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DISCLAIMER:

AUTHENTICATION

We declare that this work was done under our supervision according to the procedures described herein and that the report represents a true and accurate record of the results obtained.

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GROWER SUMMARY

Headline

- The use of the powdery mildew decision support tool may lead to a reduction of on pesticide input costs without comprising disease control
- A rose downy mildew decision support tool is developed and incorporated into the powdery mildew prediction system. However, the model has not been validated with field epidemics yet due to unfavourable weather conditions for downy mildew in 2009-2011.
- The rose disease decision support tool is ready for use by growers, especially the powdery mildew prediction system and a comprehensive user guide is available.

Background and expected deliverables

With HDC funding (HNS 165) we have developed a decision support tool for powdery mildew and implemented the model as a stand-alone computer software package. However, adopting any pest and disease forecasting systems is a gradual process and training given to growers and consultants may encourage the uptake of these systems.

Downy mildew (*Peronospora sparsa*) is a highly destructive disease on roses, causing severe and rapid defoliation. Infection is generally restricted to young plant growth. Severe leaf abscission may also occur. All rose cultivars are considered to be susceptible to this pathogen although they can greatly differ in their sensitivity. Intensive fungicide usage can result in unjustified applications and potential environmental pollution, and does not always control the disease satisfactorily due to poor timing. Severe disease is known to occur under humid conditions but published information has not been adequately synthesised

Expected results of this project include:

- <u>A prediction system</u>. This project will produce a system (computer software) to predict development of rose downy mildew, which will be integrated with the forecasting system for rose powdery mildew.
- <u>Feedback from commercial evaluation of the prediction system</u>. The system will be evaluated in practice by a number of growers with appropriate support from consultants and EMR researchers. This will lead to an improved system for final release and generate confidence on the practical benefit of the system.

Summary of the project and main conclusions

A prediction model has been developed for rose downy mildew and incorporated with the rose powdery mildew (HNS 165) as a stand-alone computer programme. The software can use weather data (text) files of various formats generated by common data loggers.

The powdery mildew model was evaluated in several nurseries in 2010 and 2011. This evaluation led to further improvements to the system and demonstrated that a considerable reduction in fungicide input (> 25%) may be achieved with use of the model predictions which is relevant for the Sustainable Use Directive. Importantly, the tool allows the growers to save spraying time and improve the precision and timing of application. The evaluation also generated several generic issues related to the use of forecasting systems in horticulture, which may be addressed by industry-funded and co-ordinated training activities.

Because of unfavourable weather conditions for downy mildew in 2009-2011, the model has not been validated with field epidemics yet. Hence, further evaluation is necessary, which may be achieved without further funding from HDC if sufficient support from growers is produced.

Financial benefits

Initial use of the powdery mildew system has demonstrated the potential saving in fungicide input (> 25%) without compromising disease control, which is equivalent to a saving of ca. £100 per ha per annum. It is important to note that this also depends on many other factors including variety susceptibility, growing environment, management practices, and products used.

Benefits resulting from using the downy mildew model are more difficult to quantify because of the sporadic nature of this disease, unlike powdery, mildew and further evaluation is necessary.

In addition, the use of these systems demonstrates the responsible use of pesticides which is relevant for the implementation of the Sustainable Use Directive and pesticide reduction programmes.

Action points for growers

- Request a copy of the computer system and the user guide (which contains advice on Installing and running the prediction software) from the HDC.
- Start to use the powdery mildew predictions to assist in the control of powdery mildew (initially on a small scale).
- Once confidence in the model prediction has been gained, gradually make decisions of mildew control based on the model predictions and incorporate this into overall management programmes.
- For downy mildew, weather stations that can record rainfall and surface wetness as well as temperature and humidity are needed.
- Initially, do not time your sprays (at least not on a large scale) according to downy mildew predictions. Monitor downy mildew occurrences (together with weather data), and send these data to Prof Xiangming Xu (Xiangming.xu@emr.ac.uk) to evaluate and improve (if necessary) the model.

SCIENCE SECTION

Introduction

Downy mildew (*Peronospora sparsa*) can be very destructive but tends to be sporadic in its occurrence (Horst, 1983). Although not as common as powdery mildew, downy mildew is considered in the UK to rank in the 'top four' most important foliar diseases of cultivated roses along with rust, powdery mildew and black spot. Infection is generally restricted to young, apical plant growth although it can infect leaves, stems, peduncles and petals. The main effect of the disease is short-term disfigurement caused by foliar lesions and extensive premature leaf abscission or 'leaf drop'.

Under humid, cool conditions, sporangia and sporangiophores appear copiously on the lower surfaces of leaves but, under less favourable conditions, spore production is sparse and difficult to detect (Wheeler, 1981). Sporangia germinate within four hours in water and germination is favoured under cool conditions (<18°C) (Breese et al., 1994b). Field observations indicated that as little as four hour wetness may be sufficient for infection to take place (Baker, 1953). Using detached leaves, it has been shown that infection can take place after only two hour leaf wetness at an optimum temperature and disease severity increased with increases length of leaf wetness (Aegerter et al., 2003). Latent periods range from four to seven days, depending on temperature (Aegerter et al., 2003). In the same study, an empirical model was developed to describe the effects of weather conditions on development of rose downy mildew.

