Decision Support Systems for Plant Disease and Insect Management in Commercial Nurseries in the Midwest: A Perspective Review[1]

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Abstract

Decision-support systems (DSS) are techniques that help decision makers utilize models to solve problems under complex and uncertain conditions. Predicting conditions that warrant intervention is a key tenet of the concept of integrated pest management (IPM) with the use of expert systems and pest models being characteristics of higher-level IPM. In this paper, potentials of four DSS including Ag-Radar, NEWA, RIMpro and Skybit to be used for ornamental nursery production are discussed. These systems were previously developed for orchard growers to effectively manage plant diseases and insects. Their development was based on the input of historical disease, insect pest and weather information. It will be an instrumental management aid to control insects and diseases in a timely manner if nursery growers can adaptively implement these orchard DSS into their production practices. In order to maximize effectiveness, however, next-generation DSS should consider the addition of consensus forecast models into user interfaces by combining the information generated from multiple independent models into a single spray-decision recommendation.

Index words: expert system, DSS, model prediction, forecast, insect, disease.

Significance to the Horticulture Industry

The decision of whether or not and when to apply a pesticide for a given insect pest or plant disease is not always obvious. Decision-support systems are tools that help growers to decide which management options to employ and to make spray decisions. To date, no decision-support systems have been developed to aid in the management of insect pests and plant diseases for commercial nursery production. As the development and implementation of decision-support systems takes considerable time and resources, the authors reviewed and propose four decision-support systems originally developed for orchards that have the capacity to be adapted for use in commercial nursery production. Additionally, the authors propose the development of a consensus forecast model, by combining the information generated from multiple independent models into a single spray-decision recommendation. The model will assist nursery managers, extension agents, consultants, and other agricultural clientele in the management of plant diseases and insect pests to solve problems under complex and uncertain conditions.

Introduction

Modern decision-support systems (DSS) are expert systems that often take a final form as interactive computer-based systems. These systems help assist nursery managers, extension agents, consultants, and other agricultural clientele in the management of plant diseases and insect pests by utilizing data and models to solve problems under complex and uncertain conditions (Magarey et al. 2002, Shtienberg 2013). DSS can be implemented to justify inputs, to prioritize resource allocation, to reduce pesticide use, and/or to improve disease and insect control (Gent et al. 2013, Morgan et al. 2000, Trapman 2016). Convincing evidence is available to support the claim that DSS can reduce pesticide use substantially compared with traditional, calendar-based spray schedules with no added risk of yield loss (Campbell and Madden 1990, Funt et al. 1990, Gleason et al. 1995, Gleason 1997). Campbell and Madden (1990) suggested that DSS would become more valuable to producers as the cost of pesticides increased, pesticide registrations were lost, and regulatory constraints increased (Campbell and Madden 1990, Gent et al. 2011).

Predicting conditions that warrant intervention is considered a key tenet of the concept of integrated pest management (IPM), with the use of expert systems and dynamic crop-pest models being characteristics of higher-level IPM (Jacobsen 1997, Kogan 1998, Stern et al. 1959). The use of meteorological data is considered a key element of modern DSS and aid in site-specific management recommendations. Growers are encouraged to have at least one weather-monitoring station for each unique management site. In cases where on-site weather stations are not possible, DSS are oftentimes able to use publically available meteorological data, although some degree of accuracy for model predictions is lost due to the possibility of local variations in weather.

As changes in growing seasons occur due to climate change, DSS are needed to assist growers and nursery managers in continuing to manage plant disease and insects effectively. Climate change is expected to raise growing season temperatures, alter the amount and variability of rainfall, reduce soil moisture, and ease the wider spread of plant pests and diseases (OECD 2016). These develop-

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ments could have significant effects on crop production and prices (Malcolm et al. 2012, Schlenker and Roberts 2009). Broad descriptions of climate change effects are widely published in scientific literature, but each plant production site will be uniquely impacted and require customized responses (Janowaik et al. 2016, Pachauri et al. 2014). The integration of climate change information into management plans will highlight the usefulness of automation and intelligent decision making in maintaining commercial nursery productivity (Janowaik et al. 2016, Ojha et al. 2015).

The integration of DSS and expert systems can allow for automated spraying through use of variable-rate sprayers or fixed-spray systems, allowing for potential reductions in spray volume and drift reduction. Use of an automated, variable-rate, air-assisted precision sprayer has the capacity to reduce average pesticide use by up to 68 percent, which can result in an annual average cost savings of up to $520 per hectare ($211 per acre) in floral nurseries and orchards (Zhu et al. 2017). If variable-rate sprayers are used in conjunction with DSS, further reductions in pesticide use and even greater cost savings per hectare could be expected. In situations where variable-rate spraying is not an option, optimal application timing of spray materials can be achieved while conserving resources.

