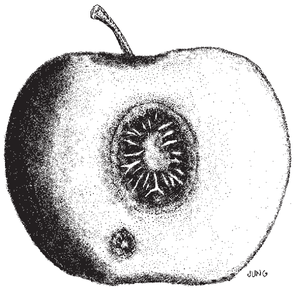
DISEASES (Fungal and Bacterial pests)

APPLE SCAB BIOLOGY and EPIDEMIOLOGY



Apple scab, caused by the fungus *Venturia inaequalis,* is the most important disease of apples in New England. This is because the humid, temperate climate and frequent rains, particularly in spring, provide favorable conditions for infection by the fungal pathogen. In addition, major commercial cultivars are also highly susceptible to scab. (Table 2).

Table 2 – Disease susceptibility of selected New England apple cultivars to apple scab, rusts, and powdery mildew.*

Cultivar	Scab	Quince Rust	Cedar Apple Rust	Powdery Mildew
Cortland	4	3	3	4
Delicious	3	3	1	2
Empire	3	2	2	3
GingerGold	-	-	-	4
Golden Del.	3	3	4	3
Honeycrisp	3	-	-	-
Idared	3	2	3	3
Jerseymac	4	—	1	—
Jonagold	4	3	3	3
Macoun	4	2	2	3
McIntosh	4	1	2	3
Mutsu (Crispin)	4	2	3	4
Paulared	3	1	2	3
Spartan	3	2	2	2

Key to ratings: — = not rated

1 = Resistant. No management needed for the disease.

2 = Slightly susceptible. Normal management may be reduced.

3 = Moderately susceptible. Normal management adequate.

4 = Highly susceptible. May require extra management.

***Adapted from**: *Management Guide for Low-Input Sustainable Apple Production*. 1990. USDA et al.

The disease can be devastating, causing reduction in fruit quality and yield. Severe foliar infection can lead to premature defoliation.

The apple scab fungus overwinters on fallen apple leaves that had been infected during the growing season. Fungal reproductive structures (pseudothecia) are produced in the infected leaves on the orchard floor in autumn. In spring, usually beginning around green tip, mature ascospores are produced in these pseudothecia and are discharged into the orchard air when there is sufficient rain (at least 0.01 inch) to wet the leaves.

Ascospore maturation usually continues until approximately 760 Degree Days (DD) (base 32 F) have accumulated from silver tip/green tip. As a conservative estimate, the final scab ascospore release in commercially managed orchards can be assumed to have occurred when 900 DD have accumulated before a daytime rain of at least 0.1 inch and temperatures of at least 50 F during the wetting period. Exceptionally dry periods can delay the end of ascospore maturation and release.

This period during which ascospores are being released from overwintered, infected leaves is referred to as the *primary* scab season, and lasts roughly 6–8 weeks. The duration of scab season in any one year depends on temperatures and frequency of rain. Initial infections by ascospores (called primary infections) can occur on various susceptible apple tissues (e.g., young leaves, petioles, sepals, pedicels and young fruit). Whether or not discharged ascospores will cause infection depends on temperature and the length of time susceptible tissue remains wet after ascospores land on the tissue. If infection does occur, scab lesions will become visible in 9 to 17 days, depending on the average temperature during the incubation period (see Table 3).

Scab lesions are important to the epidemiology of the disease because they produce spores (conidia). Spores are dispersed by rain or heavy dew to susceptible tissue, usually on the same tree, where the spores can cause additional infections (called *secondary* infections).

Each scab lesion can produce conidia for four to six weeks. After ascospore discharge has been completed, scab lesions are the sole source of spores for the remainder of the growing season.

IDENTIFYING PRIMARY INFECTION PERIODS

The key to managing scab is *preventing primary infections*. By successfully preventing or limiting the development of primary lesions, the threat of continued infection by conidia is reduced. Thus, it is important to determine if a scab infection period has occurred. Use Table 3 and the procedure described below to identify infection periods during the primary scab season:

- When rain begins *during the day* (between 8:00 a.m. and 7:00 p.m., DST), count the hours of leaf wetness from the first hour rain is recorded until the leaves are dry.

- When rain begins *at night* (between 7:00 p.m. and 8:00 a.m., DST), count the hours of leaf wetness *from 8:00 in the morning* until the leaves are dry.

