ANNUAL REPORT

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HDC Project BOF 59
Annual Report (2007)

Narcissus Smoulder
Decision Support System

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Grower Summary

BOF 59

Narcissus Smoulder Decision Support System

Annual Report 2007

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Signed on behalf of: **Warwick HRI**

Signature:…………*Simon Bright*…………… ***Date***: …25 February 2008……………………

Name: Professor Simon Bright
Director and Head of Department

The results and conclusions in this report are based on an investigation conducted over one year. The conditions under which the experiment was carried out and the results obtained have been reported with detail and accuracy. However, because of the biological nature of the work it must be borne in mind that different circumstances and conditions could produce different results. Therefore, care must be taken with interpretation of the results especially if they are used as the basis for commercial product recommendations.

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BOF 59: Narcissus smoulder decision support system

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GROWER SUMMARY

Headline

Three years into this four-year project to validate and deliver a decision support system for managing smoulder disease of narcissus, the results indicate it could be used successfully to determine the target dates for fungicide applications at an individual farm level. This offers growers the opportunity of achieving better disease management with fewer sprays, reduced costs and a positive environmental impact.

Background and expected deliverables

The control of pests and diseases is a major factor in meeting the exacting specifications for fresh produce of the export and multiple-retail sectors. In UK narcissus crops there appears to have been an increase in the incidence of the foliar disease smoulder (caused by *Botrytis narcissicola*) over the past 10 years. It is estimated that the disease regularly reduces bulb and flower yields by about 10%.

The application of fungicide sprays is currently based either on (1) sprays applied by the calendar (say, from soon after shoot emergence and continuing at regular intervals until after flowering), or on (2) the experience of growers and consultants, built up over many years, of controlling these diseases. In an earlier project funded through the 'Horticulture LINK' programme, the HDC and ten companies, a predictive model for smoulder infection was formulated. It was shown that the time of infection is largely determined by adequate periods of leaf surface wetness combined with optimum temperatures. These criteria can be ascertained by collecting temperature and leaf surface wetness data from a metereological station/logger operating in the field. Used in conjunction with a model describing the effect of temperature and leaf suface wetness on smoulder infection, the occurrence of smoulder on crops can be derived. Additional results showed that leaf damage increased the likelihood of smoulder development. The predictive model for smoulder infection indicates the dates when fungicides should be targetted to obtain the most effective control. In trials it was shown that the number of fungicide sprays applied in one growing year could be reduced from six to three by the expedient of applying these sprays only at the dates predicted by the model.

The aim of the current project is to validate – to test, then confirm or modify – the predictive model of smoulder infection and deliver it to the industry as a practical 'spray-timing system'. Such a system would provide improved management of smoulder, leading to enhanced yields of better quality bulbs and flowers with lower costs and a smaller environmental impact. It is likely that there will also be some incidental control of other fungal foliar diseases.

Summary of the project and main conclusions

2005 and 2006

The validation and delivery of a spray-timing system for the control of smoulder requires the assessment of disease levels on plots sprayed according to the criteria of the predictive infection model. Two methods of comparing infection risk were used. Half-hourly temperature and leaf surface wetness readings were collected through data loggers in the field and used with the infection model to derive daily infection scores. These infection scores were compared with observations of actual smoulder levels on field-grown crops over time. The infection scores were also compared with disease levels on trap-plants (pot-grown plants exposed in smoulder-infected field plots for periods of 24h). Because of the crop damage they can cause, the impact energy of precipitation and the occurrence of frosts were used as additional criteria to determine spray timings.

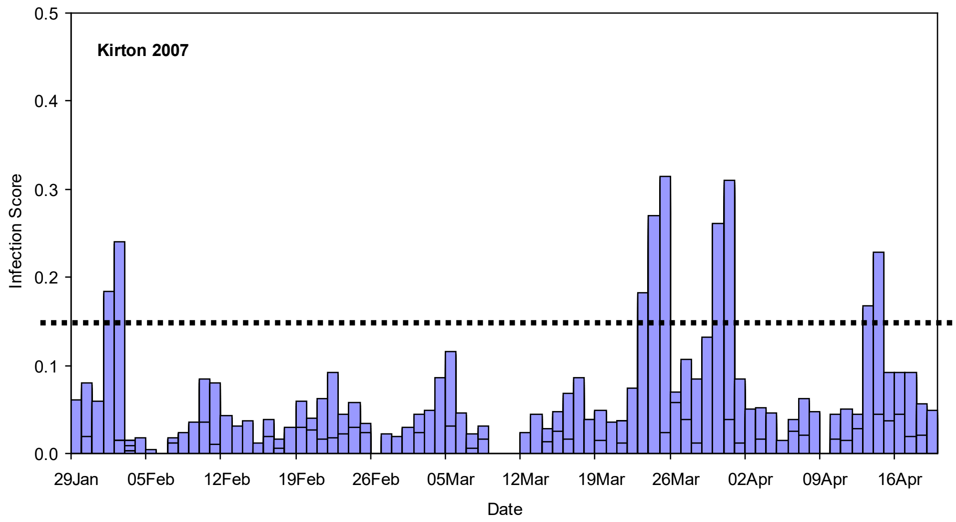
Using the model to predict outbreaks of smoulder confirmed the potential of the concept. There was a reasonably close relationship between trap-plant infection and the occurrence of the higher predicted infection scores. The results confirmed that other factors, notably crop damage, were important if infection were to follow, though the precise nature of the damage - perhaps related to frost, heavy rain or hail, or high wind speeds - needs to be defined. Spore trapping during these trials confirmed that smoulder inoculum was available during the predicted infection periods. Conidia of *Botrytis narcissicola* were detected in the field, although there was only a weak association between numbers of conidia and infection model scores on the days when comparisons were made.

2007

During 2007 the infection model was used to determine the target spray dates for narcissus crops at three farms. The model gives an 'infection score', but does not tell how high this score should be for spraying to be necessary. Therefore the infection score was used in a different way at each site, to determine how best to use the model on a practical level.