There are numerous reports discussing the development, adoption and use of DSS for orchard and other horticultural crops (Cox 1996, Crassweller et al. 1993, Damos 2015, Gent et al. 2011, Gent et al. 2013, Haider and Kumar 2014, Hochman and Carberry 2011, Lentz 1998, McCown 2002a, McCown 2002b, Shaw 2002, Shtienberg 2013, Yuen 2006), but none for diseases and insect pests of ornamental nurseries due to a large number of plant varieties and species, often grown closely together. Nursery crops are often attacked by pests and diseases that require treatments with conventional pesticides or natural pest control agents in a timely manner. There are many variables affecting pesticide application efficiency in nursery production. Growers are often confused by these variables when they must make decisions to apply chemicals. Accordingly, a simple "best guess" practice is common, which could result in applying excessive amounts of pesticides in response to an escalating pest density within a very narrow time window. In many cases, improper application schedules are chosen due to a lack of accurate information on pest populations for a specific geographical area.

The objective of this paper was to introduce four orchard-available DSS for commercial nursery disease and insect management. It presents a summary of currently available online model-based DSS that could be readily adapted for use in tandem with variable-rate sprayers and fixed-spray systems.

Decision Support Systems

Ag-Radar. Ag-Radar (https://extension.umaine.edu/ipm/ag-radar-apple-sites/), formerly Orchard Radar, is a web-based weather charting and pest management system developed by Glen Koehler at the University of Maine (Fig. 1). This system uses weather data from SkyBit (http://www.skybit.com/). Users contract with SkyBit to send data to the University of Maine where it is used in integrated pest management models. SkyBit is discussed further in a following section in this paper. Ag-Radar uses the 30-year average of historical weather data for weather forecasts beyond 10 days past the current day (Cooley et al. 2011).

Disease models available from Ag-Radar include apple scab [*Venturia inaequalis* (Cooke) G.Winter], fire blight [E*rwinia amylovora* (Burrill 1882) Winslow] and sooty blotch (disease complex, *Peltaster fructicola*, *Geastrumia polystigmatis*, and *Leptodontium elatius*). Apple (*Malus x domestica* Borkh.) insect models that Ag-Radar provides include plum curculio (*Conotrachelus nenuphar* Herbst), coddling moth (*Cydia pomonella* L.) and apple maggot [*Rhagoletis pomonella* (Walsh)]. Additionally, a model for European red mite (*Panonychus ulmi* (Koch) is available (Table 1). Ag-Radar is updated three times a day, seven days a week. Ag-Radar users must provide key biofix (growth stage event) dates as the starting point. Output includes a variety of textual, graphical and tabled summaries of weather, disease and insect reports. There are multiple scenarios provided for fungicide and antibiotic spray and resprays. Nursery crop diseases that Ag-Radar could be used to manage include apple scab, fire blight and powdery mildew for crabapple (*Malus* spp.) cultivars. Insect pests that Ag-Radar could aid in the management include codling moth on crabapple and walnut, plum curculio on crabapple, apple maggot (*Rhagoletis pomonella* Walsh) on dogwood (*Cornus* spp.), and San Jose scale (*Quadraspidiotus perniciosus* Comstock) and European red mites for many species of ornamental trees and shrubs.

Ag-Radar provides growers with information on when the protection from protectant applications of fungicides should be depleted based on depletion information for fungicide residues and an estimate of when symptoms will first appear if no fungicides were applied (Rosenberger and Meyer 2007). Three estimates are provided, the first being a worst-case prediction for the wettest 20% of years, the second based on SkyBit and historical average data, and the third a prediction intended to estimate possible timing of symptoms appearance (Cooley et al. 2011). In future versions of Ag-Radar, users may be able to add data from private weather stations, but presently only data provided by SkyBit can be used.

NEWA. The Network for Environment and Weather Applications (NEWA, http://newa.cornell.edu/) was developed by Cornell University in 1995 and is operated by the New York State IPM program and the Northeast Regional Climate Center. Weather data provided to NEWA is from farmers, commodity groups, agricultural industries, private consultants and state land grant universities who own the weather stations. Private weather stations must be capable of uploading data to a network by use of either an Ethernet or cellular telemetry connection. Weather stations should have sensors that measure temperature, humidity, rainfall, leaf wetness, wind speed and direction, solar radiance and barometric pressure and set to upload data every 15 minutes. Climate data is archived in NEWA and run through quality control routines prior to calculating and

