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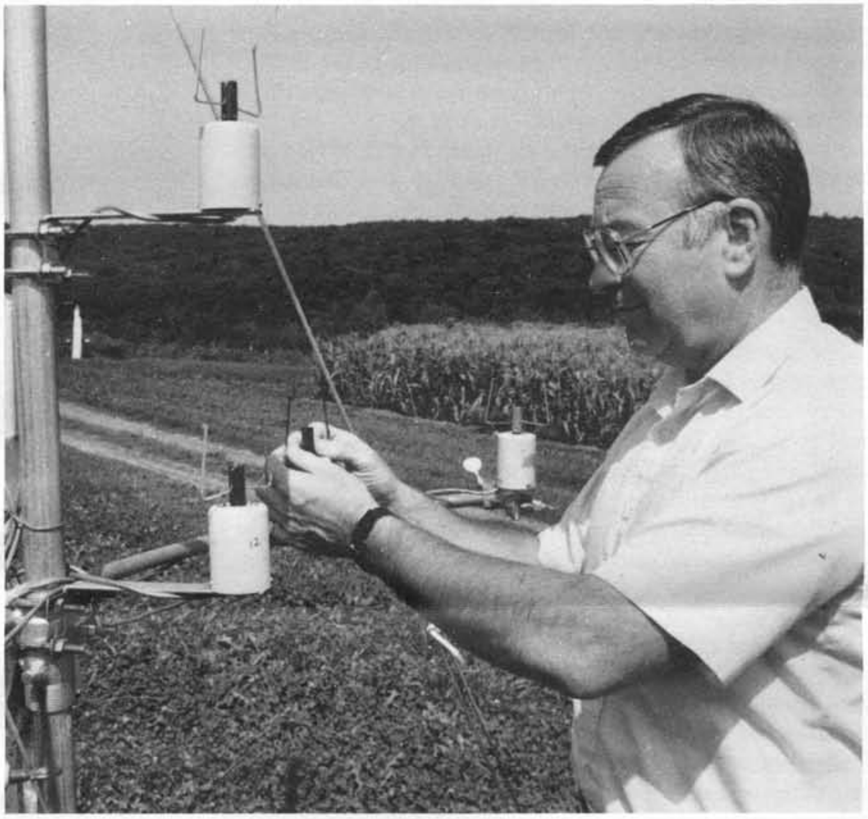

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Raspberries: a revived crop for Connecticut farms

By George R. Stephens and Richard K. Kiyomoto

Although raspberries were once commonly grown on Connecticut farms, low yield, trellis requirements, and labor shortage led to their abandonment. However, because raspberries are highly perishable, fresh fruit sales are ideally suited to a local market. Because of Connecticut's high population density and the popularity of pick-your-own, raspberries now seem made to order for increased production.

Normally, raspberries produce a biennial cane. Vegetative growth occurs the first year (*primocane*) and flowering, fruiting, and death of the cane (*fructocane*) occurs in the second. The fruit generally ripen in midsummer. Conventional management requires annual removal of dead fructocanes, thinning of primocanes, and trellising to support the canes.

The introduction of Heritage, a cultivar with heavy fruit set on new canes in late summer and early autumn and a simplified system of management, suddenly made raspberries a more promising crop. With a heavy fall crop, there is little incentive to carry the canes for a second year. Thus, the canes can be mowed to the ground in early spring. The need for thinning and a trellis was eliminated. However, this made raspberries available only from late August until early October. Furthermore, early fall frost could terminate the harvest prematurely.

In 1986 John Elliston of the Experiment Station surveyed Connecticut raspberry growers and found that 33 farmers were growing raspberries on approximately 42 acres. About 86% were red raspberries and 71% of the red raspberries were Heritage managed for a fall crop only. All were marketed as pick-your-own. Accordingly, the Station embarked on raspberry research in 1987 with cultivar and cultural practices trials, principally with summer bearing types.