The fungus is believed to overwinter as dormant mycelium in cuttings and plants. However, the role of oospores in overwintering and initiating infections is less certain. Mycelium of *P. sparsa* may survive the winter in the cortex of rose stems (Wheeler, 1981). Systemic infections appear to be important in rose rootstocks in the downy mildew epidemics seen in California (Aegerter et al., 2002). Recent studies indicated that systemic infection in U.K. bush roses is not important and that oospores may play an important role in overwintering (Xu & Pettitt, 2004).

Current knowledge on the biology and epidemiology of the rose downy mildew fungus is very limited. As a result, current control of downy mildew in roses relies almost totally on routine fungicide applications, (10-14 day intervals between applications), especially in crops grown outdoors. In U.K. container-grown crops this can mean 10-15 sprays applied over the period from leaf emergence in spring to the onset of dormancy in autumn. Recent work has shown that compounds for control of potato blight that are effective against *Peronospora* species infecting other host species can give good control of rose downy mildew (O'Neill et al., 2002). However, resistance to these compounds is widely seen in the oomycetes and especially in other downy mildews (e.g. *P. parasitica*). Recently HDC has funded work on evaluating alternative products for controlling rose downy mildew (HNS 135). Correct timing of fungicidal products is important, which is partially determined by the risk of fungal infections.

Materials and methods

Model Development

We have developed a predictive model, which is primarily based on the results from two published results (Breese et al., 1994a, Aegerter et al., 2003) and unpublished results from EMR. The model simulates the infection process at an interval of 3 minutes. Thus to run the model, weather data should be logged at an interval less than or equal to half an hour. Otherwise, interpolation of weather data at the 3-minute interval is likely leading to relative large errors.

Rainfall triggers the model to start a potential infection period, e.g. release sporangia from overwintering lesions or from lesions on plants. Under some circumstances, it is possible to have two concurrent infection processes at the same time, depending on several factors (e.g. the length of dry periods interrupting the two wet periods, the amount of spores survived from the first infection period). Figure 1 provides a simplified model flow diagram at each simulation time step.

The model assumes that all spores are viable and land on the leaf surface immediately following a rainfall event. It also assumes that the rate of infection by each spore depends on temperature only, with greater rates in the range of 5-12°C. If wet leaves become dry, the model halts any current infection process and any infecting spores are liable to die during the dry period. The rate of spore mortality depends upon the relative humidity and temperature during the dry period. When a leaf is re-wetted by rain, dew or overhead irrigation, the surviving spores continue to infect. An infection period ends when all spores landed following a rainfall event have either infected the leaf or are dead.

The progress of infection is measured as Infection Efficiency (IE), defined as the accumulated percentage of spores which have successfully infected plants. The final IE of each infection period quantifies the favourability of weather conditions for infection. Thus, a value of IE = 100% that all the spores landed on the leaves following a rain event have successfully infected plants – indicating favourable conditions for disease development (long wet period and suitable temperature for infection).

Since the model does not consider cultivar susceptibility and the level of inoculum, users need to interpret the IE value with care. The importance of an infection event is not only dependent on the weather conditions (characterised by the IE value) but also cultivar susceptibility and the level of inoculum present in the planting.

