage debris, they were reducing the amount of *P. brassicae* inoculum that overwintered to the next year.

We need to do the same thing with ornamental diseases, both during a disease outbreak and after that outbreak. Rose black spot is a good example.

Each spring when black spot-susceptible roses leaf out, they are exposed to infections by *Diplocarpon rosae*. Where does the fungus come from? From spores that survived the winter on old black spotted leaves and canes.

You cannot prevent spores from blowing in from other areas but you can greatly lessen the amount of fungal inoculum and the amount of black spot disease by cleaning up infested debris from the previous year.

Not only that, but since this sanitation effort is never perfect, it is also important to clean up the black spotted leaves that develop during the current season’s infections. Do not wait until the end of the year to clean up the planting.

Of course, the other way to preventively manage *D. rosae* is to spray labeled fungicides on foliage as it emerges and develops in order to kill the fungus as the microscopic spores are germinating and trying to enter wet leaf tissue. This effort, too, is of course always imperfect as timing and complete coverage are always challenging.

So combining sanitation and fungicides to control the pathogen, and use of at least some black-spot-resistant rose varieties mentioned earlier, and modifying the environment that we will discuss later — all combine to provide good integrated rose black spot control. All too often only one facet of the triangle — e.g., use of fungicides — is employed, and control is inadequate.

Another example of sanitation to help control the pathogen is with hollyhock rust disease (*Puccinia malvacearum*). The orange turning to brick-red and chocolate-brown rust pustules are a common sight for almost everyone who has ever grown hollyhocks.

This fungus, like the rose black spot fungus has a repeating cycle that just goes on and on as the season progresses, so removing infested leaves during and after the season is one big key to getting the disease under control. Otherwise, it just gets worse and worse.

Fungicides help with hollyhock rust, but they must be applied multiple times and will not be enough without the help of removing pathogen inoculum when infestations do occur.

Another issue with hollyhock rust is a further aspect of sanitation — removal of additional hosts of *P. malvacearum*. It turns out that this fungus also infects a number of hollyhock’s relatives in the Malvaceae
family, including weeds such as the round-leaved mallow, Malva rotundifolia.

Sometimes plant diseases become issues only after pathogens arrive in an area. Dutch elm disease (Ophiostoma ulmi) is a classic example. American elm (Ulmus americana) and other elms native to the United States are highly susceptible to infection by O. ulmi. The environment conducive to disease is present. The missing ingredient until the 1920s was that the pathogen was not present in the United States.

Then, in the late 1920s, elm logs were imported to the United States and transported across the country in open, flat-bed railway cars. These European elm logs were infested with European elm bark beetles which in turn carried O. ulmi. The beetles hopped off, fed on American elms, and vectored the pathogen to these highly susceptible elms.

The result was an epiphytotic that continues to this day. The disease triangle was completed by the introduction of the pathogen to the United States.

Continued control efforts range from looking for genetic resistance in elms; sanitation in communities where the disease has not already swept through, including removal of any infested wood where bark beetles can survive; and use of fungicides and insecticides for the bark beetle vectors.

Without question, sanitation is often not enough to prevent key diseases. Sometimes it is a matter of practical marshaling of resources. Though cleaning up a rose planting of black spotted rose tissue or a hollyhock planting of leaves and stems with rust may be possible, cleaning up all the scabby leaves from crabapples or an apple orchard is too time consuming.

Fungicides, in conjunction with the other facets of the triangle, are clearly one important approach. Proper selection of the right fungicide, applied with appropriate timing to prevent infection (we are not good at eradicating infections), and application in the right way to obtain good coverage and limit off-target application are all keys to proper fungicide use.

**The Environment**

The importance of an environment that is conducive to specific diseases cannot be overemphasized relative to the disease-triangle concept and infectious plant-disease control. Rose black spot is again a telling example.

Typically, wet seasons mean heavy rose black spot, and dry seasons mean light rose black spot problems.

Of course, even a dry season can mean plenty of black spot if you irrigate regularly with overhead sprinklers. Therein lies a tale.

The tale is of greenhouse rose production. In the 1930s, rose black spot was a major problem in many rose greenhouse ranges. Today it is virtually non-existent. What changed? What facet of the disease triangle brought about this change?

