POMOSAT - 'An Orchard System for Monitoring and Modeling Apple Scab (Venturia Inaequalis)'

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Apple scab, Venturia inaequalis, is the most serious fungal disease of apple in Romania. The fungus attacks foliage, blossoms and fruits by defoliating trees and rendering fruit unmarketable. In addition, to cultivated apple, apple scab also attacks flowering crabapple, mountain ash and firethorn..

A simple system for apple growers to monitor environmental weather data (temperature and leaf wetness particularly) to be used in models for predicting apple scab infection periods would make their fungicide application(s) more timely and accurate, thereby potentially reducing pesticide use, improving disease control, and saving money. Additionally, raw weather data and model output can now be easily shared regionally via the Internet to be used by neighboring growers. Such a system has recently become feasible with the availability of inexpensive electronic weather data monitors, personal computer (PC) based models, e-mail delivered weather data and models by commercial services(s), and grower familiarity with PC's and the Internet.

In this paper I present apple scab related with our project objectives:

1. Establish a series of onsite weather stations that collect data, which can be used in models to predict apple scab infection periods. Such models will help growers determine the need (or lack of) for fungicide sprays to control apple scab based on accurate environmental information previously unavailable to them.

2. Post weather and apple scab infection period information from these orchards on the Voinesti Fruit Grower's Association web site (http://www.pomosat.ro) for neighboring growers access and use in helping them make fungicide application decisions.

3. Compare weather data collected by onsite weather stations in trial orchards to ANMH-Weather information, particularly when used in models to predict apple scab infection periods. Survey trial growers to ascertain their preference, and be able to make recommendations to other growers based on their preference.

Keywords: apple scab, orchard system, monitoring and modeling

The probable impact of climate changes on the environment and, implicitly, on the fruit tree agro ecosystem is a comprehensive and complex topic. The aim of this project is to investigate the potential impact of climate changes on fruit tree species development and growth, and the impact of the diseases (apple scab) and pests attacking these cultures, using regional climate numeric models, impact models and the latest satellite monitoring techniques. Creating a complex database of climate records, satellite images, field and laboratory observations and measurements, the members of the consortium established through this project will create a sustainable fruit farm management system. The system will be coordinated by the Integrated Fruit-Growing Research Center from Bucharest University of Agronomic Science and Veterinary Medicine (USAMV), through a central data collection and storage unit. The field meteorological data will be transmitted, using the GSM system, to the automatic stations existing at the farms (one at the USAMV Didactic Field, one at Moara Domneasca and two on Dambovita Valley, in Manesti and Voinesti). Two of the partners, the National Meteorology Administration and the Mathematics and Computer Science Department from Technical University of Civil Engineering, Bucharest (TUCEB) will be responsible for updating the database and managing the mathematical models. The third partner, Dambovita Fruit Growers Association, will be the main beneficiary of the consortium's research activity results, by direct access, via internet, to the center's web page. This page will offer free access to important information for fruit growers: analysis of the climate parameters influencing the fruit-growing ecosystem and the estimated evolution of these parameters, disease and pest attack forecast, precipitations forecast, news regarding fruit tree and bush ranges, non-polluting culture technologies, production certification systems, fruit market, etc. Also, the site will offer useful information to the Ministry of Agriculture, Food and Forests and to other institutions monitoring the regional and national fruit-growing situation as regards the current condition of plantations, land areas occupied by trees, whether-control elements, etc. The system created within this project may also be extended to other fruit tree areas in the country, requiring minimum expenses. Thus, a dynamic structure will be created, integrating education, research and development units, public institutions, producers' associations, farmers' associations, etc., whose aim is to increase the economic competitiveness of fruit farms, to reduce inputs, to increase food security and to reduce the negative environmental impact. Taking into consideration the emergence, in the near future, of a Romanian computerized society, the system created by this consortium may be integrated into the national computerized system as a component representing the field discussed.

Apple Scab

Apple scab over winters in infected apple leaves on the orchard floor. During the winter and early spring, small black pseudothecia develop in the infected leaves (Figure 1). This is the sexual phase of the fungus, and by early spring, ascospores are formed that serve as the primary inoculum for early season infections (Figure 2).

Figure 1. Mature asci containing ascospores.

Figure 2. Apple scab ascospores.