- At Kirton, where smoulder infections were expected to be high, a 'cautious' criterion was used, spraying when the infection score was 0.15 or more;
- At Surfleet a more 'economical' criterion was used, spraying when the infection score was 0.25 or more;
- At Holbeach Marsh, a more exposed site, spraying was triggered either when the infection score reached or exceeded 0.25, irrespective of precipitation impact levels, or when the score reached 0.15 and there was a 'heavy rain event' in that week.

Flowers were cropped at all sites, and, because of the damage to foliage that this causes, one fungicide spray was additionally applied at each site following flower picking. An example of the predicted infection scores for one site (Kirton) is shown in the figure below. There were considerable variations between sites in those weather features relevant to the infection model. The amount of smoulder in plots sprayed according to the infection model (the ‘model spray programme’) was compared with that in adjacent control (non-sprayed) plots and in plots sprayed with a conventional or typical commercial spray programme (the ‘conventional spray programme’). For the conventional spray programme the growers of the crops applied fungicides according to their normal commercial practices.



At Kirton, the critical infection score of 0.15 was exceeded on four occasions, 2-3 February, 23-25 March, 30-31 March and 13-14 April. Fungicide sprays were applied to the model spray programme plot following the last three warning scores, though technical problems in accessing weather data earlier in the year prevented the first warning score being used. The model spray programme therefore consisted of four applications (one as a result of flower cropping, and three due to high infection scores), while the conventional spray programme plot also received four applications, though at different timings - starting and finishing earlier than the model programme.

At Surfleet, the infection score also exceeded 0.15 early in the season, in January, but, as described above, it had been decided to operate on a warning level of 0.25 at this site, a level exceeded only on 24-25 March, following which two fungicide sprays were applied to the model spray programme plot. The model plot therefore received three fungicide applications in all (one as a result of flower cropping, and two due to high infection scores). At this site only one fungicide spray was applied to the conventional spray programme plot, due to commercial considerations, this one spray being applied in mid-February.

At Holbeach Marsh the critical level of 0.15 was exceeded on 25 February and around 24 March, but as these scores were not accompanied by heavy rain events no sprays were applied as a result. However, the higher warning level, 0.25, was greatly exceeded over the period 29 March to 4 April, resulting in fungicide application to the model spray programme plot. The model spray programme plot therefore received only two fungicide applications in all (one as a result of flower cropping and one due to high infection scores combined with heavy rain), while the conventional spray programme plot received three applications, starting earlier and finishing later than the model spray programme.

At all three sites the incidence of smoulder increased slowly from early-February, and later in the season became more severe at Kirton than at either Holbeach Marsh or Surfleet. The higher level of smoulder at the experimental site at Kirton may have been partly due to the greater concentration there of diseased crops used in trials, and at the start of the growing season there were more smoulder primaries at this site than at the others. Here, for the model spray programme plot, the omission of the early spray (see above) was clearly detrimental. Nevertheless, the non-sprayed control plot had a higher smoulder incidence than the plots receiving either of the fungicide spray programmes, with the model spray programme plot remained greener than the conventional spray programme plot towards the end of the growing season. At Surfleet and Holbeach Marsh there was no evidence of treatment effects on smoulder incidence over most of the growing season, but towards the end of the growing season there were periods with beneficial effects due to fungicide sprays; at Surfleet the model spray programme proved the better, while at Holbeach Marsh the conventional spray programme was the better. At Kirton and Surfleet the model spray programme resulted in crops remaining greener than the other plots at the end of the growing season. At Kirton, the model spray programme was considered a success, despite the high levels of smoulder at the site. At Surfleet the curtailment of the conventional spray programme inevitably meant that the model spray programme was the more effective of the two. At Holbeach Marsh, waiting for a high infection score before spraying was, in retrospect, unwise; it would have been better to have used a lower critical infection score and not to have waited for high-impact precipitation to occur.

For the more reliable control of smoulder, the results suggest that a relatively low predictor score (0.15 in this case) should be used to trigger fungicide spraying, noting that applications early in the growing season are important. Until the effects of weather-induced damage are better understood, it would be better generally to rely on the predicted infection scores alone, taking frost, heavy rain and other crop damage into account when the predictor score was boarderline for spraying.

Financial benefits

The earlier 'Horticulture LINK' project was subject to independent scrutiny, which concluded that considerable financial saving could be made by using a fungicide spray programme that reduces the total number of fungicide sprays applied. The present project will help growers to apply these fewer fungicide sprays to crops at the best, most effective time to control smoulder, thereby improving crop quality and reducing wastage due to foliar disease.

Action points for growers

Until the smoulder infection model and associated spray-timing system are fully available to the industry at the conclusion of this project, growers could apply smoulder fungicides following prolonged wet periods when temperatures are relatively high (10-15°C), and also following crop damage (such as that caused by flower picking).

SCIENCE SECTION

Introduction

The previous annual report (2006) outlined the rationale for the project, and described the monitoring of smoulder in commercial Lincolnshire narcissus (daffodil) crops that had not been treated with fungicides. This enabled the 'natural' development of the disease to be recorded, so that these (observed) data could be compared with smoulder development as predicted using a smoulder infection model formulated in an earlier 'Horticulture LINK' project (project CSA 4716) funded by Defra, the HDC (as BOF 41) and ten companies. Comparing the observed and predicted periods when smoulder infection developed enabled the accuracy (or otherwise) of the model to be ascertained. Using the infection model to predict outbreaks of smoulder showed potential for use in forecasting the disease. There was a reasonably close relationship between trap-plant infection and the occurrence of higher infection scores. The results confirmed that crop damage was also important for infection to take place, though the exact extent of the damage required (say, due to frost, heavy rain, hail or high windspeeds) needed to be defined.

The present annual report (2007) describes the next stage in this project – using the smoulder infection model and other environmental criteria to determine the optimal dates for spraying commercial crops with fungicides, and comparing the effects of this 'model spray programme' with those of the growers' normal or 'conventional spray programme'. This gives an opportunity to validate the infection model in a wider variety of crop situations, and will also provide opportunities to develop practical methods for using the model and seeing how it could best be delivered to growers. This work is being repeated on further commercial crops in 2008, with a view to delivering a usable 'spray-timing system' by the end of the project.