Was it the host with new rose taxa with better genetic black-spot resistance? No. Was it better fungicides that preventively controlled Diplocarpon rosae during the infection process? No. The difference in incidence of rose black spot in greenhouse ranges between the 1930s and today is a change in the environment conducive to disease.
Here is what happened. One of the big problems in greenhouse rose production is spider-mite feeding. In the 1930s, the available miticides for spider mite control were inadequate. As a result, growers did the best they could; they washed off the spider mites with a coarse spray of water — many times a day. Presumably the spider mites could only take so much of this and in the end not as many of them made it back up to feed on rose leaves. The result was mite control — and serious rose black spot disease.

This was the case because Diplocarpon rosae needs water on the leaves in order to infect, the longer the better. During the 1940s and afterwards, effective miticides were developed, spider mite control resulted, and greenhouse rose growers no longer needed to wash the mites off the foliage regularly. In addition, over time growers have gone more and more to trickle irrigation.

Bottom line: virtually no water gets on the foliage of greenhouse-grown roses — and black spot has ceased to be a problem. Of course, production of these roses has migrated mostly to south of the border — but that is another story.

Unfortunately, if you grow roses outside, the equation shifts. You cannot control cosmic irrigation — rainfall — but you can still use the power of the triangle to limit the amount of time water is on the foliage.

Plant roses in sunny sites rather than in shaded areas where there are poorer drying conditions and poorer air movement. Prune surrounding vegetation and do a good job of weeding — all to limit moistness in the planting. And, when possible, use surface rather than overhead irrigation.

If overhead irrigation is unavoidable, at least water early in the day, giving foliage a chance to dry before nightfall. Sometimes even this is not enough, for example, in very wet seasons, which is why you must employ all facets of the disease triangle.

Attack rose black spot in your plantings by using resistant varieties to the extent possible, by doing a good job of sanitation, by using preventive fungicides, and by managing the growing environment of your roses.

As noted earlier, the environment and the role it plays cannot be overestimated. For example, in Kentucky, Indiana, and Ohio, during the past three years we have learned some real lessons about bacterial fireblight disease (*Erwinia amylovora*).

Prior to these years we did not consider Callery pears as being seriously affected by this disease. When it did occur, the fireblight strikes often extended only a few inches on the shoots, rarely causing any significant dieback down the stem.

One of the keys to fireblight, though, is the extent of blossom infections, and one of the environmental factors leading to blossom infections is warm, wet weather during bloom. During the past three years in our area of the country, temperatures during Callery pear bloom have been unusually warm.

These temperatures in the 70s and even 80s (Fahrenheit) have correlated with very unusual and severe amounts of fireblight on Callery pears with many strikes per
plant and strikes extending much further down the stem than is typical. We now need to pay more attention to which Callery pears are more susceptible.

At Secrest Arboretum in Wooster and other areas of Ohio, for example, ‘Aristocrat’ and ‘Autumn Blaze’ seem to be especially affected, and we may even lose several ‘Autumn Blaze’ specimens, which is something we would have never imagined. Not until, that is, warm weather occurred during the Callery pear blooming period in mid-April for the past two years.

So, when you think of infectious plant diseases, remember the disease triangle and use it as a way to develop an integrated way to understanding and approaching disease control.

Infectious disease is not a simple thing with simple solutions, but a dynamic interaction between a susceptible host, a virulent pathogen, and an environment conducive to disease. Focusing on this, you can find many ways to try to break that triangle.

Sometimes one approach will do — a host with great resistance, outstanding sanitation in a greenhouse environment, keeping water off the foliage. More often it is the creative combination of approaches that involve all three facets of the triangle.

**Expanding the Triangle**

As noted previously, the idea of the plant-disease triangle as a way of understanding and controlling infectious plant diseases can be expanded with a few modifications. It can apply also to insects and mites.

For example, consider our native bronze birch borer insect, *Agrilus anxius*. We know that birches differ in their susceptibility, with European and Asian birch species such as *Betula pendula* and *Betula maximowicziana* more susceptible than our native birches such as *Betula populifolia* and especially *Betula nigra*.

We know that the insect pest *A. anxius* can be at least partially controlled with insecticide applications. And we know that environment plays a role in the problem, with birches growing in hot summer soils being more affected than those with less root stress due to mulched, shaded, cooler soils.

Bronze birch borer is a bigger problem in Kentucky and southern and central Ohio than it is in the upper peninsula of Michigan or the New Hampshire woods. So, this plant pest triangle involves the susceptible host, the pest, and the environment conducive to pest infestation.

Fittingly, there is a third three-sided triangle, to consider — one that we call the horticultural problem triangle. What are the three components of this triangle? What are the needed factors for horticultural problems to develop?