The maturation of the ascospores in the dead leaves on the orchard floor usually occurs at the same time as the apple tree is emerging from dormancy. Therefore, mature ascospores will be present and ready to infect green tissue when it appears each spring (Figure 3). Generally, the percentage of mature ascospores present in the orchard peaks when apples are at the late pink to early bloom stages of bud development.

Figure 3. Early symptoms of a primary infection.

Figure 4. Developing scab lesion on leaf surface

Mature ascospores are discharged from the pseudothecia by splashing raindrops and carried up to emerging green tissue in the trees by wind currents. Moisture is necessary or discharge as well as for germination and subsequent infection of apple tissue. Olive green, velvety lesions appear at the site of a leaf infection 10-28 days after it was infected by an ascospore. The lesions initiated by ascospores result from primary infections (Figure 4). These lesions, in turn, produce asexual spores called conidia. Conidia are spread from lesions when the combination of temperature and leaf wetness enables them to germinate and infect. The lesions caused by conidia are called secondary infections (Figure 5).

The secondary cycle can be repeated many times during the growing season, and with frequent rainfall, the control of apple scab becomes extremely difficult, particularly if the primary infections become established in the spring.

Figure 5. Developing secondary scab lesions

Lesions occur on both sides of the leaves, usually developing earliest on the lower side. With time these olive green lesions turn dark brown to black (Figure 6). On the fruit, dark lesions form is characterized by small black spots that enlarge much more slowly than on leaves (Figure 7). As these spots grow and become older, the centre loses the velvety appearance and becomes brown and corky (Figure 8). The loosened cuticle of the fruit appears as a whitish band around the dark spot. When fruits are infected in an immature stage, distortion of fruit follows, and cracking of the surface covered by the lesions may occur (Figure 9). Fruit infection that occurs late in the summer may not be visible to the naked eye at harvest but enlarge in storage to pinhead size, these lesions are referred to as "pinpoint scab" (Figure 10).

Figure 6. Lesions turn dark brown or black as they mature.

Figure 7. Developing lesions on fruit let.

Figure 8. Older scab lesions on developing apples.

Figure 9. Cracking and fruit distortion can occur as the fruit grows.

Figure 10. Pin-point scab.

Monitoring and Modeling Apple Scab

Monitoring

In 2006 we buy five M2M (Machine to Machine communication) systems manufactured by Metrilog, as well as by well-known companies such as Adcon Telemetry (Austria), Metrilog (Austria), Vaisala (Finland).The weather stations were installed in the cooperating grower orchards. The Remote Terminal Units (RTUs) play an important role in any telemetry system (SCADA - Supervisory Control and Data Acquisition). They collect data from sensors, store it temporarily in their local memory and depending on the communication systems they are based on, they send it at predefined intervals to a base station (alternatively, the base station is asking for the data at predefined intervals). M2M systems (Machine to Machine communication) are also using a variety of RTUs. We use the GPRS based T707 manufactured by Metrilog; operation of the T707 devices is done via an

M2M Gateway in cooperation with Metrilog Data Services GmbH of Austria. The T707 series is based on open protocols and technologies (TCP/IP, WAP, XML/WBXML) which confers it an outstanding flexibility. In addition, the initial costs are relatively low, compared with other technologies, due to the fact that it is built on standard modules and components. The radio communication is done through the GSM networks, using GPRS, thus reaching a throughput of up to 50 kBps. The use of GPRS reduces the operating costs, as the invoicing is based on the data transfer unit (Byte) rather than the connection time. The use of WBXML and WAP substantially reduces the amount of data transferred, thus keeping the running costs low. The GPRS based RTUs can be installed virtually everywhere GSM coverage is present, they don't need a base station and/or relaying stations, therefore keeping the initial costs very low. Data transmission is done through the GPRS network to the GSM provider, then via the Internet to a central M2M Gateway (operated by Metrilog Data Services); from the gateway the data can be transferred to any SCADA program via the Internet. The T707 RTU can sample and store 50 sensor values. As disadvantages of the system you can count the requirement of GSM coverage and the slightly higher operating costs due to the monthly SIM card and M2M Gateway related fees.