The cultivar trials contained red, black, and purple raspberry cultivars. Purple raspberries, hybrids of red and black raspberries, display some characteristics of each. The red raspberry cultivars included summer-bearing Festival, Canby, Taylor, and Titan and fall-bearing Heritage and Ruby. The black raspberries were Haut and Jewel; and the purple raspberries were Brandywine and Royalty, all summer bearing. Planting was in spring 1987. Losses were replaced in spring 1988 and all plants were cut to ground level to encourage upright growth. In the cultivar trials, plants were set 30 inches apart in rows 12 feet apart (1344 plants/acre). In the cultural practices trial Canby and Titan plants were set 24 inches apart (1815 plants/acre).

The cultural practices trials included four trellis types and two methods of aisle management. *Linear trellis* is used extensively in Scotland and the Pacific Northwest and is intended to produce a smaller number of larger berries. The trellis had two wires at 24 to 30 inches and one at 48 to 54 inches above ground and no crossarms. The lower wires were spaced 1 inch apart, and developing primocanes were trained to grow between them. These wires were clipped together at intervals between posts to support the canes. In early spring the canes were thinned to the strongest 6 to 8 per "stool", laced to the top wire about 3 to 4 inches apart, and pruned to extend no more than 4 to 5 inches above it. During the growing season primocanes appearing outside a 1-foot band beneath the wires were removed.

Figure 1. Richard K. Kiyomoto with raspberries growing on a Narrow Trellis.

The *narrow hedge trellis* had a crossarm at 24 to 30 inches that held a pair of wires 24 inches apart; another crossarm at 48 to 54 inches held a pair of wires 36 inches apart. A pair of guidewires just above ground level and 12 inches apart determined the width of the hedge. Primocanes growing outside of the guidewires were removed periodically during the growing season. In early spring canes were thinned to three or four per linear foot of row. With this trellis, fruiting canes and primocanes were intermingled. Developing primocanes were shaded and harvest was more difficult.

The *narrow hedge "V" trellis* was almost identical to the narrow hedge trellis, except two additional movable wires were installed on the upper crossarm 1.5 inches inside the first set. At flowering these movable wires were used to pull the fructocanes against the outer wires to open the center and form a "V". The wires sandwiching the fructocanes to the outside were clipped together at intervals to restrict cane movement. Spreading the fruiting canes to the outside had two benefits: fruit was confined to the outside of the hedge for easier spraying and harvest, and developing primocanes grew up the middle fully exposed to sunlight, which should produce stronger growth and increase yields.

Table 1. First pick, harvest span, yield (lb/acre), and berry weight (oz/100 berries) of raspberries at Lockwood Farm in 1989 and 1990.

Type Cultivar	1st pick mm/dd		Span days		Yield lb/A		oz/100 berries	
	1989	1990	1989	1990	1989	1990	1989	1990
Red								
Canby	6/30	7/02	31	18	6140	2491	7.96	6.80
Festival	6/30	7/02	35*	37	6562	5313	8.25	6.95
Taylor	7/04	7/05	31*	34	4356	2162	7.53	5.78
Titan	6/30	7/02	35	26	2894	1595	12.18	7.57
Black								
Haut	7/05	7/02	16	22	2958	1600	5.33	4.37
Jewel	7/05	7/02	16	22	2575	1241	7.27	5.43
Purple								
Brandywine	7/05	7/11	30*	30	3988	3199	10.17	8.68
Royalty	7/05	7/11	30	17	3772	3368	10.27	10.83

* A few berries continued to ripen after the last harvest.

The *wide hedge trellis* was similar to the narrow hedge except that the hedge was allowed to spread 24 inches wide at ground level, and the wires on the lower crossarm were 30 inches apart. The only advantage of this trellis was that canes were more widely spaced and air movement was better.

Sod aisles were established by seeding to mixed grasses. The sod was mowed biweekly. A 2-foot wide band along the row was maintained weedfree with herbicide and selective hoeing and pulling of weeds. *Bare aisles* were maintained weed-free by periodic shallow rototilling.