Well, the host plant and the environment it is in are crucial, as with the other triangles. The third and final ingredient is — PEOPLE! Yes, as the cartoon character Pogo used to say: “We have met the enemy and he is us!”

We, the people, are often intimately involved in why plants decline. We are analogous, so to speak, to the pathogen and the pest in the other triangles.
So, let’s look at some of the main horticultural problems we perpetrate on plants. Let’s call them the...

Seven Deadly Sins of Horticulture

No. 1: Planting Too Deep.
Plant roots need water, of course, but they also need oxygen. The fact is, concentrations of oxygen decline with depth of soil. This becomes critical when transplanting, even with the difference of a few inches, because transplanting already has resulted in significant stress to or loss of the root system.

So, when transplanting in a landscape, it is important to plant such that we are not burying the root flare too deep. We used to say that transplants should be planted at the same grade as the plant came from the nursery, but that is not quite right. Sometimes, due to cultivation or the planting process in the nursery, the top of the ball is already significantly higher than the root system. So this must be adjusted to the extent possible at planting. Nevertheless, it is not uncommon to see trees and shrubs planted several inches to as much as a half foot or more too deep. Then everyone wonders why this tree declines in its first few months or years after transplanting. It is often simply too tough to overcome a bad start.

One final note: It is also a bad practice to plant too high, with the root ball sticking well out of the soil. “Plant ‘em high, watch ‘em die; plant ‘em low, never grow; plant ‘em right, sleep at night.”

No. 2: Over-Mulching.
Organic mulches are a great asset in the landscape. They are attractive and help prevent weed infestations. They help provide organic matter for the soil as they break down and thus help improve long-term soil structure. Mulches also help moderate soil moisture and temperatures. Mulched areas help prevent lawn mower and weed whip injury of woody plants by keeping us away from the plants. Composted mulches even provide a microbial mix which can help moderate effects of certain plant pathogenic fungi.

Yet we tend to overdo too much of a good thing. Organic mulches should be at a depth of about 2-1/2 to 3 inches. Mounds of mulches up against trunks reaching depths of 4, 6, 8, 12 inches and more are common and simply keep too much moisture against trunk tissue and in the root zone, turning good horticulture bad.

No. 3: Over-Fertilizing.
Fertilizers with NPK and with micro-nutrients as needed are important to plant growth and development. They are important components in the landscape and in nurseries and greenhouses. Yet they are also salts which can damage root tissue when over-applied.

Base application rates on soil tests and needs for optimal plant growth, rather than simply applying without
However, all too often we prevent good wound closure by leaving stubs or making flush cuts. And sometimes the cut we do not make is the unkindest un-cut of all. Pruning is time-consuming and time is money, but it is better to pay as you go rather than to let pruning needs get out of hand and pay much more later.

No. 6: Pesticide Misapplications.

Pesticides such as insecticides, herbicides, and fungicides are obviously useful tools in plant health-care management. But we must avoid turning them into iatrogenic agents. Say what?

Iatrogenesis, according to the American Heritage Dictionary is “induced in a patient by a physician’s activity, manner, or therapy.” In medicine, then, an iatrogenic agent then might be something like a drug in which the side effects are worse than its intended beneficial effect.

As plant doctors, our pesticides can become iatrogenic agents when an insecticide results in leaf scorch or an off-target herbicide causes leaf curling on desired plants in addition to killing unwanted weeds. For that matter, all of the good horticultural practices gone bad, from over-mulching to over-watering, are examples of iatrogenic agents. Just don’t do it!

No. 7: Second-Degree Girdling.

This is our final example of when one of the seven deadly sins really turns into a crime. Loose non-degradable twine or wires at the planting of a tree become tight as time passes as the plant stem grows outward as new plant cells are
being produced by the vascular cambium in the stem.

This twine or wire becomes tight enough that it surrounds the stem, imbedded in the inner bark where the plant phloem is conducting food produced in the leaves down the stem to the roots. This girdling twine or wire thus girdles the stem, food backs up above the point of girdling, and the roots below the girdle die. The rest of the plant soon follows.

All because the natural conducting system of the plant no longer functions and the roots starve. All because of the action of us — the plant criminals. Yes, we may claim we did not mean to do it — that it was not pre-meditated murder. Fine, maybe it is second-degree murder — but the plant is dead nevertheless.

You might say that these things are all so obvious — yet they are also all so common. As we said earlier: It’s not one darn thing after another — it’s the same darn thing over and over and over again.