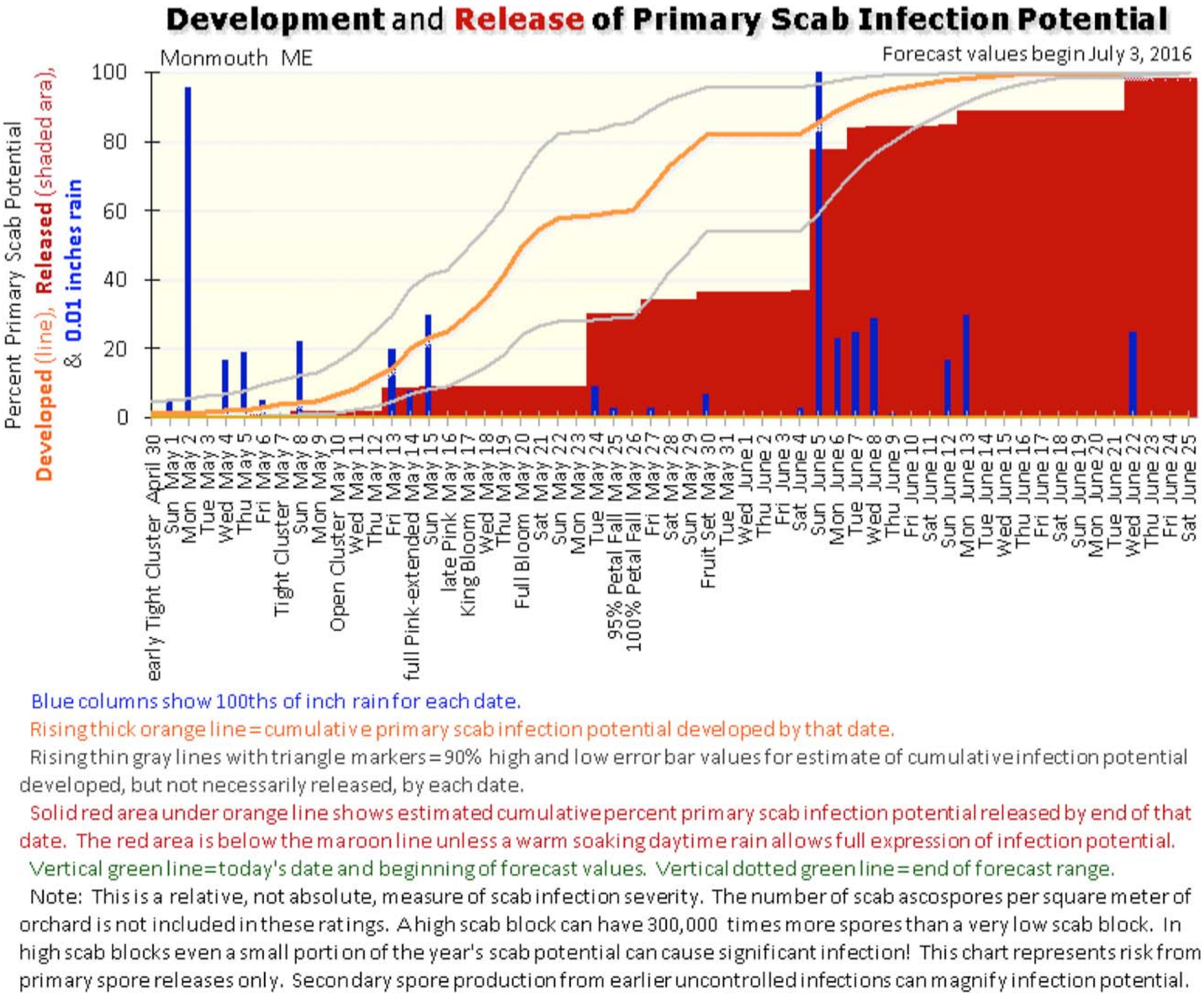


Fig. 1. Overview of a report generated by Ag-Radar for apple scab.

displaying weather summaries and forecast tools for precision agriculture (Carroll et al. 2009).

NEWA delivers weather data from weather stations to a website (newa.cornell.edu) and automatically calculates and displays weather data summaries and IPM forecast model results (Carroll et al. 2009). IPM forecast models are available for diseases and insects of apple and grape, plus others. NEWA pest forecasts update when users run the individual models. Sources for the models can be found on the NEWA model references page online. Apple disease forecast models available through NEWA include apple scab (Fig. 2), fire blight and sooty blotch/flyspeck. Forecast models available for apple insects include, oriental fruit moth (*Grapholita molesta* Busck), coddling moth, plum

Table 1. Decision support systems suitable for commercial nursery production applications.

Decision support system	Available models	Spray degradation estimate
Ag-Radar	apple scab, fire blight, sooty blotch, plum curculio, coddling moth, apple maggot, European red mite	Yes
NEWA	apple scab, fire blight, sooty blotch/flyspeck, oriental fruit moth, codling moth, plum curculio, oblique-banded leaf roller, spotted tentiform leaf miner, apple maggot, San Jose scale, phomopsis, black rot, powdery mildew, downy mildew, grape berry moth	No
RIMpro	apple and pear scab, fire blight, powdery mildew, sooty blotch, apple canker, Marssonia blotch, codling moth, apple sawfly, black rot, downy mildew	Yes
Skybit	apple scab, fire blight, sooty blotch, oriental fruit moth, codling moth, tufted apple bud moth, oblique-banded leaf roller, spotted tentiform leaf miner, apple maggot, phomopsis, black rot, powdery mildew, downy mildew	No