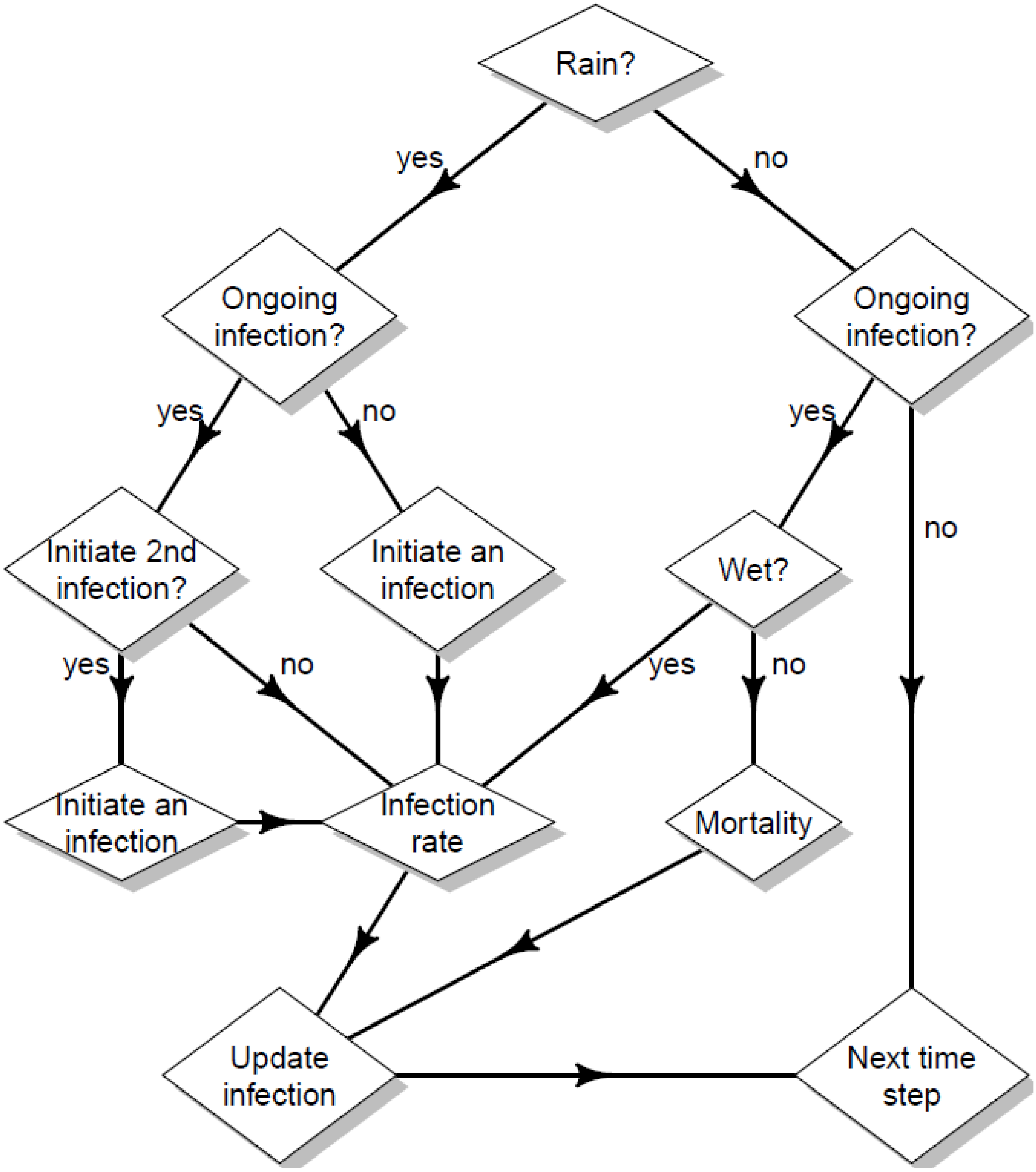

Figure 1. Flow diagram of the rose downy mildew prediction scheme developed at EMR

Model evaluation

Both powdery and downy mildew were evaluated with the focus on powdery mildew because the powdery mildew model was ready for evaluation by early 2010 and growers involved in evaluation did not have weather stations able to record rainfall and surface wetness that are required to run the downy mildew model. Thus, for downy mildew we simply asked growers to report its occurrence. Once reported, EMR would find weather data from weather stations closest to the disease site. In addition, a full downy mildew evaluation trial was conducted at EMR under natural conditions.

In 2010, the powdery mildew model was evaluated at the Whartons Nurseries, Norfolk. There were two primary aims of this initial evaluation: (1) to assess the usability of this computer software, and (2) the usefulness of model predictions for practical disease management. The usability of the system was mainly assessed in terms of (1) user interface, (2) ease of operating the systems, (3) logic flow in operating the system (particularly in handling weather data), and (4) presentation of model predictions. Because of this, it was purposely decided that the whole system would be managed by the grower alone, including initialising data loggers, downloading weather data, running the model, and interpreting model predictions for applying fungicides. During this evaluation phase, John Adlam of Dove Associates provided support to the grower as necessary. A battery powered data logger was placed in a rose plantation to record temperature and humidity (Figure 2); data were regularly downloaded to run the model.

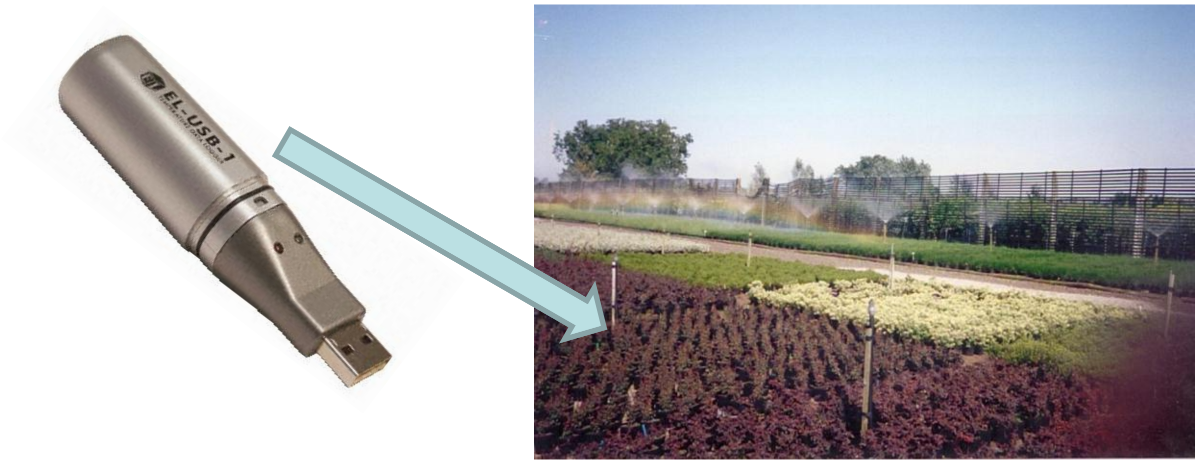

Figure 2. A simple diagram of the data logger and trial site for evaluating the mildew model

In 2011, the system was evaluated in four nurseries: Whartons Nurseries, Fryers Nursery, David Austin Roses and John Woods Nurseries. Again, John Adlam of Dove Associates provided support to the grower as necessary, especially in the initial phase of setting up the system.

In 2010 and 2011, in order to monitor downy mildew development under field conditions for evaluating the model, we placed six plants each of two cultivars (Prima Ballerina and Zéphirine Drouhin) on a sandbed at EMR. These plants were regularly monitored for downy mildew. Weather conditions (temperature, rainfall, wetness and relative humidity) were also recorded.