Materials and methods

Trial sites and spray programmes

In autumn 2006 two second-year and one third-year narcissus (daffodil) crops in Lincolnshire were selected for trialling, two on commercial farms and one at the Kirton Research Centre (KRC) (Table 1). The crops used were considered typical commercial crops for the region. In each crop an area *ca.* 0.6ha in extent was designated, this being divided into three equal *ca.* 0.2ha plots, one for each of three treatments. Each set of three plots was clearly marked with corner posts and signage. The total area used varied at each site, according to availability and suitability, from 40 to 96m wide (*ca.* 45 to 126 ridges with ridges at either 0.76 or 0.90m centres) and 70 to 220m along. The central *ca.* 0.1ha of each plot was further marked for monitoring and observation, leaving the surrounding areas as buffer zones against spray drift from adjacent plots and crops.

Table 1: Smoulder trial sites, 2007-2008

Site reference	*Grid reference*	*Cultivar*	*Crop year*
Kirton	TF302395	'Golden Harvest'	2
Surfleet	TF259293	'Fortune'	3
Holbeach Marsh	TF388306	'Carlton'	2

The three treatments were:

1. *Control* - no fungicide sprays applied to these plots.
2. *'Conventional spray programme'* - each grower applied to these plots his routine fungicide spray programme, as used on his other daffodil crops, deciding the fungicides, rates and number and timing of sprays. It had been anticipated that growers would apply up to six sprays to these plots at each site.
3. *'Model spray programme'* - each grower applied an agreed fungicide spray programme to these plots, the application dates being triggerred by Warwick HRI staff using the predictions of the smoulder infection model with weather data from stations/loggers situated in the individual crops. The fungicide used on each occasion was tank-mix Amistar (0.5L product/ha) plus Folicur (0.5L product/ha). It was anticipated that no more than three sprays would be applied to these plots.

In all other respects crops were grown according to the grower's current commercial practices.

Weather data

A meteorological data logger ('Smaartlog'; Intelligent Micro Design Ltd.) was set up close to the centre of each trial area prior to crop emergence. The loggers, powered by battery and solar panel and downloadable *via* a modem and digital cell telephone, were provided with sensors recording soil and air temperature, relative humidity, surface wetness, rainfall and precipitation impact (PI) at 30-minute intervals. The PI sensor ranks impacts into 14 levels from the lowest impact energy (1) to the highest (14).

Crop and disease monitoring

The allocated areas were checked at weekly intervals from December onwards, and the date of first appearance of smoulder symptoms was recorded (see Annual Report for 2006 for a description of symptoms). Following the appearance of first symptoms, disease levels were assessed weekly as incidence and severity. The central area of each plot was walked in a standard fashion in an X-pattern, starting from a marked corner, and on crossing ridges a 0.5m-long sub-sample was delimited with a ruler at the intercept to give 50, 0.5m-long sub-samples for assessment over the area. To identify the sub-samples, numbered canes were inserted at one end of each of these 50 sampling locations.

The incidence and severity of smoulder were scored in each of the sample locations according to the scale shown in Table 2; overall incidence and severity scores for each plot were then calculated by summing the scores for all 50 sub-samples. The crop growth stage and (later in the season) the percentage of foliage that was senescent or dead were also noted.

Table 2: Smoulder incidence and severity scales

Score	*Incidence*	*Score*	*Severity*
0	None	0	None
1	1 or 2 leaves affected	1	Single lesions
2	>2 but <10 leaves affected	2	Single lesions, occasionally >1 lesion/leaf
3	>10 leaves but <50% leaves affected	3	Generally 2 or more lesions per leaf
4	>50% but <100% leaves affected	4	Lesions coalescing into larger areas
5	All leaves affected	5	Extensive leaf die-back

Spore trapping using trap-plants

In August 2006 daffodil bulbs (grade 12-14cm cv 'Carlton') were allocated from a stock grown at KRC for the production of trap-plants. To achieve comparability with the second- or third-year field-crops being monitored, these bulbs were not given the usual hot-water treatment before planting, nor did they receive any fungicide applications after lifting in June/July. The bulbs were stored at 17°C until early-October 2006, when they were planted in a standard fashion, five bulbs per 20cm-diameter, 4L-capacity plant-pot, using a peat growing medium. After planting the pots were placed on a standing ground outdoors at KRC, covered with fleece for protection from extreme weather, and kept watered as required.

Between 6 March and 7 May 2007, pot-grown trap-plants were placed adjacent to crop foliage near the centre of each crop for exposure periods of 7 days. For each exposure period, six plant-pots were used. Before exposure the plant leaves in three pots of each batch were damaged by drawing a stiff bristle nail-brush across the leaves in a standard fashion, the other three pots remaining undamaged as controls. Following collection from the field sites the exposed trap-plants were placed in a frost-protected glasshouse at KRC (minimum maintained temperature 3ºC, ventilated at 10ºC, and free of known infective plant material). Further control pots, not exposed in the field, were moved straight to the glasshouse (three pots per week). For an initial 48-hour period the pots were placed in high humidity provided by a humidifier running under a polythene-film cover within the glasshouse, after which they were moved to the body of the glasshouse. The three replicate pots in each set were arranged in the glasshouse in three blocks, all pots being spaced well apart to reduce the liklihood of cross-infection. Pots were kept well watered, bottom-watering into saucers to avoid spreading infection. The trap-plants were examined for disease lesions at weekly intervals, and incidence and severity scores (Table 2) were recorded over a 14-week period.