Infection Events Summary								
	Past	Past	Current	5-Day Forecast	Forecast Details			
	May 11	May 12	May 13	May 14	May 15	May 16	May 17	May 18
Infection Events	No	No	Combined	Combined	Yes	No	No	No
Days to Symptoms	-	-	-	-	12-13	-	-	-
Average Temp (F) for wet hours			63	60	56	44	57	52
Leaf Wetness (hours)	0	0	5	8	10	1	5	4
Rain Amount	0.00	0.00	0.26	0.12	0.03	0.00	Trace	0.01
Rain Prob (%) Night|Day ?			0 | 13	81 | 11	68 | 85	13 | 0	3 | 8	19 | 0

Fig. 2. Example of a Network for Environment and Weather Applications (NEWA) infection event summary for apple scab.

curculio, oblique-banded leaf roller (*Choristoneura rosaceana* Harris) , spotted tentiform leaf miner (*Phyllonorycter blancardella* Fabricius), 1, apple maggot and San Jose scale. Forecasting models available through NEWA for grape diseases include phomopsis (*Phomopsis* spp.), black rot [*Guignardia bidwellii* (Ellis) Viala & Ravaz], powdery mildew (*Podosphaera* spp.) and downy mildew (*Peronospora spp*.). For grape insects, NEWA offers a forecasting model for grape berry moth (*Paralobesia viteana* Clemens) (Table 1). Additionally, NEWA provides IPM forecasting models for alfalfa (*Medicago sativa* L, cabbage , onion (*Allium cepa* L.) , potato (*Solanum tuberosum* L.) and tomato (*Solanum lycopersicum* L.).

Nursery crop diseases that NEWA could be used to manage include apple scab and fire blight for crabapple cultivars. Insect pests that NEWA could be used for aiding in the management of include apple sawfly (*Hoplocampa testudinea* Klug), codling moth and plum curculio on crabapple, codling moth on walnut, grape berry moth on sassafras, apple maggot on dogwood and San Jose scale on many species of ornamental trees and shrubs.

To use NEWA, the weather stations must be added to the NEWA network. For participating states, there is no charge to add a private weather station to the network; for non-member states there is an annual cost for individual users. NEWA users must track important biofix dates or phenological stages for many of the pest forecasts available. Important biofix dates can be found on the individual crop pages and are entered into the NEWA pest forecast results page generated when a user runs the model. Output of NEWA includes a simple summary graphic, which clearly indicates whether a critical threshold is expected to occur within the upcoming seven days (Small et al. 2015). Additional output provided depends on the particular model being run and can include graphical risk and weather summary charts, a degree-day chart, and tables with pest status, previous infection events and pest management recommendations. The user-friendly simple summary tables and graphics are easily interpretable.

RIMpro. RIMpro (http://www.rimpro.eu/) is a set of simulation models for management of fruit pests and diseases that was developed in 1993. The RIM in RIMpro stands for Relative Infection Measure. Local weather data requirements include measures of temperature, relative humidity, and rainfall and leaf wetness. Weather stations must be capable of uploading data to the internet by use of either an Ethernet or cellular telemetry connection. RIMpro's initial aim was to produce an apple scab infection simulation tool that would provide a better epidemiological approach than that offered by Mills system alone, that could run with any weather station and that would be easy for growers and orchard consultants to use (Trapman and Polfliet 1997). The Mills system is an apple scab predictive model usually presented as a table or figure for predicting three levels of infection by the pathogens primary inoculum, ascospores (MacHardy and Gadoury 1989).

RIMpro contains disease simulation models for apple and pear scab (Fig. 3), fire blight, powdery mildew, sooty blotch, apple canker [*Neonectria galligena* (Bres.) Rossman & Samuels], and Marssonia blotch [*Marssonina coronaria* (Ell.0 J.J. Davis] (Table 1). Simulation models available for apple insects include coddling moth and apple sawfly. Simulation models available through RIMpro for grape diseases include black rot and downy mildew. RIMpro models were developed in close collaboration with a project or expert group on the pest or disease in question, and with the potential end-users of the DSS. Sources for the models can be found on RIMpros model parameters page online. Models are adjusted annually following progress in knowledge and experience, as well as technical developments and possibilities (Trapman and Polfliet 1997).

Nursery crop diseases that RIMpro could be used to manage include apple scab, fire blight and powdery mildew for crabapple cultivars. Additionally, powdery mildew control for dogwoods, sycamore (*Platanus* spp.), and birch (*Betula* spp.) is possible. Insect pests that RIMpro could be used to aid in the management of include apple sawfly on crabapple and codling moth on crabapple and walnut (*Juglans* spp.).