One function of the cultivar trial was to determine whether cultivars were suitable for Connecticut conditions. During winter 1987-88 there was no observable winter injury to canes or buds. However, during 1988-89, winter injury of red raspberries was pronounced. The percentage dieback, estimated from dead buds, was least on Festival and Taylor, 8 to 11%; and greatest on Titan, Canby, Ruby, and Heritage, 33 to 40%. In 1989-90, winter injury was less, 5% on Festival and 13 to 15% on Canby, Titan and Taylor. In 1989 in the cultural practices trial, dieback of Canby was 30% and Titan, 49%. In 1990 dieback was 10% for Canby and 20% for Titan. Trellis type or aisle cover had no effect on winter injury. In 1988-89, winter injury on black and purple raspberries was slight and restricted to cane tips. In 1990, injury on Haut and Jewel was 13 and 10%; on Brandywine and Royalty, 34 and 25%.

The first yield was from Heritage and Ruby. Harvest began August 19, 1988 and continued until October 6 (7 weeks). Heritage yielded 7700 lb/acre and Ruby, 5900 lb/acre. In 1989, during August 17-October 16 (nearly 9 weeks), Heritage yielded 3645 lb/acre and Ruby, 1657. Yield in 1989 compared to 1988 was 45% for Heritage and only 28% for Ruby. This great yield reduction was partly due to frequent rain which inhibited pollination and fruit ripening and favored fruit rot.

The remaining red, black, and purple cultivars were first harvested in summer 1989. The first harvest date, harvest span, and yield are shown in Table 1. In 1989, both Festival and Canby yielded well, more than 3 tons/acre. The low yield of Titan was due to poor survival of the plants. During winter 1988-89 many canes split apart at the base and subsequently dried. A long harvest span benefited Festival, but not Titan. In 1990, yields were reduced with Canby, Taylor and Titan producing half or less of 1989; only Festival approached the 1989 yield. Black and purple raspberries yielded less than the red in both years. In 1989, Haut and Jewel yielded more than in 1990 even though the harvest span was 6 days shorter. In 1989, the purple raspberries had nearly twice the harvest span of black, but their yield was only 45% greater. Yield of Brandywine and Royalty was about 20% less in 1990 than in 1989.

The influence of aisle cover and trellis type is shown in Table 2. In 1989, yield of raspberries with sod aisles was about 23% greater than with clean cultivation. Root injury may have occurred during shallow rototilling because suckering was clearly greater on the bare compared to sod aisles. There appeared to be less rain splash of mud on low berries in sod aisles. In 1990, the yield reduction on bare aisles persisted only for Canby; yield of Titan was the same on sod or bare aisles. In 1989, linear trellis reduced yield about 33% compared to the other trellises; in 1990, yield of Canby was greatest on linear trellis, but least for Titan. In 1990, differences among trellises were variable; wide and narrow-V yielded more than linear or narrow hedge. In the 1989 cultural management trial, Titan yielded more than Canby and the longer harvest span for Titan accounted, in part, for the increased yield. In contrast, Canby yielded slightly more than Titan in 1990, despite a shorter harvest span. It is not clear whether the prolonged hot weather of July 1990 affected harvest span and reduced total yield.

Based on the results of 2 years, Festival and Canby were the most promising red raspberry cultivars for summer yield. The large berry size of Titan would likely make them very attractive in a pick-your-own setting, but Canby had better flavor and better keeping quality. Festival was an attractive berry with good flavor, but it tended to shatter when picked unless completely ripe. Although the black raspberries have their own distinctive flavor, the lower yields would require a premium price in order for a farmer to realize the same financial return as red raspberries. The sharp thorns would likely deter some from picking. Although purple raspberries yielded more than black, their yield was substantially less than most of the red raspberries.

The cultural practices trial clearly showed that linear trellis offered no advantage over other types of trellis (Table 2). In view of its greater labor requirement for tying the canes, it will not likely find use among farmers. In 1990 the canes were not tied to the top wire. The increased yield from raspberries with sod aisles came as a surprise; it was anticipated that the competition from grass would decrease yield. Observations during picking suggested that fewer low berries were splashed with mud after heavy rains. This contributed to the increased yield. Certainly, sod underfoot was much more comfortable than bare soil, especially after heavy rain.

The trials continue. In the future new cultivars will be added, unsuitable ones deleted, and practices will be amended in our attempt to increase yield in this promising crop.