Potency of rose downy mildew spores

In all three years (2009-2011), we have asked rose growers to send us leaves that were suspected to have been infected with downy mildew. In addition, we have obtained two isolates in 2010 from a German researcher (Dr Dietmar Schulz, Inst. f. Pflanzengenetik, Abt.

Molekulare Pflanzenzüchtung, Hannover) who is currently involved in rose downy mildew research for fungal isolates. These isolates were maintained on *in vitro* detached leaves.

In 2010, experiments were conducted to study the infectivity of *P. sparsa* sporangia on detached leaves *in vitro*. Four concentrations of sporangial suspension were tested, and the experiment was repeated once. For each concentration, there were two replicate Petri dishes, each with up to 5 leaves (i.e. 15-25 leaflets). Detached rose leaves of an unspecified cultivar of the flower carpet type (known to be very susceptible to downy mildew based on the experiences of the grower) were first surface sterilised with sodium hypochlorite (0.025% available chlorine (w/v)) for 15 min, rinsed with distilled water immediately, and then inoculated with sporangia (each leaflet receiving 10 μl of sporangial suspension). Three levels of inoculation concentrations were used: 1000, 10000 and 100000, giving 10, 100 and 1000 sporangia per leaflet, respectively. In addition, an un-inoculated control (applied with distilled water) treatment was included as well. Inoculated leaflets were incubated at 10-12°C, regularly checked for infection by downy mildew. Sterile filter paper was put onto the surface of the agar to prevent the leaves disintegrating.

In both 2010 and 2011, as we have difficulties to obtain viable isolates from the industry, we attempted to use cold-stored dried leaf debris previously infected with downy mildew as inoculum to generate new spores for this potency studies as we suspected that oospores may be present in these dried leaf debris. Suspension was made from the debris and inoculated to leaves of a very susceptible cultivar of the flower carpet type (obtained from the Waltons' nursery).

Training growers for using the system

This was carried out in collaboration with John Adlam of Dove Associates over the two year period of the model evaluation phase. In addition to problem solving via telephone and email, we also attended two meetings with growers in 2009, and presented the evaluation results and implications at the HDC-HTA sponsored rose growers' meeting in 2010 and 2011. For ease of reading, the outcome of these activities will be presented in the section of model evaluation.

Results

Model development

A prediction model has been developed for rose downy mildew and incorporated with the powdery mildew prediction scheme. Figure 3 shows the user-interface of the resulting computing software package. By integrating these two models in one package, we have greatly simplified running the programmes. Procedures for running the system are fully described in the accompanying Users' Guide.

Figure 3. Screenshot of the programme showing the main menu interface

Once the programme is properly set up in terms of weather data format and the master data file, there are three steps for running the programme regularly

1) Download weather data using logger manufacturer's software and append newly downloaded weather data to a master weather data file
2) Run either or both the powdery and downy mildew models (Figure 4).
3) Display model predictions either in a graphic or tabular form (Figure 5).