To use RIMpro a weather station must be added to the cloud-based self-service network by the user. Weather

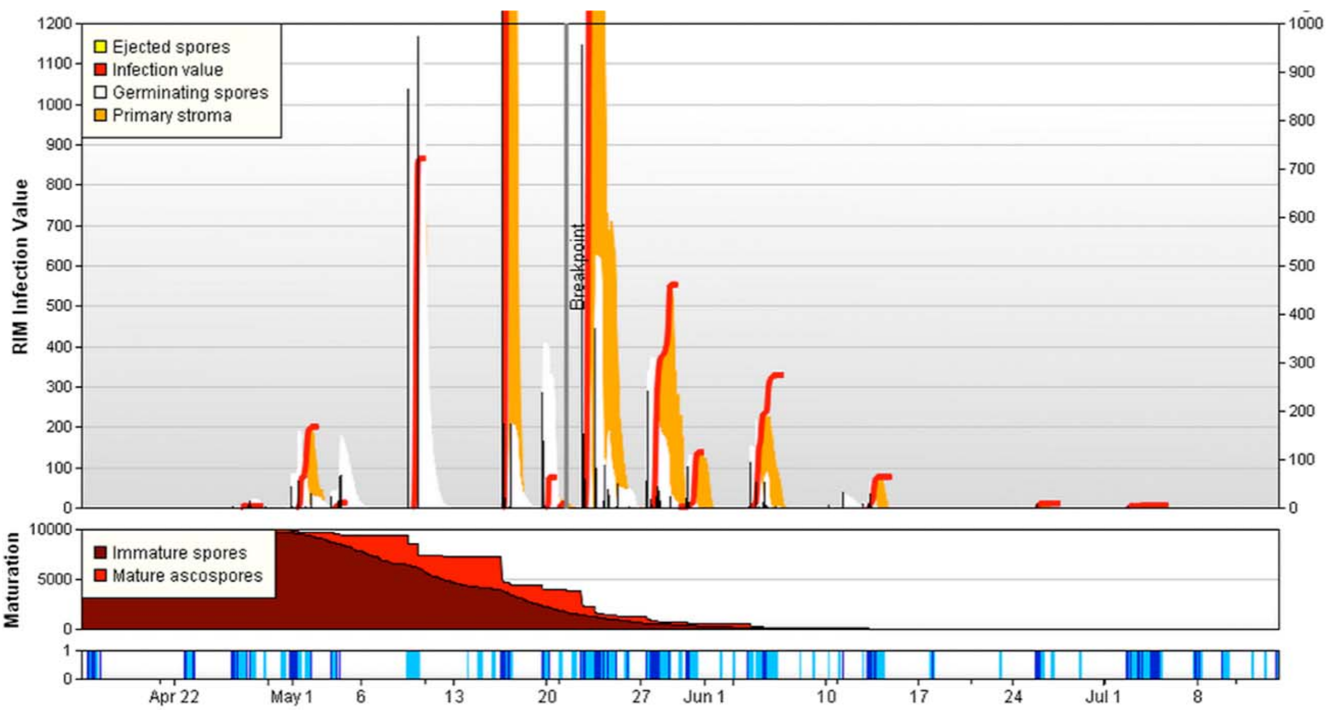


Fig. 3. Example of the RIMpro apple scab simulation model.

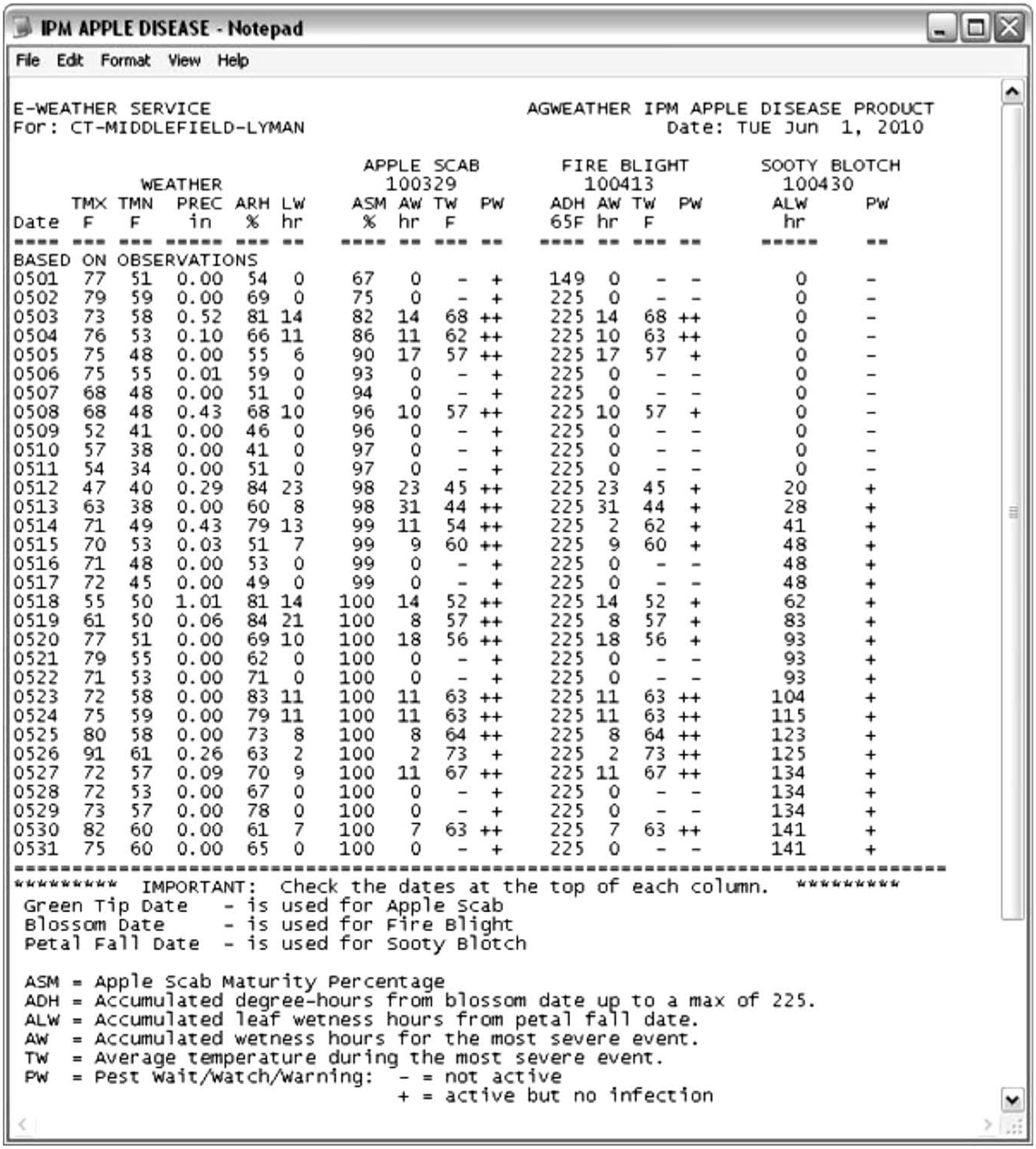
stations should have sensors that measure temperature, humidity, rainfall, leaf wetness, wind speed and direction, solar radiance and barometric pressure and be set to upload data every 30 minutes. There are multiple annual license types available for individual producers and advisory service providers. To run RIMpro models, biofixes and local weather data are needed to initiate the calculations. If a reliable biofix date is unavailable, the phenological stage of the crop can be used. Output of RIMpro is a chart-based summary of past and forecasted weather data and infection predications for each of the individual models. Uploaded weather data is delivered to RIMpro's website (www.rimpro.eu) and forecast models are updated every 30 minutes.