Caution for high inoculum blocks: A small percentage of the potential ascospore dose are released at night. If the inoculum level is high (many scab lesions from last season) and ascospore maturation is at its peak, the risk of infection from this small portion may be significant. In this situation, it would be advisable to count hours of leaf wetness from the first hour of rain, regardles of the time of day it started.

DETERMINING THE IMPORTANCE OF A PRIMARY INFECTION PERIOD

Table 4 will tell if the minimum hours for infection have occurred, but it will not indicate *how much* infection will occur, i.e., how many lesions will develop. The *number* of lesions that will develop depends mainly on:

1. the total amount of scab inoculum (i.e. **ascospore density**) in the orchard,
2. the **portion** of the total inoculum that is released during a wetting event,
3. the amount of **susceptible tissue** on the trees at the time of the infection period,
4. the susceptibility of the **cultivar(s)**,
5. **how long the leaves and fruits remain wet** after the minimum hours for infection.

Information about each of these factors will

Table 3 – Levels of noticeable differences in scab development as a function of the hours of leaf wetness at different temperatures[1]

Average Temp (°F)	Relative infection level[2] Low	Moderate	High	Days until first lesions[3]
78	10	14	23	
77	8	11	18	
76	6.5	9	16	
61-75	6	9	16	9-10
60	6.5	10	17	11
57-59	7	11	19	12-13
55-56	8	12	20	13-14
54	8.5	13	21	14
52-53	9	14	22	15
51	10	15	24	16
50	11	16	26	16
49	11.5	17	27	17
48	12	17	27	17
47	14	20	32	17
46	16 (13)	21	34	17
45	17 (15)	23	37	17
44	19	25	40	17
43	21 (18)	27	44	17
42	23	30	47	17
41	21	34	50	?
40	29	38	53	?
39	33 (28)	42	57	?
38	37	47	61	?
37	41 (30)	52	65	?
36	48 (35)	69	93	?
34	48 (41)	69	93	?

[1] Adapted from the table of W. D. Mills, revised by W.E. MacHardy. *This table can be used only in conjunction with the criteria for determining an infection period described in this guide.* Numbers in parentheses are the minimum hours of continuous leaf wetness that resulted in scab lesions on apple leaves inoculated with ascospores at controlled temperatures from 36 to 46 (reported by Gadoury *et al.* in the New York Fruit Quarterly.

[2] Low identifies the minimum hours for infection. Moderate and high identify the hours of leaf wetness required for noticeable increases in scab lesions. The average temperature during wetness should be based on hourly temperatures.

[3] Additional days may be required if conditions are unfavorable for lesion development (a prolonged period above 80°F or very dry weather).

help you categorize the *severity* of an infection period and to determine the *risk* associated with not having preventive or retroactive (kickback) fungicide protection against scab infection.

ASCOSPORE DENSITY

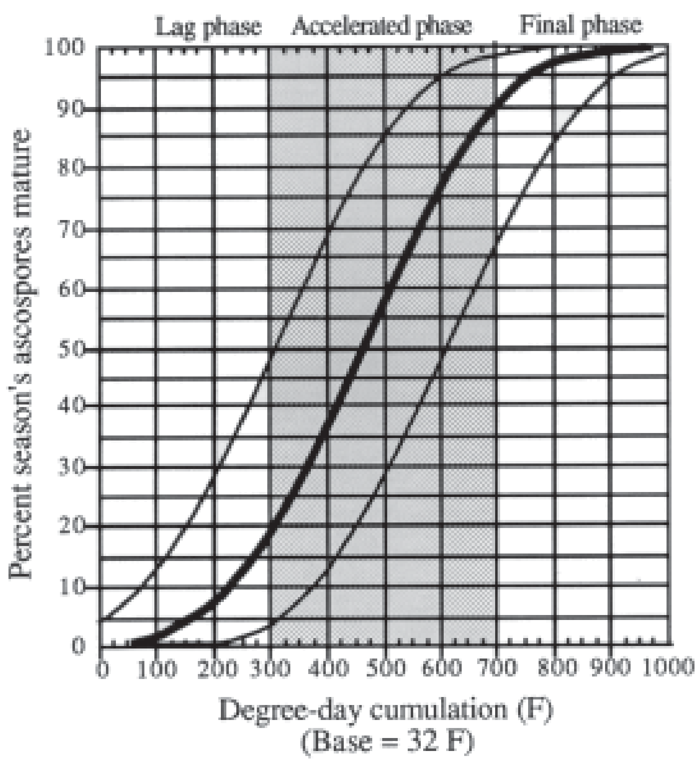
There is no direct method to trap ascospores in the orchard air during a rain event and determine the density of airborne ascospores, but a useful prediction of the percentage of the season's ascospores that had matured prior to the infection period can be obtained using the scab ascospore maturity model (Chart 1). The orchard's inoculum level and the phase of ascospore maturation (i.e., lag phase, accelerated phase, and final phase) are key factors to consider in determining the risk of scab during an infection period. Predicting an orchard's level of "scab-risk" is directly related to the amount of ascosporic inoculum predicted for an orchard, referred to as the *potential ascospore dose* (PAD).