Table 2. Red raspberry yield (lb/A) according to aisle cover and trellis type at Lockwood Farm in summer 1989 and 1990.

Cultivar	Aisle	Year	Linear	Narrow	Narrow-V	Wide
			lb/acre			
Canby	Bare	1989	2684	4894	4658	5567
		1990	2601	1883	3485	2929
	Sod	1989	4839	7476	7548	7331
		1990	3682	2828	3151	2857
Titan	Bare	1989	4389	5960	7380	6700
		1990	2173	2457	2612	4232
	Sod	1989	5434	6506	6833	7978
		1990	1959	2887	2957	3346

Glossy leaf wax in cole crops affects insect resistance

By Kimberly A. Stoner

The cole crops, including cabbage, broccoli, cauliflower, Brussels sprouts, collards, and kale, are popular with many consumers and home gardeners for their excellent nutritional value, their versatility in many different types of cooking, and their variety of flavors and textures. But anyone who has grown plants of this group knows they are also popular with several different species of insects.

The premier pest of cole crops in this area, and certainly the most highly visible, is the imported cabbageworm. The name comes from the fact that this caterpillar was accidentally imported from Europe to North America in the 1860's. The velvety green caterpillar is about an inch long when fully grown, and the adult is a very common large white butterfly with black dots on the wings. The caterpillar damages the plant by eating holes in the leaves, and reduces the attractiveness of the produce when the consumer finds bodies of caterpillars or masses of their wet, greenish excrement in a cauliflower or broccoli head.

Figure 1. Kimberly A. Stoner with a colony of imported cabbageworm butterflies.

Another common pest on cole crops is the larva of the diamondback moth, a smaller green caterpillar that develops into an inconspicuous moth with a gray and brown diamond-shaped pattern. This insect is widespread but not often damaging in Connecticut because of its many effective natural enemies. But in areas where high amounts of insecticide are used on cole crops, diamondbacks have developed insecticide resistance and escaped from their more susceptible natural enemies to become a very serious problem.

The cabbage aphid is also an important pest of cole crops. This is a green aphid that covers itself with a waxy gray coating. These insects use their sucking mouthparts to remove sap and inject chemicals into the plant, distorting the growth pattern by causing the leaves to curl and shrivel. The aphids may also be found by the consumer in the final product, reducing its attractiveness and value.

Flea beetles, tiny shiny black beetles that eat "shot holes" in leaves, are mainly a problem just after planting in the spring, when they may overwhelm a small plant, but they also feed on leaves in large numbers in the fall.

All of these insects are affected by changes in the leaf wax of cole crops. Although all plants have wax on the surface of their leaves, cole crops normally have a particularly thick and structurally complex layer of wax (see Fig. 2A), which gives them the characteristic hazy blue-gray color of cabbage plants seen at a distance. I have made a collection of plants with different naturally occurring mutations in the genes that interfere with the production of normal wax. These plants