RIMpro's apple and pear scab model allows users to evaluate fungicide schedules for individual sites. By entering spray dates and conditions and the fungicide applied, RIMpro estimates fungicide coverage and degradation. RIMpro estimates the decline of the fungicide cover in time as a result of wash-off by rain and dilution by leaf growth. The advised normal dose, or the label rate per standard acre is regarded as 100% cover. If you apply a higher or lower dose than would be normal for a site within a nursery, the initial cover is higher or lower accordingly. RIMpro allows users to correct for Tree Row Volume and to provide an estimate of the quality of the spray cover.

Also, RIMpro users can set breakpoints in the model to clear all germinating spores from the system (Figure 2). This helps to understand the situation better when a fungicide was applied that is believed to have killed all germinating spores. At that time, growers want to estimate the impact from spores discharged after the treatment, or when infections accumulate over several days and one wants to separate infection events. When an infection event is in the 5-day forecast, the actual weather data logged may or may not translate into an actual infection event. Therefore, the prediction output from RIMpro may change once actual weather data is logged. Finally, descriptions of model parameters are available and users have the ability to adjust or refine model parameter settings as desired.

SkyBit. SkyBit was developed by Joe Russo in 1993 as a joint venture between ZedX, Inc and Meso, Inc (Magarey et al. 2001 and 2002, Russo 1997). SkyBit uses weather data from global and regional models located in government centers, such as the U.S. National Weather Service's National Center for Environmental Prediction (NCEP) (Russo 1997). The spatial resolution of global and regional weather centers is usually inadequate for site-specific forecasting. Therefore, it is necessary to employ additional models for specific applications, such as plant disease forecasting. These models can take the form of physics-based "canopy" models or "statistical" models. The statistical models, unlike the physics-based models, require biofix dates in order to generate model-based predictions for a specific location (Russo 1997). The output from the canopy or statistical model is used to drive plant disease or insect models, which in turn, provide the forecasts for SkyBit's Ag-Weather products.

SkyBit does not require an on-site private weather station to receive weather, pest insect, or disease reports. Subscribers provide SkyBit with the latitude, longitude and elevation for a desired site and reports are simulated for that location. Additional input includes entering key biofix


IPM APPLE DISEASE - Notepad

File Edit Format View Help

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E-WEATHER SERVICE                                   AGWEATHER IPM APPLE DISEASE PRODUCT
For: CT-MIDDLEFIELD-LYMAN                                       Date: TUE Jun  1, 2010