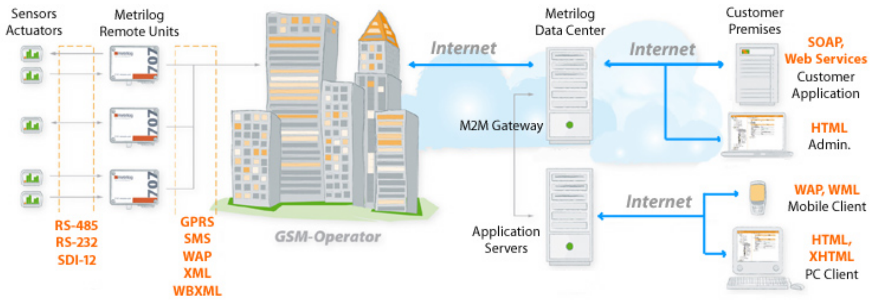

Figure 11. Metrilog's M2M system (http://www.metrilog.at/services.html)

The WXT510 Weather Station combines in a compact housing six different meteorological parameters: wind speed, wind direction, precipitation, atmospheric pressure, air relative humidity and temperature. The weather station delivers stable and accurate measurements, is very compact and light, it has no moving mechanical parts (it uses revolutionary techniques to measure the wind speed and direction, as well as the precipitation), it requires extremely little power and its installation is very simple. Add to this the leaf wetness sensor {works on the principle of electric conductivity, measuring in ten increments if the sensor surface is anything from completely dry to completely wet), the MS-020VM Pyranometer is suitable for measuring solar radiation (W/m2) in the range of 400 to 700 nm (the sensor is fully cosine-corrected for improved performance and has less than 0.5% temperature dependence over a 50°C (122°F) range) and the RCI P 400V temperature probe was specially developed for measuring soil temperature at various depths (It is housed in a corrosion-resistant enclosure and can be inserted into the ground down to 30 cm (12 in.)).
Also we use addVANTAGE Professional 4.3 software for collecting and displaying weather data and mathematical models for analyzing apple scab infection periods. Growers were instructed to use our website http://www.pomoisat.ro and to interpreting the information, and casually comparing it to the weather data collected on-site. It was assumed – and suggested that – growers would use the environmental information from this sources to help determine the need for and the timing of orchard fungicide sprays for apple scab.
During the growing season, contact was maintained with grower cooperators to make sure the weather stations were functioning properly and accurately, and that apple scab model data were being posted to the POMOSAT web site.

Figure 12. http://www.pomosat.ro

Accurate weather data will provide daily maximum and minimum temperatures, a necessary component in using the degree day model for assessing ascospore maturity (described below).

Determining the Inoculum Level

A hygothermograph recorder for temperature and relative humidity and a leaf wetness recorder are essential for accurate monitoring of scab infection periods (Figure 13). Computerized weather instruments are also commercially available can measure this information can calculate degree days. To predict the amount of inoculum in the orchard in the spring, an assessment of the leaf scab present in the fall (Potential Ascospore Dose, or PAD) should by made. In late September or early October, before leaf fall, an assessment for foliar acab is made using the following technique: Select a sampling scheme that allows sampling every 10-30 trees, making sure that trees are selected throughout the block. The total number of shoots examined should equal 600. Three sampling schemes are presented below:

- 20 shoot on each of 30 trees (a block of 300-900 trees) or
- 15 shoots on each of 40 trees (a block of 400-1200 trees) or
- 10 shoots on each of 60 trees (a block of 600-1800 trees).

Use the following procedure:

- On each selected tree, examine shoots at random from the top, bottom, inside and outside of the canopy. It is particularly important to include shoots near the top of the tree. This is where scab is more likely to occur due to a greater chance of poor spray deposition. If sucker shoot are common, include one sucker shoot per tree.
- On each selected shoot, scan the upper and lower surfaces of the leaves and record the number of leaves with one or more scab lesions, including spots you think may be scab lesions.
- Total the number of scabbed leaves you recorded.
- If the number of scabbed leaves is 50 or fewer, then you can assume that the orchard has a low inoculum level for the next season.
- If the number of scabbed leaves is 50-100, select a sanitation program (see the management section), perform the practices you select, then assume that the orchard has a low inoculum level for the next season
- Caution: If the number of scabbed leaves if greater than 100; then you have a high inoculum orchard and should maintain a protectant fungicide program beginning at green tip the following season.

This method of determining the scab potential cannot be used where the SI fungicides (Nova) have been applied that season, particular when used for after-infection activity. Scab lesions are inhibited but not killed and this inhibition has been shown to break down in the fall. These lesions cannot be detected in the fall when doing PAD sampling. The PAD technique also assumes that there are no scabby, wild trees contributing inoculum within 200 metres of the orchard perimeter.