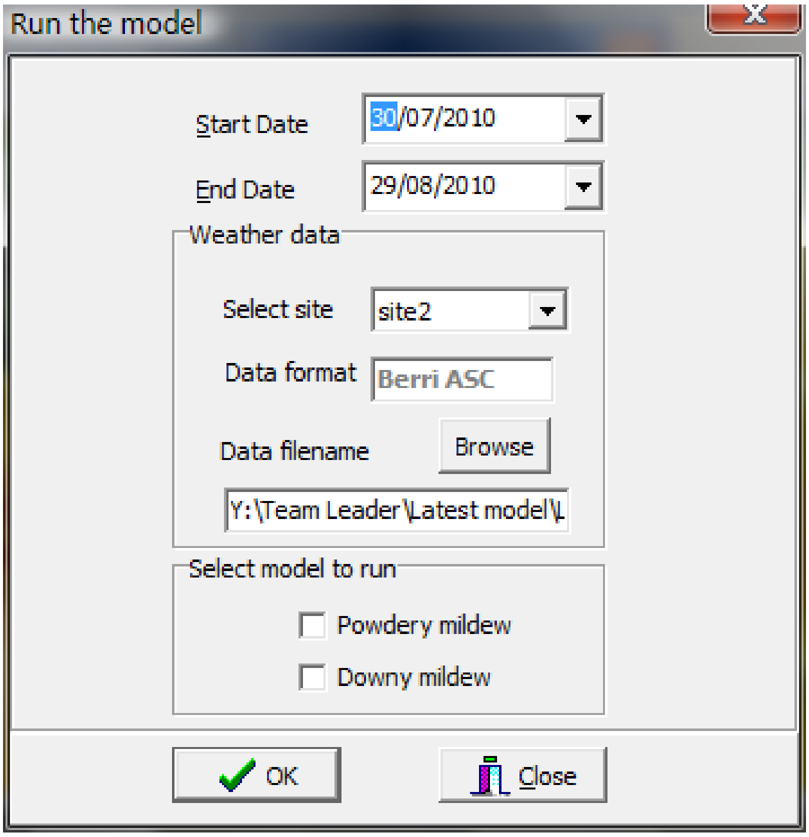

Figure 4. A screen shot of the window used for initiating the predictive model

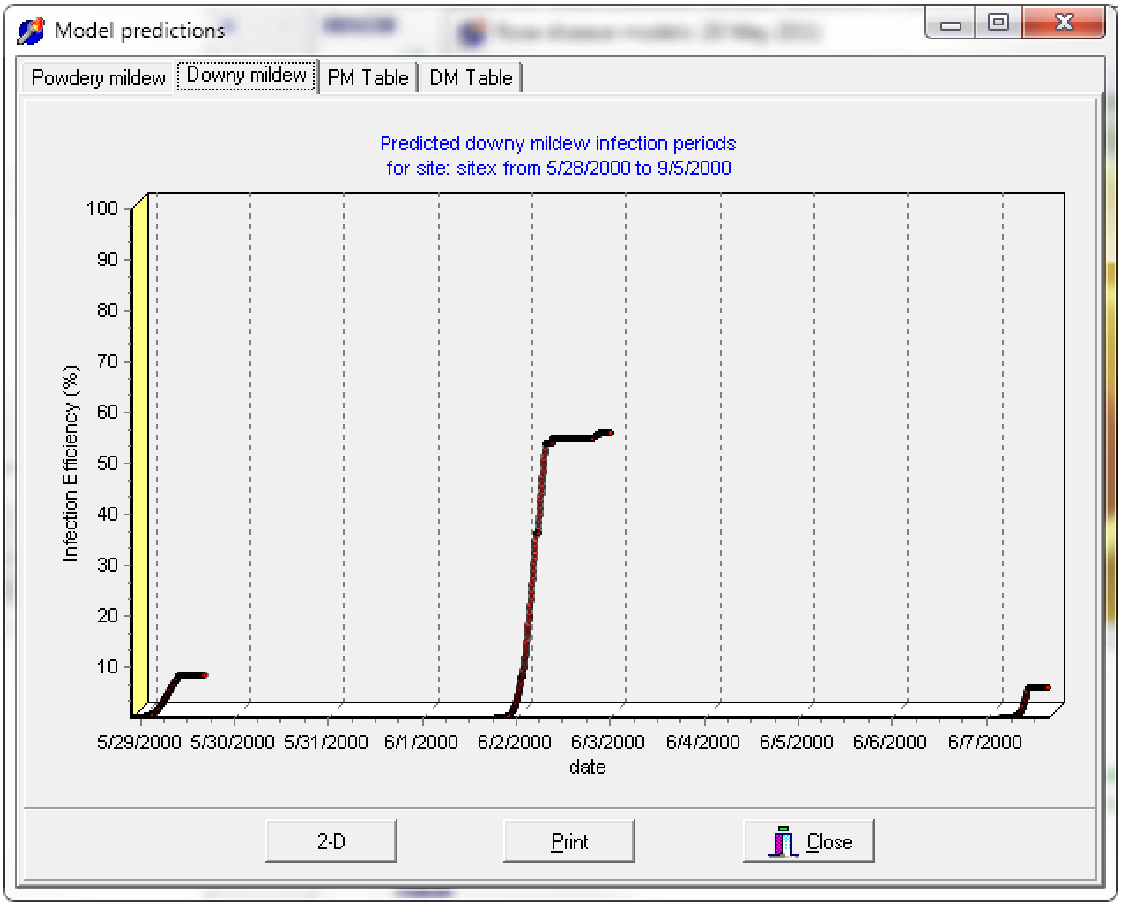

Figure 5. Graphic display of the downy mildew model predictions

The program also provides a context-sensitive help system. Thus whenever users press F1 key, a help screen will be displayed with relevant information. This computer software package is available to download by HDC members via the HDC website.

Model evaluation

Wharton's Nurseries: The programme was first run at Wharton's Nurseries in 2010, on a crop of container grown roses. A whole bed was devoted to the programme which determined the need for a powdery mildew protective spray. Over the trial period (April – August), the conventional treatment received nine sprays, compared to seven sprayed on the model-based management programme (Table 1). This is equivalent to reduction of £108 per ha, including labour cost.

Table 1. Summary of spray records in the model-based and conventional programme of managing powdery mildew in 2010 at Wharton's Nurseries

Model-based strategy			**Conventional strategy**		
Date	**Product**	**Cost/ha**	**Date**	**Product**	**Cost/ha**
14-04-10	Systhane	£21.86	14-04-10	Systhane	£21.86
14-05-10	Systhane	£21.86	14-05-10	Systhane	£21.86
24-06-10	Amistar	£40.43	25-05-10	Folicur	£25.23
06-07-10	Folicur	£25.23	07-06-10	Nimrod	£65.05
13-07-10	Nimrod	£65.05	24-06-10	Amistar	£40.43
23-07-10	Folicur	£25.23	06-07-10	Folicur	£25.23
09-08-10	Amistar	£40.43	13-07-10	Nimrod	£65.05
			23-07-10	Folicur	£25.23
			09-08-10	Amistar	£40.43
Spraying	7 x £9.00/ha	£63.00		9 x £9.00/ha	£81.00
TOTAL		**£303.09/ha**			**£411.37/ha**

They were keen to look at the additional downy mildew module and felt that if the data logging could be automated in some way then the system had value.

Fryers Nursery: This site ran the system through the season and had a good level of success at both running the programme and translating the information into reduced fungicide sprays. Once installed the programme ran well with no operational difficulties. Over the trial period (May – July), the plot subjected to the model-based management received four sprays, three less than the remaining container rose area.

David Austin Roses: The programme was installed on one of their workstations and the logger placed in a nearby container rose bed. The programme ran well and the data was successfully loaded into it. The levels of powdery mildew on both the trial area and the remaining crop were very high and therefore they felt the need to spray their normal programme to gain control. They applied fungicides nine times within a period of 5-6 weeks (June-July). It was noted that there was drift onto the trial area from air-blast sprayers.