                                  APPLE SCAB        FIRE BLIGHT      SOOTY BLOTCH
           WEATHER                  100329            100413           100430
     TMX TMN  PREC ARH LW      ASM AW TW  PW     ADH AW TW  PW       ALW     PW
Date  F   F    in   %  hr       %  hr  F          65F hr  F             hr
---- --- --- ----- --- --     ---- -- --- --    ---- -- --- --      -----    --
BASED ON OBSERVATIONS
0501  77  51  0.00  54  0      67   0   -  +     149  0   -  -          0     -
0502  79  59  0.00  69  0      75   0   -  +     225  0   -  -          0     -
0503  73  58  0.52  81 14      82  14  68 ++     225 14  68 ++          0     -
0504  76  53  0.10  66 11      86  11  62 ++     225 10  63 ++          0     -
0505  75  48  0.00  55  6      90  17  57 ++     225 17  57  +          0     -
0506  75  55  0.01  59  0      93   0   -  +     225  0   -  -          0     -
0507  68  48  0.00  51  0      94   0   -  +     225  0   -  -          0     -
0508  68  48  0.43  68 10      96  10  57 ++     225 10  57  +          0     -
0509  52  41  0.00  46  0      96   0   -  +     225  0   -  -          0     -
0510  57  38  0.00  41  0      97   0   -  +     225  0   -  -          0     -
0511  54  34  0.00  51  0      97   0   -  +     225  0   -  -          0     -
0512  47  40  0.29  84 23      98  23  45 ++     225 23  45  +         20     +
0513  63  38  0.00  60  8      98  31  44 ++     225 31  44  +         28     +
0514  71  49  0.43  79 13      99  11  54 ++     225  2  62  +         41     +
0515  70  53  0.03  51  7      99   9  60 ++     225  9  60  +         48     +
0516  71  48  0.00  53  0      99   0   -  +     225  0   -  -         48     +
0517  72  45  0.00  49  0      99   0   -  +     225  0   -  -         48     +
0518  55  50  1.01  81 14     100  14  52 ++     225 14  52  +         62     +
0519  61  50  0.06  84 21     100   8  57 ++     225  8  57  +         83     +
0520  77  51  0.00  69 10     100  18  56 ++     225 18  56  +         93     +
0521  79  55  0.00  62  0     100   0   -  +     225  0   -  -         93     +
0522  71  53  0.00  71  0     100   0   -  +     225  0   -  -         93     +
0523  72  58  0.00  83 11     100  11  63 ++     225 11  63 ++        104     +
0524  75  59  0.00  79 11     100  11  63 ++     225 11  63 ++        115     +
0525  80  58  0.00  73  8     100   8  64 ++     225  8  64 ++        123     +
0526  91  61  0.26  63  2     100   2  73  +     225  2  73 ++        125     +
0527  72  57  0.09  70  9     100  11  67 ++     225 11  67 ++        134     +
0528  72  53  0.00  67  0     100   0   -  +     225  0   -  -         134     +
0529  73  57  0.00  78  0     100   0   -  +     225  0   -  -         134     +
0530  82  60  0.00  61  7     100   7  63 ++     225  7  63 ++        141     +
0531  75  60  0.00  65  0     100   0   -  +     225  0   -  -         141     +
==========================================================================================
*********  IMPORTANT:  Check the dates at the top of each column.  *********
 Green Tip Date   - is used for Apple Scab
 Blossom Date     - is used for Fire Blight
 Petal Fall Date  - is used for Sooty Blotch

 ASM = Apple Scab Maturity Percentage
 ADH = Accumulated degree-hours from blossom date up to a max of 225.
 ALW = Accumulated leaf wetness hours from petal fall date.
 AW  = Accumulated wetness hours for the most severe event.
 TW  = Average temperature during the most severe event.
 PW  = Pest Wait/Watch/Warning:  - = not active
                                 + = active but no infection
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Fig. 4. Overview of a report generated by Skybit for apple diseases.

dates. SkyBit emails or faxes subscribers weather forecasts and risk-predictions to subscribers once daily (Figure 4). Weather, insect, and disease reports contain observational summaries for the two-week period preceding the present day and forecast conditions for the following ten days.

Apple disease models available from Skybit include apple scab, fire blight and sooty blotch. Apple insect model include; oriental fruit moth, coddling moth, tufted apple bud moth, oblique-banded leaf roller, spotted tentiform leaf miner, and apple maggot. Grape disease models are available for phomopsis, black rot, powdery mildew and downy mildew (Table 1). Additionally, SkyBit provides forecasting models for carrot [*Daucus carota* subsp. *sativus* (Hoffm.) Schübl. & G. Martens], grape (*Vitus* spp.), peanut (*Arachis hypogaea* L.), potato, tomato and wheat (*Triticum* spp.).

Nursery crop diseases that SkyBit could be used to manage include apple scab, fire blight and powdery mildew for crabapple (*Malus* spp.) cultivars. Pest insects that SkyBit could aid in the management include codling moth on crabapple and walnut, plum curculio on crabapple, apple maggot on dogwood and San Jose scale many species of ornamental trees and shrubs.

SkyBit's email reports are easy to interpret and users can customize the time at which reports are delivered. Frost alerts are also provided. The E-Weather report contains estimates of how favorable conditions are for drying and spraying crops. Both drying and spraying estimates are ranked from 0-10 with lower values being less favorable and higher values representing more favorable days. Estimates are provided for 0-48 hour forecast, the 1 to 7 day forecast plus 8 to 10 day outlook, and for the seven previous days. In future versions subscribers will be able to add data from private weather stations to SkyBit.