Figure 13. Temperature / leaf wetness recorder for predicting scab infections.

Determining Apple Scab Infection Periods

Primary Infection Periods Once the tree break dormancy and there is green tissue present, a primary infection can occur if the following three conditions are met: presence of mature ascospores, available moisture and resulting ascospore discharge.

Presence of Mature Ascospores There will always be mature ascospores at bud break. The number of ascospores will depend on the amount of inoculum in the overwintering leaves, that is whether it is a low or high inoculum orchard. (See determining the inoculum level.) The rate at which ascospores mature in the overwintering leaves on the orchard floor is determined mainly by temperature. A model has been developed that relates temperature to maturation (expressed in degree days celcius, DDC). The model allows one to predict the percentage of the season's ascospores that have matured as shown in Figure 14. Daily accumulated degree days are calculated as follows:

$$(DDC) = (\text{daily max. } ^\circ C + \text{daily min.} ^\circ C) \div 2 - 0^\circ C$$

For example, on a day with a high of 10°C and a low of 2°C, the daily accumulated degree days will be 6 DDC. Note if temperatures are below freezing, (i.e., minus number) then use a value of 0 DDC. The daily degree day accumulations should begin at bud break, which is defined as the day on which at least one half of the fruit buds on McIntosh are between silver tip and green tip.
The daily degree accumulations are used to estimate the percentage of mature ascospores from the central curve in Figure 14. The upper and lower curves are the upper and lower 90% confidence limits on the estimates from the graph.

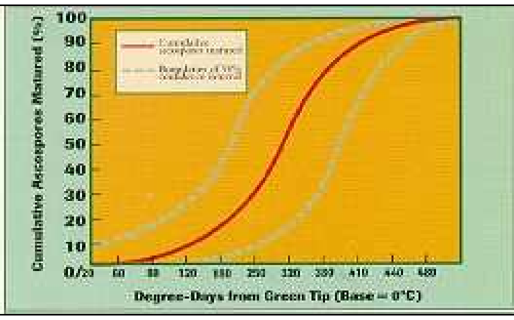

Figure 14. Cumulative percentage of ascospores mature at various degree day accumulations.

Degree days should be recorded from the date when 50% of McIntosh fruit buds are between silver tip and green tip. The base temperature for degree-day accumulation is 0°C (Data of Gadory and MacHardy, 1982.) The width of the 90% confidence interval is a statistical measure of the precision of estimated maturity. It is the range within which estimate should fall 90% of the time.
Two points of particular interest of this graph are:

- at 125 DDC - there is a rapid maturation of ascospores indicating a higher risk of infections occuring
- at 418 DDC - over 95% the ascospore supply should be depleted if sufficient rain events have occurred (see Table 1). This would then mark the end of primary infection season. With this model (combination of Figure 14 and Table 1) the grower can obtain a site-specific forecast of ascospore maturity and discharge for their own orchard(s).

Table 1. The percentage of available ascospores that will be discharged under various environmental conditions.

Type of Rain Event	Percentage of Available Ascospores
Night rain only	5%
Day rain <0.25 cm, temperature <10°C	25%
Day rain >0.25 cm, temperature <10°C	50%
Day rain <0.25 cm, temperature >10°C	50%
Day rain >0.25 cm, temperature >10°C	90%

Ascospore Release Ascospores are released when there is rain to wet the pseudothecia on the dead leaves. Most of the available mature spores are discharged within two hours after the start of a rainy period. Ascospore release is strongly light dependent. Only a small percentage of available ascospores is released at night (from 7 pm to 8 am eastern daylight savings time). Ascospores are not released to any significant extent during nighttime hours in low inoculum orchards. In an orchard where the ascospore inoculum is high, although the percentage of ascospore release is small, the total number of ascospores released is large and can cause significant primary scab.
In a low inoculum orchard, calculate the length of wetting period using the following method:

- When rain begins during the day (between 8:00 am and 7:00 pm EDST) count the hours of leaf wetness from the first hour rain was recorded until the leaves are dry.
- When the rain begins at night (between 7:00 pm and 8:00 am EDST) count the hours of leaf wetness from 8:00 in the morning until the leaves are dry.
- For a high inoculum orchard, calculate the length of wetting period from the start of the rain until the leaves are dry, regardless of the time of day.

Various scenarios to calculate leaf wetness are outlined in Figures 15-17.