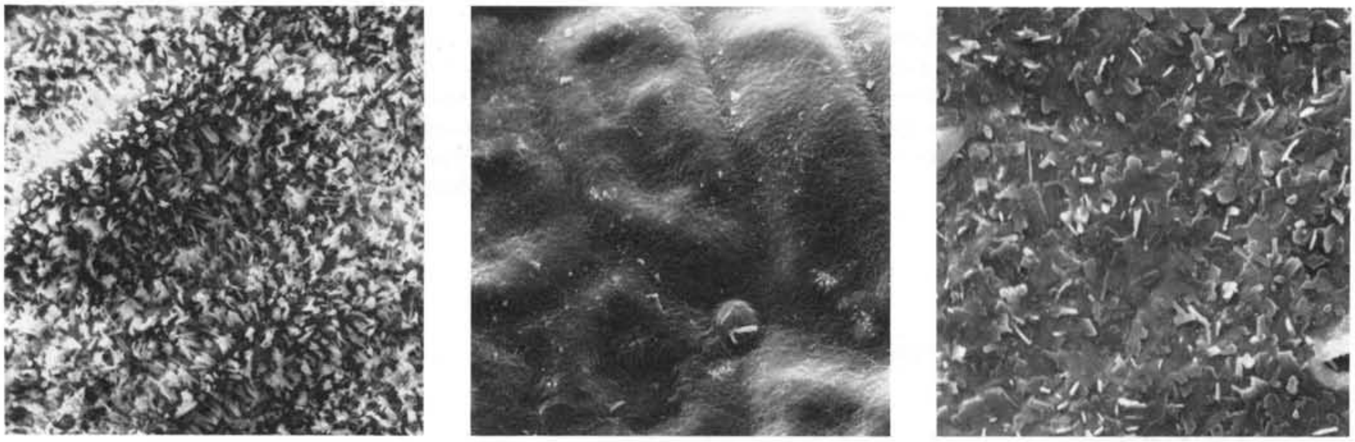

Figure 2. Scanning electron micrograph of the surface of normal and glossy broccoli leaves. (A) Packman, a commercial variety with normal wax. (B) Broccoli 3, a glossy strain. (C) Broccoli 5, a strain intermediate in glossiness (x1300)

Photograph by Alan Pooley, Yale Peabody Museum

appear to be glossy, rather than hazy, and dark green. Under the scanning electron microscope, there may be almost no visible structures at all (Fig. 2B) or there may be sculptured plates (Fig. 2C), or thinly scattered knobs or filaments.

I have measured resistance to insects in plants with glossy and normal wax by planting them in the field (four plantings per year in early May and in mid-July, and at both the Lockwood Farm in Mt. Carmel and the Valley Laboratory in Windsor), allowing them to be attacked by the naturally occurring populations of insects, and counting the number of insects on each plant every 2 weeks during the growing period. Some of these data from plantings at the Lockwood Farm are shown in Table 1. (All data are from 1989 except for those for the diamondback moth. Because diamondbacks were scarce in 1989 in both locations, data from 1988, when Broccoli 5 was not planted, are shown).

Glossy plants tend to be more resistant to imported cabbageworm, diamondback, and cabbage aphid than normal plants. The resistance to imported cabbageworms and cabbage aphids has been very consistent among many genetically different glossy plants in four different crops (broccoli, cauliflower, collards, and kale) and with differences in wax structure. Resistance to diamondbacks has been consistent in some glossy lines, but others vary in resistance from one planting to another.

Flea beetles, however, have a different response to glossy wax. In spring, there are plainly more flea beetles on glossy plants than on normal plants. In fall, there are no significant differences in the numbers of beetles on glossy and normal plants, but the glossy plants still look more heavily damaged. I have begun to study the behavior of spring and fall generations of flea beetles on glossy and normal plants in the laboratory in order to address some of the questions raised by these field studies: Why are the relative numbers of flea beetles on glossy and normal plants different at different times of the year? Is flea beetle behavior different in the spring than in the fall? Are counts of flea beetles good predictors of damage? Do flea beetles feed differently on glossy plants, causing damage out of proportion to their numbers?

I have also started more intensive studies of imported cabbageworms in the field and laboratory in order to better understand why glossy plants are resistant to them. I have found fewer imported cabbageworm eggs on glossy than on normal plants, so glossy plants may be less attractive to the butterflies laying eggs or more attractive to predators eating the eggs. However, the differences in numbers of caterpillars between glossy and normal plants are much larger and more consistent than differences in numbers of eggs. This means that the strongest resistance must act on the caterpillar stage.

There are three possible ways that glossy wax could cause resistance to imported cabbageworm caterpillars. The wax could be toxic to the caterpillar, it could affect the caterpillar's behavior, or it could interact with other forces in the environment (such as predators, diseases, or rain), causing them to kill more caterpillars. The wax itself is probably not directly toxic to the caterpillar, because it survives and grows just as well when confined on glossy plants as on normal plants in the greenhouse.

Wax has been shown to affect the behavior of other caterpillar species, so it may affect imported cabbageworm behavior, too. I am focusing on the behavior of newly hatched caterpillars to see if the glossy wax causes them to move farther or take longer to begin to feed, and to see how much they feed. If a caterpillar wanders more and feeds less on glossy plants, it would be more likely to encounter hazards in its environment, and it could wander off the plant entirely and die.