Discussion and Perspectives

The main difference between Ag-Radar, NEWA, RIMpro and SkyBit is the suite of models available for users. While some similarities exist, each DSS varies slightly. For example, RIMpro is the only DSS that provides a powdery mildew model for apple. NEWA and SkyBit both have a powdery mildew model for grapes. Ag-Radar is the only DSS that includes a model for European red mite. Another main difference is how each DSS provides information to users. Ag-Radar, NEWA and RIMpro require users to access a webpage to view model predictions. SkyBit is the only one of the four DSS that emails reports to users. Ag-Radar, NEWA and RIMpro provide variety of graphs and tables to users. SkyBit reports are purely textual.

Presently, NEWA and RIMpro require on-site weather stations for sites in the U.S. In some areas, RIMpro can be run utilizing simulated weather data, removing the requirement for an on-site weather station. Ag-Radar and SkyBit do not require on-site weather stations. Future versions of SkyBit may allow users to utilize private weather station data (personal communication, Joe Russo, Bellefonte, PA). Ag-Radar, RIMpro and SkyBit save biofixes once provided by the user, whereas NEWA requires users to enter biofix dates each time a model is run. Additional differences include the timing and total number of infestations or infection events for the various pest insects and diseases, respectively.

Ag-Radar and RIMpro both estimate the severity of infection periods for the apple scab and fire blight models. RIMpro allows users to set breakpoints for apple scab infection events. Ag-Radar provides scenarios for respray dates for apple scab, fire blight, flyspeck, plum curculio, codling moth and apple maggot for commonly used fungicides, bactericides and insecticides. NEWA provides infection risk estimates for fire blight and sooty blotch. RIMpro apple scab model provides estimates for fungicide cover and degradation where users can enter pesticides and application dates. SkyBit provides estimates of whether the pathogen is not active, active but with no infections, and possible infection and damage for apple scab, fire blight and sooty blotch.

Several horticultural management tools provided by the four DSS could be useful to nursery managers. Ag-Radar has bud stage reports, bud freeze mortality estimates, degree days and scald risk. NEWA has models for irrigation, evapotranspiration, frost risk, degree day and growing degree days. NEWA also keeps a leaf wetness log that tracks wet and dry periods. RIMpro tracks degree days and leaf wetness periods. Skybit provides a frost risk advisory in addition to drying periods and estimates of suitability for spraying.

Nursery managers experience many of the same or similar issues as orchardists, therefore, adaptive implementation of DSS for orchardists should be considered. Likewise, management options are the same or similar for both systems. For example, it is common for both orchardists and nursery managers to use air-assisted sprayers, so similarity in equipment exists. Adaptively implementing orchard DSS for commercial nursery production will allow more management aids to be provided to nursery managers in a timely manner, thereby reducing the lag time normally observed between model conception, development and validation and grower-use.

There are several additional important reasons to answer the question of why nursery managers should use orchard DSS for commercial nursery production. Climate, policy/regulatory, crop insurance, and the importance of disease-free stock plant (Daughtrey 2005) all are important factors. Plant managers hoping to achieve optimal application timing of spray materials and labor and product savings should consider consulting DSS or seeking the advice of an extension agent or crop advisor who does. As a risk reduction mechanism, growers who are unsure whether a spray is necessary can consult one or several models to justify the decision of whether or not to spray. If a forecasted infection event does occur and a grower has opted not to apply a protectant spray, they then have the option to apply post-infection fungicides or to make remedial treatments. If the forecasted infection event does not occur and no protectant spray is made, a reduction in the total number of sprays occurs.

Future work should focus on evaluating if existing models can be used to manage plant diseases and insects other than the original intended host species to better suit commercial nursery production. Candidates for disease model expansion would include apple scab, fire blight and powdery mildew for crabapple cultivars. Powdery mildew control for dogwoods, sycamore (*Platanus* spp.), and birch (*Betula* spp.) are suitable candidates that could be investigated. Candidates for insect pests model expansion include, apple sawfly on crabapple, codling moth on crabapple and walnut, grape berry moth on sassafras (*Sassafras* spp.), plum curculio on crabapple, apple maggot on dogwood , and European red mite and San Jose scale many species of ornamental trees and shrubs.

With meteorological forecasting, plant disease and insect forecasts can be made by combining the forecasts from three or more models into a "consensus forecast". The next generation of DSS should consider implementation of consensus forecast models by combining the information data generated by independent models such as NEWA, RIMpro and AgRadar into a single forecast prediction. Since SkyBit data is already incorporated into Ag-Radar, it could be excluded from the consensus model. By averaging together model forecasts, spray recommendation precision and accuracy will be enhanced, thereby increasing the usefulness of DSS while decreasing the time individual users are required to spend consulting the various models.

By fostering an effective extension and outreach program that focuses on adaptive implementation of orchard DSS for commercial nursery production, nursery managers will be better positioned to maintain economic competiveness while adapting to annual and seasonal weather variations. In addition to maintaining economic competiveness, nurseries that take a holistic management approach to decision making will be actively engaged in supporting community and environmental stewardship.

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