John Woods Nurseries: The system was run in 2011 but had considerable difficulties with installation over the computer network. Whilst the logger was run and downloaded, the prediction programme required repeated attention There were difficulties in getting the programme to retain the fungicide data due to a computer-network related problem. In the end, while the logger information was continued, the programme running was abandoned. A total 13 applications were applied from early February to mid-June.

Downy mildew: In 2009, there were no confirmed downy mildew outbreaks. Samples of leaves suspected to have downy mildew symptoms were infected by the black spot fungus (independently confirmed by Dr Tim O'Neill of ADAS). Downy mildew was not reported as a problem in 2010 and 2011. Only two batches of leaf samples with downy mildew were received in late autumn in both years. At EMR, no downy mildew was observed on the plants placed on the sand-bed. The lack of disease at EMR is likely due to lack of inoculum as the model did predict several potential infection periods. We did not obtain a downy mildew isolate that could be used to inoculate plants under controlled conditions to generate independent data sets for model validation in experimental conditions.

In addition, no downy mildew was observed in 2011 in one rose planting at a Chinese research institute.

Improvement made to the model based on the evaluation

Apart from many minor programme bugs and presentation issues, the prediction system has been revised in two major aspects in response to comments from growers.

1). Running multiple sites or multiple loggers on a nursery: this will enable growers to enter fungicide spray information for each site separately.

The model has been modified to enable smooth-operating multi-site (loggers) predictions. To achieve this, we have added an additional layer in defining the data structure when initially configuring the system for use at a particular farm: defining the site name (and its associated logger data type and master data file name) (Figure 6). Many sites can be defined; once a site has been defined, all the subsequent operations only need to refer to a particular site, including running models (Figure 4) and fungicide spray diary (Figure 7).

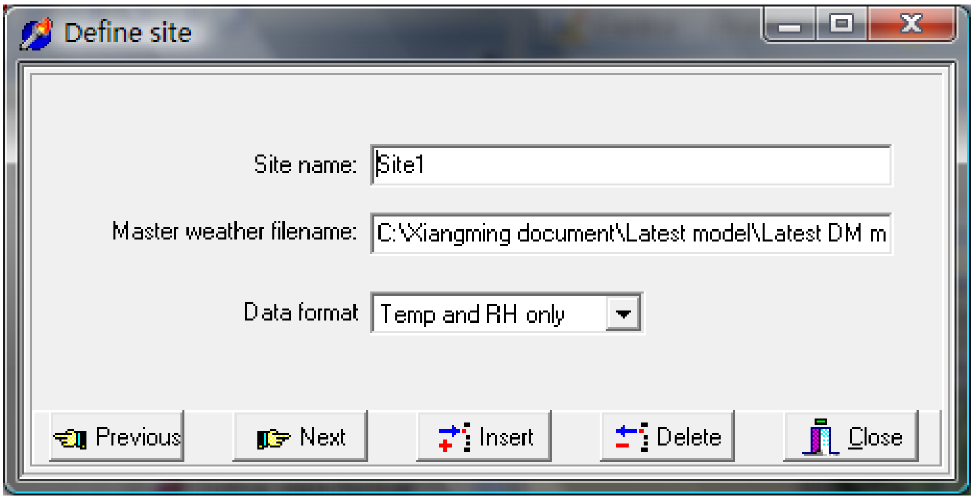

Figure 6. The 'Define site' form.

2). More information for fungicide action against powdery mildew

The default information for fungicide action against rose powdery mildew (kick-back/curative time and protectant period) is now provided for common fungicides (Figure 7). The information is provided by John Adlam of Dove Associates. <u>However, it should be noted that the information is for guide only</u>. Several factors affect the fungicide action considerably, including spray coverage, spray volume, and rate of plant growth. In particular, during the fast growing period, the protectant period must be considerably shorter than indicated. At the present time, we do not have much information on their effects against downy mildew.

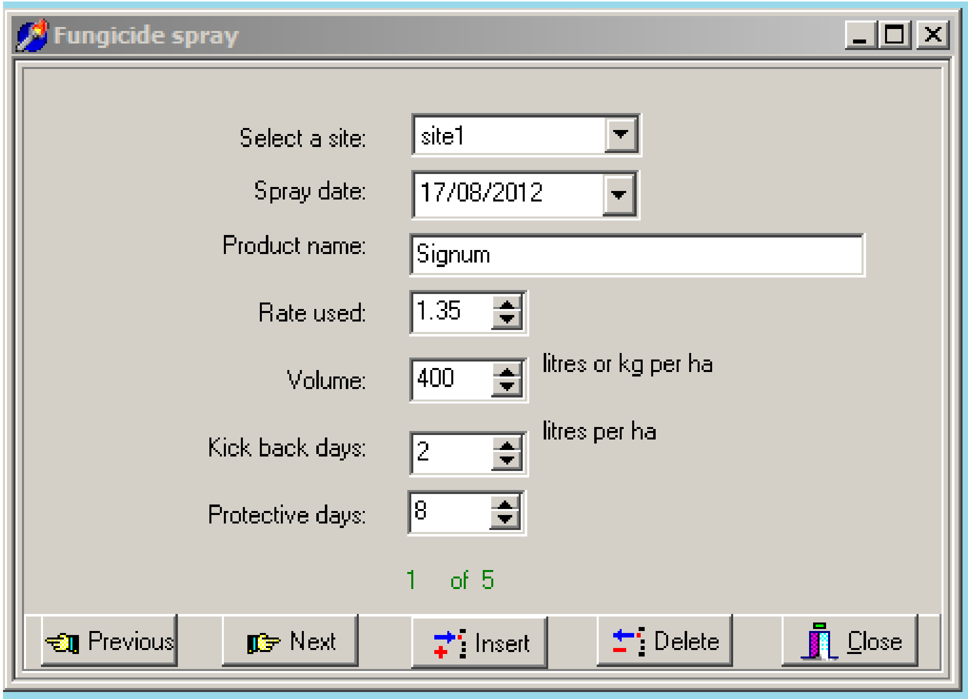

Figure 7. The 'Enter spray data' form.