Forecasting periods of risk and when to apply fungicides

The smoulder infection model predicts the number of disease lesions which is likely to occur, based on temperatures and the durations of periods of leaf wetness. The model showed that the critical weather conditions favouring smoulder infection were temperatures between 10 and 15ºC combined with leaf wetness durations of 12 to 24h. The model was run weekly using the weekly weather data obtained from the logger in each crop, producing an infection score. The infection score was averaged for 24-h periods starting at 00:00 hours. The smoulder infection model gives an infection score, but does not state what score should be used as the threshold to trigger spraying, so this was investigated by applying different threasholds at the different sites (see below). As crop damage has also been shown to favour infection by the smoulder pathogen, both the infection score and the extent of any crop damage (e.g. due to frost, damage caused by flower picking, or high-energy rainfall) were considered when deciding on dates for spraying. The occurrence of crop damage was taken into account and used to confirm a spray when the infection score was borderline; in practice, the main physical damage occurring was through flower picking.

At the three sites, different model and damage criteria were tested:

1. At Kirton, where, on past experience, infections were expected to be high, a ‘cautious’ criterion was used, spraying the model spray programme plot when the infection score was 0.15 or more daily during any week;
2. At Surfleet an ‘economical’ criterion was used, spraying the model spray programme plot when the infection score was 0.25 or more daily during any week;
3. At Holbeach Marsh, a more exposed site, a spray for the model spray programme plot was triggered either when the infection score reached or exceeded 0.25 in any one day, irrespective of precipitation impact (PI) levels, or when the score reached 0.15 and there was a ‘heavy rain event’ in that week. A ‘heavy rain event’ was defined as rain in levels 7 to 14 over a rolling 24-h period.

Once the model gave the agreed infection level for a site, the grower was asked to apply fungicide to the model spray programme plot as soon as practical. Dates and other details of the fungicide sprays applied are shown for all treatments in Table 3.

The unsprayed, control plots were used to compare the predicted (modelled) and actual (observed) levels of smoulder symptoms. The correspondance of predicted and actual levels would validate the accuracy of the model, while dissimilar results would indicate that the model is inappropriate or needs to be refined. In these tests the results are strictly not directly comparable, since symptoms often take time to appear. However there should be some correspondence between observed and predicted occurrence of smoulder in the field, for example an increase in disease being observed after high predicted infection scores.

Table 3. Details of fungicide spray applications in commercial and model spray programmes in 2007.

Spray programme	*Spray number* 1	2	3	4
(a) Surfleet				
Commercial	14 February Ronilan Fl 0.72 L/ha	*	*	*
Model	09 March[a] Folicur + Amistar 0.5L + 0.5L/ha	26 March Folicur + Amistar 0.5L + 0.5L/ha	09 April Folicur + Amistar 0.5L + 0.5L/ha	-
(b) Holbeach Marsh				
Commercial	16 February Bravo + Dithane 945 2.0L + 2.5kg/ha	28 March Folicur + Bravo + Dithane 945 0.5L + 1.5kg + 1.5kg	16 April Amistar + Folicur 0.5L + 0.25L	-
Model	02 March[a] Folicur + Amistar 0.44L + 0.44L/ha	28 March Folicur + Amistar 0.58L + 0.58L/ha	-	-
(c) Kirton				
Commercial	1 February Folicur + Delsene Flo 0.5L + 0.5L in 450L/ha	17 February Scala + Folicur 2.0L + 0.5L in 450L/ha	8 March Dithane + Delsene Flo 1.5kg + 0.5L in 450L/ha	28 March Folicur + Amistar 0.5L + 0.5L in 450L/ha
Kirton	02 March[a] Folicur + Amistar 0.5L + 0.5L in 225L/ha	28 March Folicur + Amistar 0.5L + 0.5L in 225L/ha	11 April Folicur + Amistar 0.5L + 0.5L in 225L/ha	5 May Folicur + Amistar 0.5L + 0.5L in 225L/ha

* A commercial decision was taken by the grower to make no further sprays.
[a] First spray decision based on crop damage; subsequent applications based on model 'threshold' (see text).

Results

Operation of the predictive infection model

As described under Materials and Methods, the smoulder infection model was run weekly for each of the three trial sites, using the air temperature and leaf wetness duration data recorded at each site. The model produces daily infection scores, but does not define a critical infection score that signals the need to apply a fungicide spray. To test the prediction model, at Kirton and Surfleet a spray was requested for the model spray programme plots when the infection score exceeded a level of 0.15 or 0.25, respectively, in any one week, the two levels being considered respectively 'cautious' and 'economical'. Since heavy rainfall can produce leaf damage enhancing infection by the smoulder pathogen, at the third site, Holbeach Marsh, a combination of critical infection score and heavy rainfall was used to recommend fungicide application: a fungicide spray was requested either when the infection score reached 0.25 in a week, irrespective of PI levels, or when the score reached 0.15 and there was a 'heavy rain event' in that week. The predicted infection scores are shown for the three sites in Figure 1. Once the model gave an agreed infection level for a site, the grower was asked to apply fungicide to the plot designated for the model spray programme. At all three sites the first fungicide application was triggerred, in the absence of high infection scores, by flower cropping, as this results in considerable damage such as broken stems and leaves and the general trampling of the crop. The findings showed there was considerable variation in weather patterns between sites, which needs to be considered in designing spray-timing systems. It is also notable that smoulder periods can be triggerred throughout the growing season, including early in the year when frost damage might also occur.

The details of sprays are given in Table 3.

At Kirton, the critical infection score of 0.15 was exceeded on four occasions, 2-3 February, 23-25 March, 30-31 March and 13-14 April. Fungicide sprays were applied to the model spray programme plot following the last three warning scores, but technical problems with accessing weather data earlier in the year prevented the first warning score being used. The model spray programme therefore consisted of four applications (one due to damage, three due to infection scores), while the conventional spray programme plot also received four applications, though at different timings - starting and finishing earlier than the model programme.

At Surfleet, the infection score also exceeded 0.15 early in the season, in January, but, as described above, it had been decided to operate on a warning level of 2.5 at this site, a level exceeded only on 24-25 March, following which two fungicide sprays were applied to the model spray programme plot. The model plot therefore received three fungicide applications in all (one due to damage, two due to infection scores). At this site only one fungicide spray was applied to the conventional spray programme plot, due to commercial considerations, and this spray was applied in mid-February.