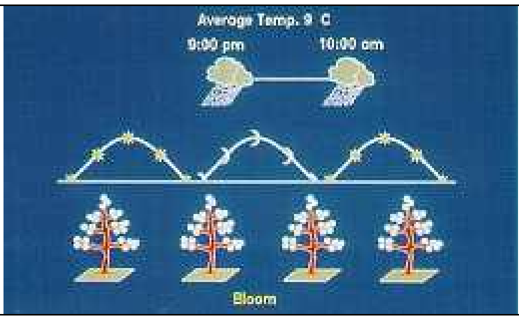

Figure 15. No primary scab infection has occurred, only 2 hours of wetting (8-10am) at 9°C.

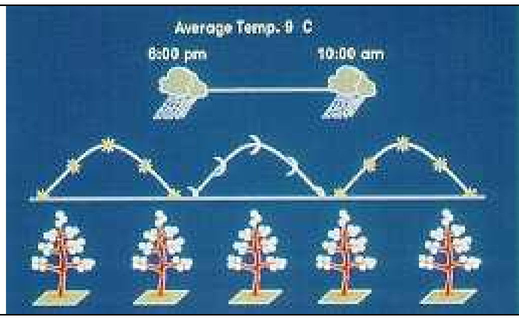

Figure 16. Primary scab infection has occurred, 16 hours of wetting (6pm-10am) at 9°C.

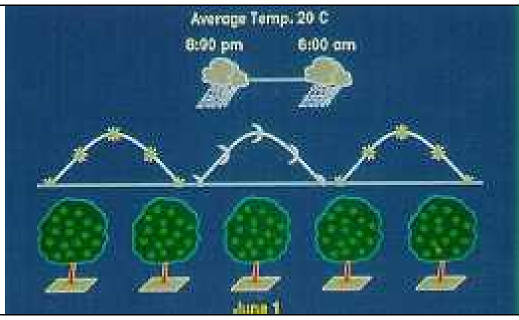

Figure 17. Secondary scab infection has occurred, 10 hours of wetting (8pm-6am) at 20°C.

Secondary Infection Periods Secondary scab infections occur when conidia developed from primary scab lesions on leaves are spread by splashing rain. As with primary infections, secondary infections only occur if moisture initiated by rainfall is present for a long enough period at a given temperature. Secondary infections are calculated from the beginning of the wetting period regardless of the time of day. Continued infections throughout the summer result from lesions caused by conidice.

Contribution of intermittent rain and dew to infections periods - periods of dew of high humidity (over 90%) also contribute to a wetting period, but are significant only of preceded by rain. Wet periods during an intermittent rain should be added together to determine the length of an infection period unless separated by 10 hours or more of dry, sunny weather.

Fruit infection - as the fruit matures it takes a progressively longer wetting period for infection by apple scab to occur. Table 2 outlines this relationship.

Table 2. The Relationship of temperature, hours of wetting, and weeks after full bloom to secondary apple scab infection of fruit.

Average Temperature	Weeks After Full Bloom			
	1 Hour of Wetting for 2% Fruit Infection	5 Hours of Wetting for 2% Fruit Infection	10 Hours of Wetting for 2% Fruit Infection	15 Hours of Wetting for 2% Fruit Infection
10°C	13	26	37	45.5
12°C	10	21.6	31	38
14°C	8.5	18.5	26.5	32.5
16°C	7.5	16	23	28.5
18°C	6.5	14.5	20.5	25.5
20°C	6	13	18.5	23

(Adapted from Schwabe et al. 1984. Cultiveras tested were: Golden Delicious, Starking Delicious, Starkrimson Delicious, Winter Pearmain.)

Wetting periods required for infection of fruit by the scab fungus are longer than those required for leaf infection, the longer infection times required for fruit may be followed in those orchards where only fruit scab is of concern. If unchecked during the growing season, leaf infection could create large amounts of overwintering scab inoculum and heavy ascospore release the following year.

Conclusion

Clearly, the objectives of this project were met. To summarize: Five on-site weather stations were easily established in grower orchards. Growers used models – based on accurate orchard weather information – to help assess scab infection periods and time fungicide sprays. The only limitation(s) encountered were occasional weather station/computer software interface issues, and lack of time during a busy period for orchard activities to fully analyze all the information available for decision-making. Weather and apple scab infection period information from these orchards were posted on the POMOSAT web site (http://www.pomosat.ro) for neighboring growers access and use in helping them make fungicide application decisions.

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