Table 1. Average number of insects per plant on glossy and normal broccoli summed over four to five samples during the growing period. (NA means that data are not available).

	Imported Cabbageworm	Diamond-back	Cabbage aphid	Flea beetles	
				Spring	Fall
Normal					
Cruiser	5.7	8.8	594.5	9.7	30.2
Packman	4.7	8.8	362.5	8.8	26.3
Glossy					
Broccoli 3	0.2	1.5	6.2	33.3	37.8
Broccoli 5	1.0	NA	26.8	36.5	29.2

Glossy wax could also cause resistance by directly increasing the mortality due to environmental forces. Glossy plants could be more attractive to predators, or a better environment for disease-causing organisms. Or, the differences on the plant surface could make the caterpillar more susceptible to non-biological factors such as being knocked off the plant or drowned in a puddle of water.

I plan to determine how the resistance operates, so I can find an easy, repeatable test for plant breeders to use in selecting the most resistant individuals in a population of glossy plants. These plants can then be used as sources of resistance to produce commercially attractive varieties that yield well and are also less popular with imported cabbageworms, diamondback moths, and cabbage aphids.

Modeling aerial dispersal of the apple scab fungus

By Donald E. Aylor

Apple scab, caused by the fungus *Venturia inaequalis*, is the most serious disease of apples in Connecticut. The disease can reduce fruit quality, and in severe infestations, can render it unmarketable. It also causes leaves to drop prematurely and decreases the vigor of the tree. The pathogen is spread to developing apple leaves and fruit in the spring by airborne spores released from infected leaves that overwintered on the ground (Fig. 1). Spores are the microscopic seeds of a fungus. The fungus causing apple scab produces two types of spores: *ascospores* (spring spores) and *conidia* (summer spores). The disease is controlled primarily by applying fungicides during the 8 to 10 weeks (usually during early April to mid-June) when the ascospores are actively discharged. The need for subsequent fungicidal sprays to control scab infections caused by conidia depends largely on the extent of the control of primary infections caused by ascospores.

If the danger of primary infection can be made slight, either by reducing the number of ascospores in leaves on the ground to a low level or by reducing the number of ascospores that become airborne, it may be possible to substantially reduce the amount of pesticide used to control apple scab. This proposition raises two important questions. First, how small must the number of overwintering ascospores in an orchard be to reduce fungicide applications? And second, what is the likelihood that infections will occur from ascospores arriving from sources outside of the managed orchard, e.g., an abandoned orchard or nearby crabapple trees?

To answer these questions for a particular orchard, we need to be able to predict the number of possible infections from these sources of spores. To do this we require a model for the aerial transport of ascospores.

Given that the wind is blowing in the right direction, the likelihood of an ascospore landing on an apple fruit or leaf depends on the number of spores released into the air at the source, the dilution of the numbers of spores per volume of air by atmospheric turbulence, and the loss of spores from the air by deposition onto plants and the ground. These parts of the spore transport process can be combined to yield an estimate of spore deposition at various distances from a source. Loss of spore viability during spore flight is generally not a major factor under the conditions that *V. inaequalis* ascospores are dispersed.

Deposition, D, of spores per area per time in an orchard can be calculated knowing the deposition rate, v_d, and the concentration, C, of spores in the air. C can be expressed in terms of the number of ascospores, Q, discharged into the air at the source, the fraction, E, of these spores that escape from the ground cover into the more freely moving air above, and the dilution of C by turbulent mixing during transport, T, which includes losses by deposition to the ground. We can summarize this in the following equation:

$$D = v_d \, x \, Q \, x \, E \, x \, T$$

To obtain the total number of spores deposited during transport, we must integrate D over the duration of the passage of the cloud of spores over the orchard.

The powerful mixing action of atmospheric turbulence, embodied in T, causes aerial spore concentrations to decrease rapidly with increasing distance from a source. For example, atmospheric turbulence alone can decrease spore concentration near the ground by a factor of about 10^5 (one-hundred thousand) within 1 mile of a 10 acre orchard. This suggests that external sources of *V. inaequalis* ascospores may be relatively unimportant compared to sources within an orchard. However, the validity of this depends greatly on size and proximity of the external source of spores.