To break these triangles, to fully employ the power of the triangle, learn to think in three dimensions.

Note: This article is adapted from one by the same authors published in the May 1, 2003, issue of American Nurseryman.
The USDA Agricultural Research Service Research Weather Station Network in Northern Ohio Nurseries

Ross D. Brazee, Keith A. Williams, David Lohnes, Richard C. Derksen, Heping Zhu, Randall H. Zondag, and Charles R. Krause

Brazee et al. (2002) reported on the status of efforts to develop a research weather network. The network is a part of cooperative research programs of the Application Technology Research Unit (ATRU) of the USDA/Agricultural Research Service, The Ohio State University, Ohio Agricultural Research and Development Center (OARDC) and nursery growers of Lake County, Ohio. This report will summarize some further developments of the network and provide information on accessing weather data.

The Weather Stations

The permanent weather stations at Sunleaf Nursery, Madison, Ohio, and at Klyn Nursery, Perry, Ohio, equipped with adapted UT-30 systems (Campbell Scientific, Inc., Logan, Utah), are intended to serve research programs and growers in the Lake County area. Data from these stations are available on a network web site. Individual growers may expect some variations in data from those that may exist at their own locations, particularly in growing degree-day information. These locations were selected as representative of commercial nursery locations, and of known or expected differences due to terrain and distance from Lake Erie. Local observations of selected data may be helpful in determining which station most nearly reflects a particular site.

A moveable station equipped with a Campbell Scientific CM-6 system is located in research plots at Madison. Data from this station is archived but not normally available at the web site. However, an experimental leaf wetness system is located with this station in a tree canopy. Some of this data is available at another web site on a seasonal basis.

Another permanent weather station is planned as part of a research program being developed at Willoway Nursery, Avon, Ohio. Meantime, this station is equipped with a CM-6 moveable system, with data currently available on the network web site.

Additional equipment has been installed and work is underway to connect the
Madison UT-30 station to the Soil Climate Analysis Network (SCAN) in cooperation with the USDA/Natural Resources Conservation Service (NRCS). This installation will enable inclusion of the Madison station on a national network, as well as providing supplemental soil moisture and temperature information.

**Instrumentation**

Brazee et al. (2002) list the main climatic variables for which data are archived or transmitted into the network, namely, wind speed and azimuth (direction), air temperature, relative humidity, and solar radiation. Rain or snow data are reported as equivalent liquid precipitation.

In the year 2003, soil temperature measurement capability was added to instrumentation at the Madison station. Soil temperature is measured at 2-, 4-, and 8-inch depths, and this data is accessible on the network web site. Later, NRCS personnel installed soil-temperature and moisture-sensing units near the existing sensors, but at depths of 2, 4, 8, 20, and 40 inches. Since special processing is required, these data are not currently available on the existing web site and will eventually appear on the SCAN Network.

Campbell Scientific leaf wetness sensors have been deployed experimentally at the CM-6 site at Madison since early 2002 and provide data on surface moisture resulting from either dew or rainfall. They sense moisture by means of electrical resistance and must be specially coated with white latex paint and aged for a period of time by the user before being deployed.

NRCS personnel have installed an auxiliary 20-ft. tower supporting a meteor-burst telemetry system to enable data transmission to the SCAN Network. Additionally, they have installed soil moisture and temperature sensing units at 2-, 4-, 8-, 20- and 40-inch depths.

**Data Access**

Data from the Avon CM-6 station and the Madison and Perry UT-30 stations are accessible at:

[www.oardc.ohio-state.edu/usdaweather/](http://www.oardc.ohio-state.edu/usdaweather/)

Either the Avon, Madison, or Perry station can be selected from among the links at the web site. The remaining links at the web site are for other locations in the OSU/OARDC Ohio network.

Wind speeds are shown in bar graph form, with wind direction given as arrows appearing at the tips of the wind-speed bars in azimuth degrees (zero to 360) clockwise from zero (north). Note that the wind azimuth arrows indicate the direction from which the wind is coming.

Occasionally, in freezing-rain conditions, the cup anemometer and even the wind vane may lock up due to icing. This gives the appearance of zero wind velocity, while the wind azimuth is indicated as north. This is a default azimuth indication, since anytime wind speed falls to zero, its azimuth becomes meaningless.

On the same page, air temperature and relative humidity are presented as red and blue “step” plots, respectively. Units of measurement are indicated for all plots, and numerical values can be read