PAD is the predicted number of ascospores that will be produced per square meter (about 1 square yard) of orchard floor during the primary scab season. Determining the specific PAD value is tedious. However, a simple sequential sampling procedure has been developed to determine the "scab-risk" of an orchard (see Delayed First-Spray Strategy section). The scab-risk rating is related to the PAD of an orchard in that a low scab-risk orchard has a low PAD value and an orchard with a high scab-risk rating has a high PAD value.

The portion of the total ascosporic inoclum that is released is determined by two factors: **ascospore maturation** and **release conditions.**

ASCOSPORE MATURITY MODEL: The ascospore maturity model (Chart 1) allows you to estimate the percentage of the season's ascospores that have matured based on the accumulated degree days (DD). A maximum/minimum thermometer, is all that is needed to determine scab DD.

Chart 1. A model for tracking the maturation of ascospores during the primary scab season.



▬ = Curve describing the relationship between the percentage of the season's ascospores that have matured and accumulated degree days.

— = The two curves that show the upper and lower boundaries between which the model is accurate 90% of the time. The two curves show the variation in maturity that can be expected at different times during the primary scab season.

= Shaded area highlights the Accelerated phase of ascospore maturation.

Alternatively, farm-specific DD accumulation reports are available from a commercial weather service, and values for your area may be published in Extension newsletters.

Each day, beginning at 50% McIntosh green tip, the maximum and minimum temperatures are added together and then averaged.

The number of degrees the average temperature is above 32° F (referred to as degree-days) is then determined according to the equation:

$$DD = \frac{(\max T + \min T)}{2} - 32$$

For example, if the low and high temperatures for a day were 45 and 65, respectively, the DD calculated for the day would be:
(110 ÷ 2) – 32 = 55–32 = 23 ascospore maturity degree days.

The accumulated DD is used to predict the percentage of the season's ascospores that have matured prior to the start of a wetting period. The two outermost curves of Chart 1 identify the variation from the predicted maturity of ascospores that can be expected 90% of the time. For example, at 300 DD, the model predicts that approximately 18% of the season's ascospores will have matured. What you should be aware of is that although 18% is the *best* prediction of ascospore maturity at 300 DD, 90% of the time the computed percentage of matured ascospores would be expected to fall anywhere between 4% and 48%.

What is the most practical way to use these estimates? The ascospore maturation curve helps you determine when risk of infection by ascospore release becomes *relatively* high because of advanced maturation, and when that risk becomes *relatively* low because virtually all of the season's ascospores had matured and released during previous rains.

The term "*relatively*" is of key importance, and refers to the distribution of risk across the duration of primary scab season **in that orchard block**.

Within the context of the risk level for a given orchard, the ascospore maturity model defines three phases:

- a **lag phase** that extends from 1 DD to approximately 300 DD, when approximately 20% of the season's ascospores mature. Ascospores mature slowly because of cool weather: the daily average DD is only 15. Thus, matured ascospores do not accumulate rapidly in the pseudothecia between rain events. For example, during a 5-day dry period, only about 5% of the season's ascospores would mature. This phase usually ends about 20 days after bud break.
- an **accelerated phase** that extends from approximately 300 DD to 700 DD. This phase occurs in warmer weather, when the daily average DD is 22. A high percentage of the season's ascospores accumulate rapidly during dry weather. For example, during a 5-day period, about 18% of the season's ascospores would mature. This phase usually lasts about 18 days.
- a **final phase** that extends from approximately 700 DD to 800 DD. The daily DD accumulation averages 25. This phase lasts only about 4 days. By this time, approximately 95% of the ascospores have matured and been discharged.