The potency of downy mildew spores

In both inoculation experiments, only a few leaflets developed downy mildew symptoms and thus we cannot draw any firm conclusion on sporangial infectivity. Nevertheless, downy mildew symptoms were seen on leaves inoculated with only 10 spores per leaflet. Unfortunately, all the leaflets with downy mildew symptoms were also rapidly colonised by *Botrytis cinerea*, which also colonised the original stock strains from Germany. Consequently, we have lost the fungal strains and hence cannot conduct further inoculation studies. In 2011, none of the leaf materials sent from Germany had developed downy mildew.

Downy mildew did not develop on the plants in the sandbed in 2010 and 2011. Downy mildew was not a problem in both years, which was most likely due to weather conditions not conducive for disease development (the general impression of the industry). We only obtained one sample of rose leaves with downy mildew symptoms from growers in each year. However, no viable fungal materials can be isolated from these materials.

In both inoculation studies where leaf debris (thought to contain downy mildew oospores) was used, no downy mildew symptoms were seen on inoculated plants.

Generic issues for using prediction systems in practice

The evaluation has raised several issues that are generic to the use of pest/disease forecasting systems in practice.

1. *Why is it necessary and so difficult to define data format? Can we just use the same type logger?*

   There are many loggers available in markets with varying capabilities. Furthermore, different loggers usually store their data in their own specific format that cannot be viewed by other programmes. For example, some growers may only want to run powdery mildew model and others may want to run both powdery and downy mildew models. For the former, a simple temperature-humidity logger is good enough; but for the latter, rainfall and surface wetness sensors are also needed, which usually are recorded by more expensive loggers. It is practically impossible to allow any model to read internal data format for common commercially-available loggers. Therefore, the compromise is to enable the system to read a text file, which all logger manufactures provide functions to export their internal data format into a text file. However, even for a text file, there are large differences in how the data are stored. For example, how is the date/time stored? For example, is the month before day? What is the separator between day and month? Is the year in two or four digit? What column is temperature stored? Logger manufacturers may also change the exported text file format without notifying users when they updated their firmware. Thus the programme needs to know the exact format of the text file, which is provided by users through data format definition.

2. *When spraying for powdery mildew according to the predictions, growers may have to go back over and spray for insect control within a short period of time. In the normal spray programme, growers would tank mix insecticides and fungicides together.*

   As always stated, you cannot and should not control diseases or pests purely on the basis of forecasting systems. Forecasting systems only give more accurate predictions on disease development and this information needs to be incorporated into the overall management programme. Consultants can be valuable in helping growers interpreting and incorporating model predictions into their management programme.

3. *There is a concern that plants are often despatched having not had a routine powdery mildew spray when the forecasting system is adopted. Hence, growers are unsure how the product shelf life is affected once on the garden centre bed. There may be a reduced protection to powdery mildew of these plants to those routinely sprayed.*

This is related to the point 2: the predictions should be incorporated into the overall management plan. Growers may still provide mildew spray before marketing as a key practice to guarantee shelf life.

4. *The single biggest need is for the system to incorporate some means of automatic data loading to avoid the need for regular logger visits.*

   This is achievable by the use of an automatic weather station. A unit such as the Davis Vantage Pro 2 would provide all the necessary environmental data as well as provide a leaf wetness module to include the necessary sensors for a future downy mildew prediction.

Discussion

Downy mildew development

We have developed a model that predicts potential downy mildew infection periods using all available published information on the epidemiology of this disease. It was planned to further evaluate this model using monitored epidemic outbreaks from natural conditions. Unfortunately, over the three years, this disease did not present any significant problem to growers and hence we could not evaluate its performance. For this reason, we propose that growers should focus their efforts on using powdery mildew prediction initially while collecting some data on downy mildew occurrence, which can be used to evaluate the downy mildew model. For this to happen, we would encourage growers to install an automated weather station that can record temperature, humidity, rainfall and surface wetness.

Unfortunately, we were unable to obtain viable pure fungal strains to collect a complete set of data on the potency of downy mildew spores. Nevertheless, the incomplete data set suggested that infection can occur with a very low number of spores applied to each leaflet, which is consistent with our previous unpublished studies (Figure 8). The potency of *P. sparsa* sporangia, therefore, appears to be high, especially if potential run-off and viability of inoculum are taken into consideration.