At Holbeach Marsh the critical level of 1.5 was first exceeded on 25 February, and also later in the season, but as these scores were not accompanied by heavy rain events no sprays were applied as a result (Figure 2). However, the higher warning level, 0.25, was greatly exceeded over the period 29 March to 4 April, resulting in fungicide application. The model spray programme plot therefore received only two fungicide applications (one due to damage, one due to infection scores), while the conventional spray programme plot received three applications, starting earlier and finishing later than the model programme.

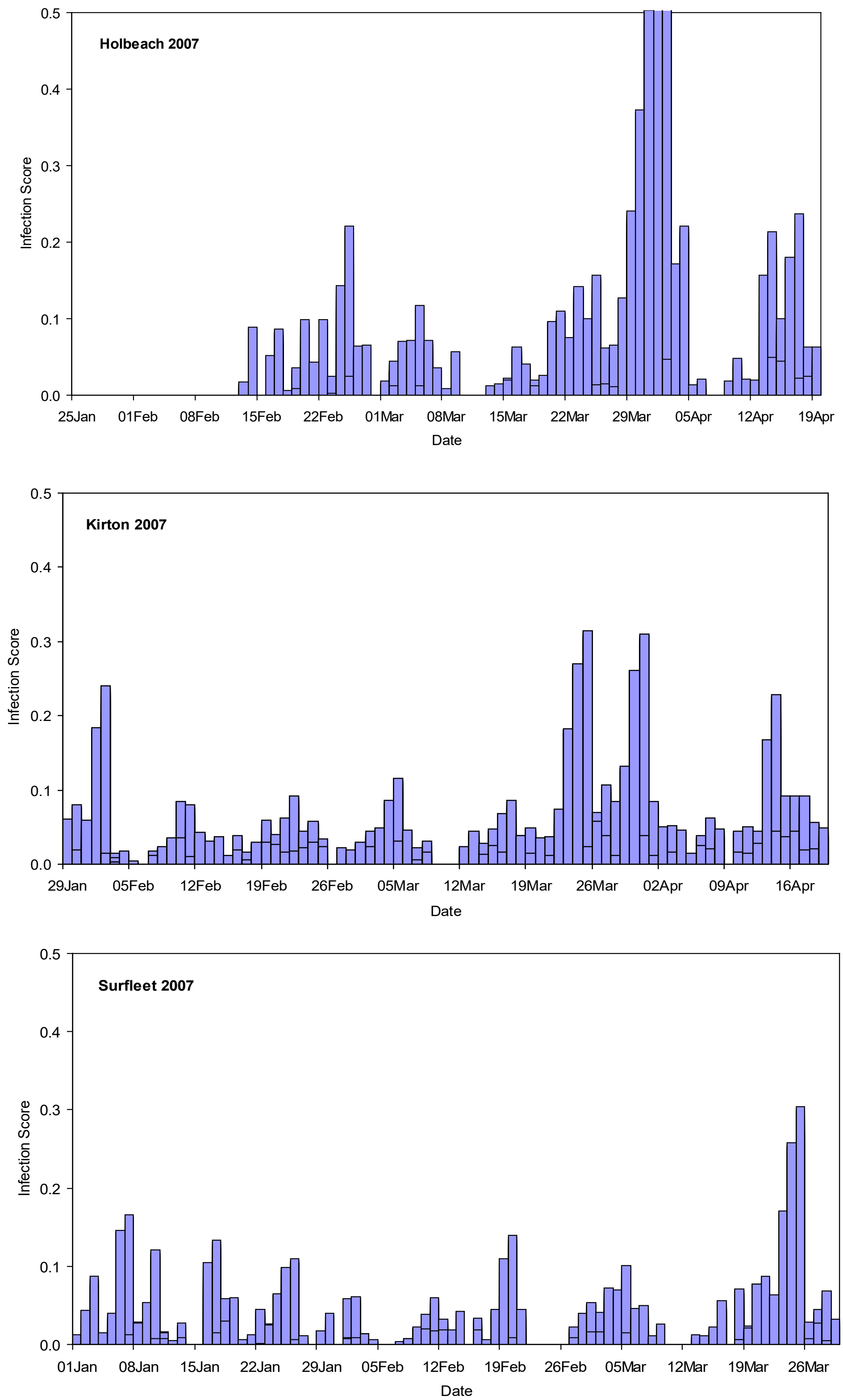


Figure 1. Smoulder infection scores derived from the predictive model using air temperature and leaf wetness duration data from each site, Holbeach Marsh (top), Kirton (middle) and Surfleet (bottom).

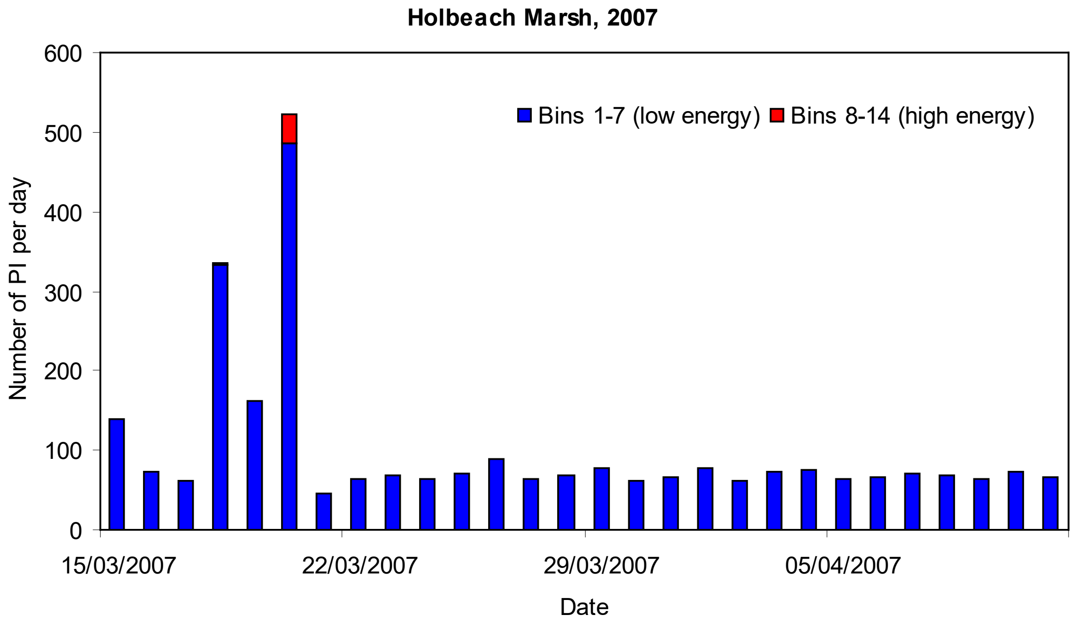


Figure 2. Daily 'precipitation impacts' (PI) at Holbeach Marsh site in mid-March to mid-April 2007. PIs have been split between low and high energy levels ('bins').