Our equation shows that reducing Q by practicing sanitation, i.e., by cleaning up and removing diseased leaves from the orchard to keep inoculum levels as low as possible, will directly reduce D. Q can be reduced in several ways, e.g., by killing the fungus by spraying the leaves with a fungicide after harvest but before leaf fall, by removing the fallen leaves and cull fruit from the orchard, or by chopping leaves and adding nitrogen to encourage their decomposition by microbes.

Another way to potentially reduce D is to try to keep escape as small as possible. Based on my earlier studies of rust diseases of wheat and beans and blue mold of tobacco, there is reason to believe that the number of ascospores that become airborne, and thus are potentially transported long distances, might be reduced if the ground cover in an orchard is allowed to grow a foot or more tall during the spring. To see how this might help, we need to understand something about how ascospores initially become airborne and about how wind speed and turbulence vary with height above bare ground and in a grass canopy.

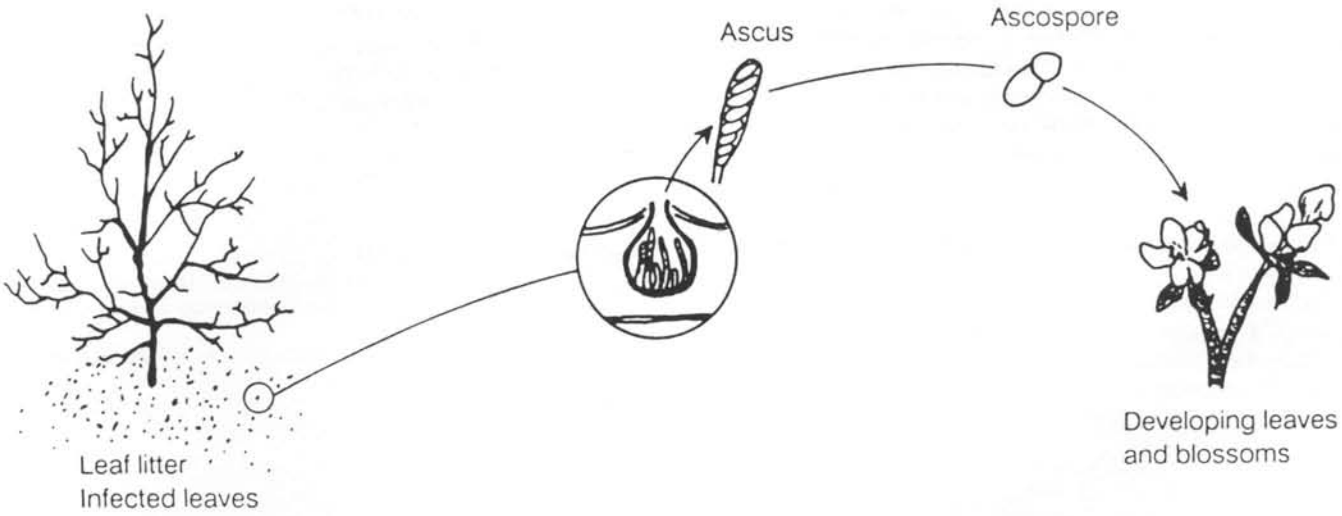

Figure. 1. In the spring, ascospores (middle, scale greatly magnified) are released during periods of rain from infected leaves that overwintered on the ground (left) and are carried by the wind to newly developing apple leaves and fruit (right).

Ascospores are actively released (usually during daylight) when the leaves are wetted by rain. My colleague, Sandra Anagnostakis, and I allowed ascospores of *V. inaequalis* to discharge into still air inside small chambers. We found that ascospores were generally actively projected between 0.004 to 0.3 inch (0.1 to 8.1 mm) away from the leaf surface. The majority of the ascospores were projected between 0.08 and 0.12 inch (2 and 3 mm) from the surface, and only 1% were projected as far as 1/4 inch (6.5 mm).