Decomposition of the leaf litter, growth of groundcover that intercepts some of the discharged ascospores before they reach the open orchard air, the buildup of microorganisms on the leaf litter that injure pseudothecia or somehow interfere with ascospore discharge, and, perhaps, deterioration of pseudothecia associated with aging, all combine to render the remaining ascospores in a well-managed commercial orchard insignificant for management purposes.

Portion of mature ascospores released.

Not all of the ascospores that have matured prior to the beginning of a rain will be released during that wetting period. If the rain falls only at night, there will be little ascospore release. Nearly all of the ascospores are discharged during the daytime. Less than 5% of mature ascospores are released during night hours. [**CAUTION:** If the inoculum level is high and ascospore maturation is at its peak, the risk of infection from the small portion released at night may be significant.]

During daytime rains, the portion of available mature ascospores that release varies with temperature and rain amount. When the temperature is above 50° F and leaves are thoroughly wet by more than 0.10 inch of rain, about 90% of mature ascospores are discharged. If temperature is below 50° F, OR if the total rain amount is less than 0.1 inch, only about 50% of available ascospores are released. If both of these conditions exist, then about 25% of the mature ascospores release.

Relationship between ascospore maturity and the amount of susceptible tissue.

The slow buildup of matured ascospores during the **lag phase,** plus the limited amount of exposed green tissue make infections during this phase relatively easy to control with fungicides. Note that in orchards that were well-managed for scab the previous year, and in which sequential sampling indicates low "scab-risk", fungicides may not be necessary during this phase (see Delayed First-Spray Strategy section).

The **accelerated phase** usually lasts only a little more than two weeks, but it identifies a period in which the crop is potentially at high risk if proper control is not exercised. This is because there is much more susceptible tissue present (it often occurs during pink and bloom) and the percentage of the season's ascospores that are matured and ready for discharge builds up rapidly. It is not important to know precisely that 28% or 63% of the ascospores have matured. However, it is *important to know whether scab maturation at your location has entered the accelerated phase*. A protectant schedule is recommended if scab was not managed well last year.

The **final phase** is significant in that it identifies the end of the primary scab season. If thorough inspection finds that scab lesions do not develop in the two weeks following the final ascospore release (but see footnote 3 under Table 3 for exceptions), then it would appear that primary scab has been controlled. In this case, fungicides should be selected and timed to control other diseases such as sooty blotch and flyspeck. Again, as a conservative estimate, the final scab ascospore release in commercially managed orchards can be assumed to have occurred when 900 DD have accumulated before a daytime rain of at least 0.1 inch and temperatures of at least 50^{o} F during the wetting period.

Relationship between cultivar susceptibility and risk assessment.

Apple cultivars differ in susceptibility to scab (see Table 3). Fungicide label specifications are based on controlling scab on highly susceptible cultivars. What this means is that it may be possible to adjust the fungicide schedule or fungicide dose in a block planted with a more resistant cultivar, e.g. Empire.

Relationship between the length of an infection period and the amount of infection.

The percentage of ascospores deposited on the leaves and fruits that actually infect depends on how long the leaves and fruits remain wet after the minimum hours of wetness needed for infection have been met (Table 3). That is, the longer the leaves and fruits remain wet, the greater the likelihood that a spore will infect. What must be kept in mind when referring to Table 3 is that the number of lesions that will result at each infection level is determined by the number of ascospores that have been deposited. *A long wet period does not necessarily mean there will be severe infection.*

For example, at 50°F and 30 hours of leaf wetness (high infection level), fewer lesions may develop in an orchard with low ascospore density than in an orchard with high ascospore density in which the leaves remained wet for only 12 hours (low infection level).

Integrating all information into decision-making

Table 3 will be most useful in reaching a decision to apply fungicide if it is used in conjunction with other information to build a more complete estimate of the scab risk: the ascospore maturity curve (Chart 1) and release condtions, a prediction of the level of ascosporic inoculum (next section), tree growth stage, and consideration of cultivar susceptibility (Table 2).

Penetration by germinating ascospore