Crop and disease monitoring

The extent of smoulder infestation in second-year and older daffodil crops can be influenced not only by current weather conditions, but also by the amount of inoculum present in the bulbs and remaining in debris on or in the ground from earlier years. This inoculum will clearly not be influenced by a fungicide programme applied later in the growing season. Such inocula are likely to be manifested as smoulder 'primaries', emergent shoots that immediately, or soon afterwards, show smoulder symptoms in the form of blackened, deformed shoots with gray, sporulating lesions. The number of primaries was recorded in each of the three stocks, so that any large differences in inocula between sites could be accounted for. This comparison showed a broadly similar incidence of smoulder primaries in each of the bulb stocks, though primaries were more frequent at Kirton in the early part of the season than at the other two sites, possibly reflected by the higher disease levels at Kirton (Figure 3).

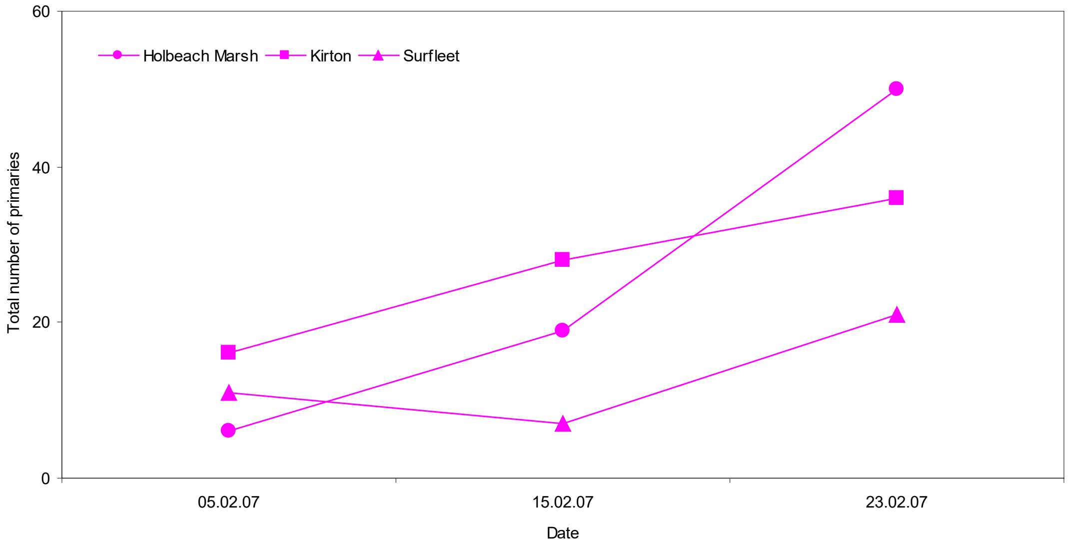


Figure 3. The incidence of smoulder primaries at the three trial sites in the early weeks of the growing season in 2007.

Following emergence and spread from the primaries, the infection and spread of smoulder via conidia is largely dependent on weather conditions. The incidence of smoulder was recorded primarily through the weekly assessment of 50 sample areas in each treatment plot. These scores are shown for the three farms in Figure 4. Figure 4 also show the dates on which fungicide applications were made as part of the conventional or model spray programmes.

For the commercial spray programme, four sprays were applied at Kirton, three at Holbeach Marsh and one at Surfleet. The starting dates varied from 1 February at Kirton to 16 February at Holbeach Marsh, and this may have been a reflection of how different disease levels were perceived by the individual growers. The number of commercial sprays was less than formerly expected, probably due to a combination of changing commercial practice, the greater effectiveness of the fungicides now being used, and the lack of suitable weather for crop spraying at the appropriate dates.

For the model spray programme, spraying at all sites started between 2 and 9 March, triggered (in the absence of high infection scores) by the damage caused by flower cropping (dates shown in Figure 4). The later sprays were triggered by high infection scores, and at Holbeach Marsh, Surfleet and Kirton there were totals of two, three and four sprays, respectively.

At all three sites the incidence of smoulder increased slowly from early-February, later in the season becoming more severe at Kirton than at Holbeach Marsh or Surfleet. The higher level of smoulder at the experimental site at Kirton may have been partly due to the greater concentration there of diseased crops used in trials, and at the start of the growing season there were indeed more smoulder primaries at this site than at the others. Here, for the model spray programme plot, the omission of an early spray was detrimental. Nevertheless, the non-sprayed control plot had a higher smoulder incidence than the plots receiving either of the fungicide spray programmes, and the model spray programme plot remained greener than the conventional spray programme plot towards the end of the growing season. At Surfleet and Holbeach Marsh there was no evidence for treatment effects on smoulder incidence over most of the growing season, but towards the end of the growing season there were periods with beneficial effects due to fungicide sprays: at Surfleet the model spray programme proved the better, while at Holbeach Marsh the conventional spray programme was the better. At Kirton and Surfleet the model spray programme resulted in crops remaining greener than the other plots at the end of the growing season. At Kirton, the model fungicide programme was considered a success, despite the high levels of smoulder at the site. At Surfleet the early curtailment of the conventional spray programme inevitably meant that the model spray programme was more effective. At Holbeach Marsh, waiting for a high infection score before spraying proved, in retrospect, erroneous: it would have been better to have used a lower critical infection score and not to have waited for high-impact precipitation to occur.