The distance that ascospores are actively projected into the air depends on the balance of forces acting on the spores. By placing *asci* (the sacks that enclose the ascospores) in varying strengths of sucrose solutions and observing them under the microscope, we found that the osmotic potential inside an ascus with mature spores is between that of a 2 and a 3 molal solution of sucrose. Osmotic potential is a measure of the tendency for water to flow across a semipermeable membrane in the direction of higher solute concentration. Spore discharge ultimately occurs because water flows across the ascus membrane and into the ascus. Because of this osmotic potential gradient, the hydrostatic pressure inside the ascus increases enough to cause the membrane to break. The spores are then projected outwards. We modeled the movement of ascospores during discharge by considering the forces acting on them: the pressure acting to project the spores outwards and the aerodynamic drag acting to retard the outward motion of the spore. The discharge distances predicted are in reasonable agreement with the distances observed.

We also observed that ascospores are not discharged when asci are placed in sucrose solutions of 1 molal or greater concentrations. If we could control the osmotic potential of the external solution to above this level, perhaps we could keep spores from becoming airborne. Although doing this seems impractical at present, it still is worth keeping in mind.

Mature ascospores are discharged once the leaf tissue is sufficiently wetted, whether the wind is a gentle breeze or a gusty gale. Within an inch or two above the ground in a grass canopy, wind speeds are generally only a fraction of those at comparable heights over bare ground (Fig. 2). The probability that a spore will be deposited on the ground, instead of an apple leaf, depends on: the settling speed of the spore (0.2 cm/sec for *V. inaequalis* ascospores), the level of turbulence, and the length of time that the spore spends near the ground. The time in contact with the ground for a spore in a grass canopy is expected to be much longer than for a spore over bare ground. Thus, it seems reasonable to expect that spores released inside a grass canopy will travel shorter distances before being deposited. My model calculations, based on average wind statistics, suggest that as many as ten times more spores will be deposited in grass than on bare soil for otherwise comparable conditions.

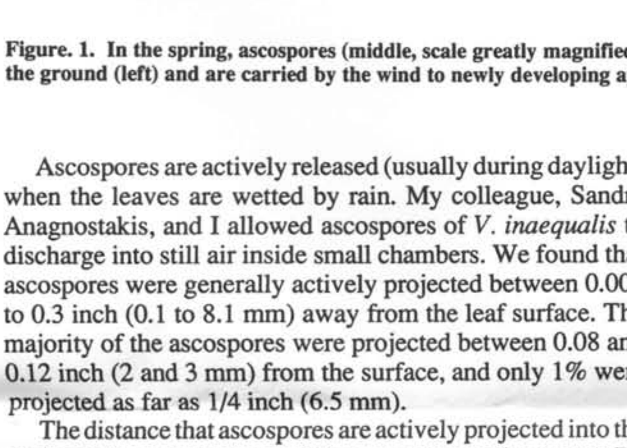

Figure 2. The average wind speed (shown by the heavy solid line) differs considerably for bare ground (left) and for a canopy of grass (right). Simulated trajectories of spores released near the ground, shown by the irregular lines, confirm the expectation that ascospores released in grass may travel shorter distances before being deposited.

My model needs to be improved to reflect the intermittent nature of the wind. Close to the ground in a canopy of grass, the average wind is a result of relatively long quiescent periods and occasional bursts due to gusts that periodically penetrate the canopy from above. To better quantify escape of ascospores, some of our studies will examine the importance of these gusts in ventilating the canopy and dispersing spores.

In addition to using mathematical models to answer these questions, we are also making field measurements. To quantify ascospore dispersal by wind we are making simultaneous measurements of spore concentration and wind speed at various heights above the ground. These measurements will allow us to calculate the number of spores per time that are passing our samplers and to obtain a measure of the rate of release of ascospores from the leaf litter.

Finally, we are developing an independent biological method to assess the number of ascospores released from leaf litter. Using modeling and experiments, we are tracing the flight of ascospores from their point of release in the litter layer to their ultimate deposition on susceptible apple leaves and fruit. Using this information we hope to judge the potential benefit of sanitation and ground cover in the integrated management of apple scab.

ADDITIONAL READING

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