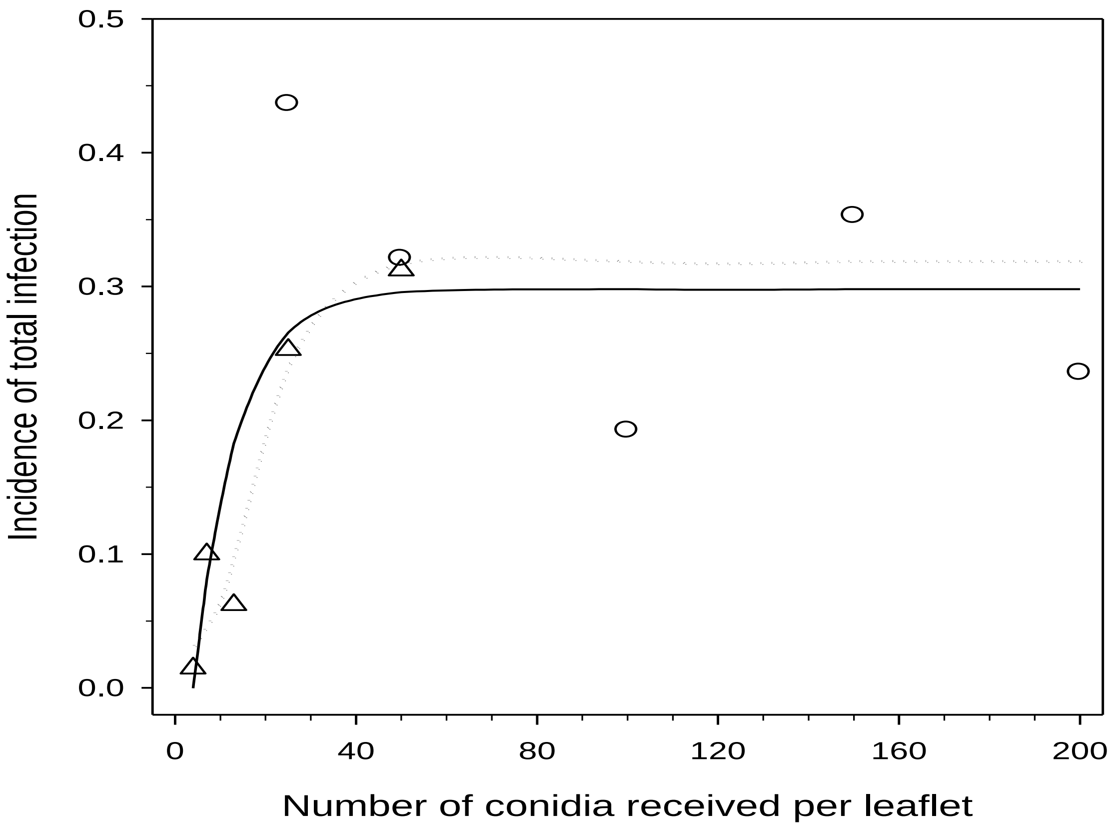

Figure 8. Incidence of rose downy mildew (including dropped leaflets) on inoculated leaflets of cv Flower Carpet over two inoculation experiments in relation to the number of sporangia received per leaflet: circles = first experiment; triangles = second experiment; dotted line = the fitted logistic equation using 2nd inoculation data only; solid line = the fitted exponential model using data pooled over the two inoculations. Inoculation was conducted in controlled environment cabinets set to 15°C and plants were subjected to a 48 h wet period after inoculation before being moved to a glasshouse compartment.

Use of the powdery mildew model in practice

We are very encouraged by the model evaluation result. On two sites where the growers were able to operate the model, considerable reduction (at least 25%) in fungicide input was achieved without comprising mildew control. However, it should be noted that amount of fungicide saving also depends on weather conditions. For effective management of powdery mildew diseases in general, initial control in the early season is essential. Once powdery mildew is established, there is little scope to reduce fungicide input although use of forecasting models may be able to time fungicide better. Thus, it is important to have good control early in the season in order to maximise the benefit of forecasting systems.

On the other hand, we were disappointed that at least two growers failed to operate the system because of weather data related issues. This is the most common problem identified in adopting pest and disease prediction systems. This problem is unavoidable because reliable (real time) predictions depend on the quality of weather data. This may explain why there is a trend for using forecasting systems where a service provider operates a network of weather station and generate forecasts for growers. To operate such as system, a co-ordinated approach is needed. Furthermore, it should stressed that frequent disease assessment is necessary no matter how a prediction system is run since the level of current disease (particularly for powdery mildew) is one of the key determinants for epidemic development.

Conclusions

- Results for the evaluation of the powdery mildew model is very encouraging
- The system's user interface as well as some of key functions has been thoroughly revised based on the evaluation for easy use on multiple commercial sites
- The system is now ready for use by growers; a comprehensive user guide was produced
- Rose downy mildew model is developed and incorporated into the prediction system
- Because of unfavourable weather conditions for downy mildew in 2009-2011, the model has not been validated with field epidemics yet. Hence, we suggest that growers initially only use the model predictions to time sprays on a very small scale but monitor downy mildew occurrence (together with weather data). With the monitored data, EMR can then evaluate the model performance and improve the model if necessary

Technology transfer

- We discussed this work and related work at EMR with Chris Warner (a rose breeder) when he visited EMR in August 2009.
- We have been in close contact (email, phone, and face-to-face meetings) with growers and consultants in relation to the evaluation trial in 2010 and 2011
- We have presented a talk on use of disease prediction systems on roses at a Rose Workshop organised by HTA-HDC in August 2009 and 2010.
- A review session was held on the practical use of the forecasting system in nurseries in the Rose Workshop organised by HTA-HDC in October and 2011.

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