For the more reliable control of smoulder, the results suggest that a relatively low predictor score (0.15 in this case) should be used to trigger fungicide applications, noting that applications early in the growing season are important. Until the effects of weather-induced damage are better understood, it would be better generally to rely on predictor score alone, taking frosts and heavy rain into account when the infection score was boarderline for spraying.

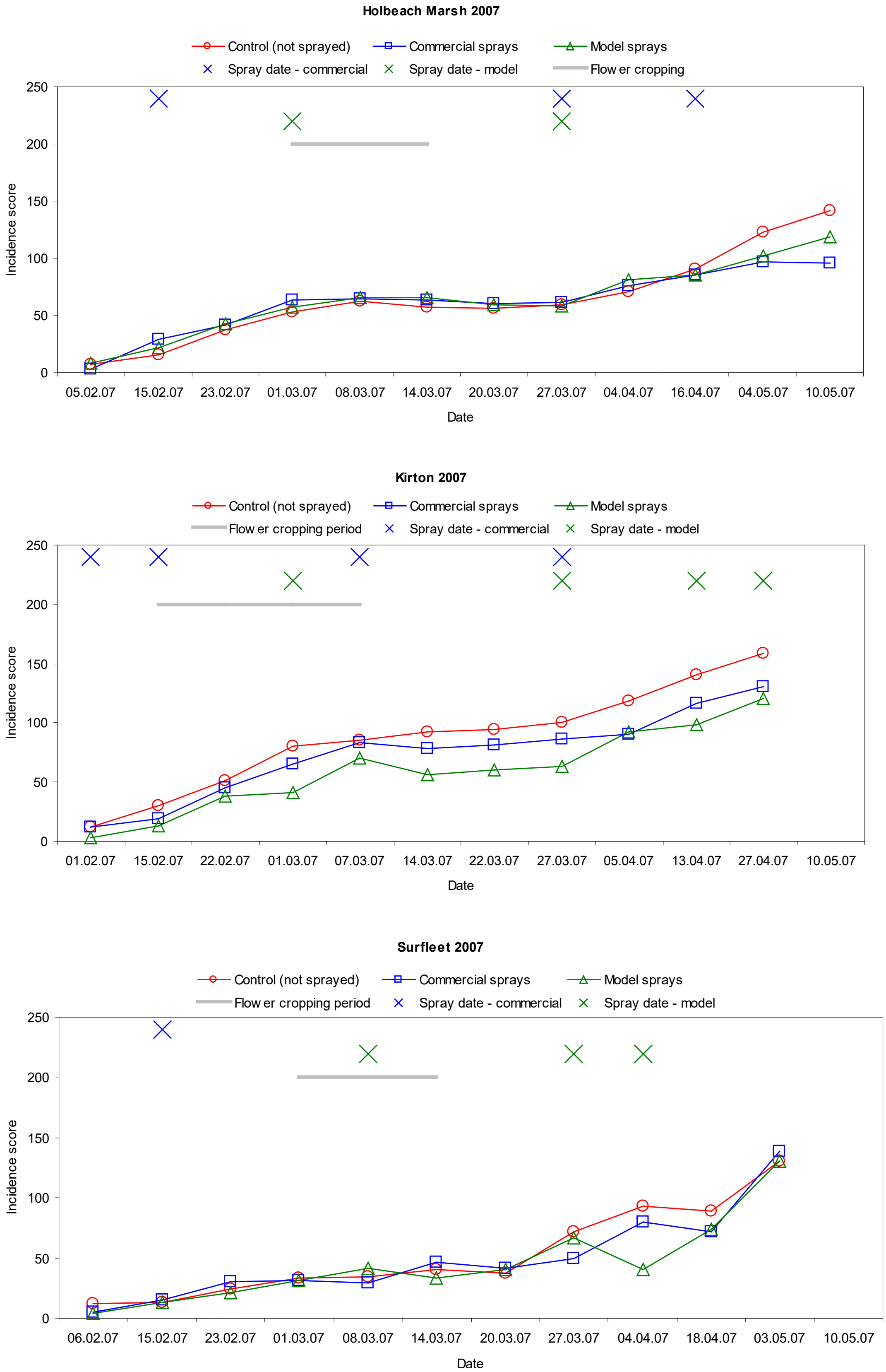


Figure 4. Smoulder incidence scores for non-sprayed daffodils and daffodils receiving a fungicide programme as part of the growers' standard treatment or applied according to the predictions of the smoulder infection model. Crops at Holbeach Marsh (top), Kirton (middle) and Surfleet (bottom), 2007. Fungicide application dates and the flower cropping period are also shown.

Incidence is only one way of expressing the amount of disease in a crop, so the severity (the degree to which affected leaves are affected) and distribution (the number of sample areas with symptoms) of smoulder were also recorded. For the Kirton site severity scores and the number of sample areas affected by smoulder, confirmed the conclusions obtained using incidence scores – most smoulder was found in the control blocks, and least where sprays were applied according to the model programme (Figure 5). Attempts were made to combine incidence and severity scores in order to give a more comprehensive means of expressing the level of smoulder in crops, but were no improvement over using the unamended incidence scores alone. For the less diseased sites at Holbeach Marsh and Surfleet, differences between the three treatments, expressed as severity or number of plots affected, were small (data not shown).

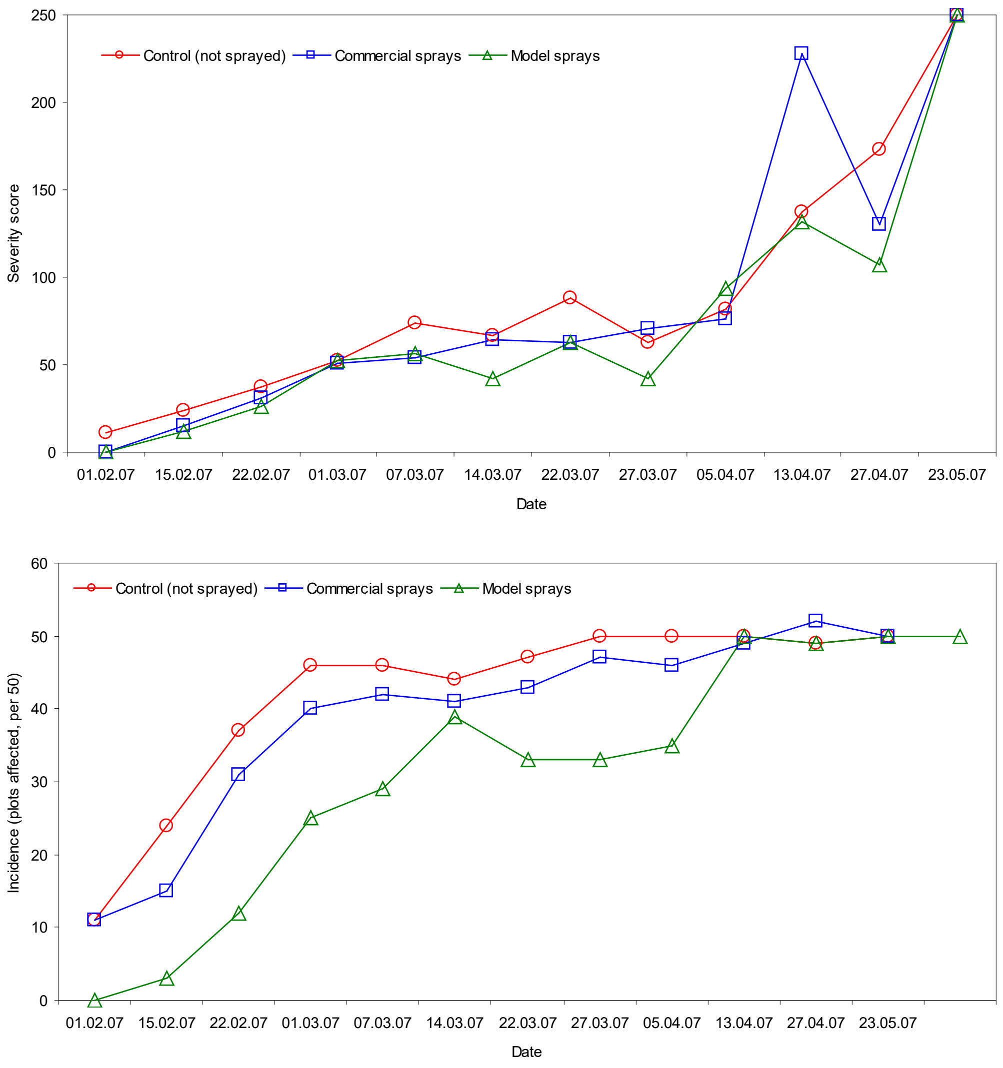


Figure 5. Smoulder in three treatments at Kirton in 2007: (top) severity score, (bottom) number of sample areas affected by smoulder.

The most obvious effect of different fungicide treatments on daffodil crops is a delay in leaf senescence, partly a result of control of foliar diseases and partly due to a direct effect on the leaves themselves. By the end of the period of regular assessments, the mean percentage of leaf die-back was still very low, averaging 3.0 over all the sample areas, a figure too low to provide meaningful comparisons. However, later observations showed clear differences in die-back between the three treatments at the Kirton and Surfleet sites, with advanced senescence in the control plots and greenest foliage in the model spray area (Plates 1 and 2). At Holbeach Marsh the foliage in all three plots died-back relatively early and at a similar rate.

Plate 1. Effects of fungicide programmes on leaf senescence at Kirton, photographed on 24 May 2007. Top, non-sprayed control plot (brown foliage, 0 sprays); middle, conventional

spray programme plot (green foliage, 4 sprays); bottom, model spray programme plot (green foliage, 4 sprays). Details of foliage shown on the right-hand side.

Plate 2. Effects of fungicide programmes on leaf senescence at Surfleet, photographed on 24 May 2007. Foreground, conventional spray programme plot (brown foliage, 1 spray); middle, model spray programme plot (green foliage, 3 sprays); distance, non-sprayed controls (brown foliage, 0 sprays).

Trap-plants

The infection of 'trap-plants' was used as a further means of assessing likely infective periods. In the previous two years' experiments, only a small number of exposed pot-plants had developed typical smoulder lesions, which could have been due to the relatively short exposure durations or to low humidity under glass where they were grown after exposure. In 2007 trap-plants were exposed with the crop for 7 days and were then placed in a high-humidity atmosphere for the first 48 hours in the glasshouse. This resulted in a much greater number of exposed plants developing smoulder lesions in 2007.

Table 4. Overall mean smoulder scores for trap-plants exposed at three trial sites in 2007.*

	Smoulder score	
Site	*Damaged leaves*	*Non-damaged leaves*
Kirton	0.64	0.09
Surfleet	0.63	0.27
Holbeach Marsh	0.54	0.02

* For meaning of smoulder score, see legend of Figure 6

In 2007 the smoulder scores recorded for trap-plants with damaged leaves were markedly higher than for those from non-damaged plants (Table 4), as had been found in trials in 2005 (but not 2006), a difference possibly associated with the longer exposure period in the field and the possible occurrence of *Botrytis cinerea* on damaged tissues. Figure 6 shows the smoulder scores for damaged trap-plants in 2007. Smoulder symptoms developed on trap-plants at all three sites, and, as noted before, the peaks of infection occurred at different dates at the different sites. The timing of these peaks was examined in relation to the occurrence of known infective weather conditions, predicted infective conditions, and the findings from spore traps (see below). At Kirton a high, sharp peak of infection occurred in mid/late-March, with a broader peak over most of April, corresponding with infective periods determined using the smoulder infection model (Figure 1). At Surfleet too, there was a broad peak over most of April, but with no large, single peak until late-March. At Holbeach Marsh there were infection peaks in mid-March, corresponding to very high infection scores (Figure 1) and in the second half of April. As a result of three years' trials, it appears that using trap-plants may be an inconsistent way of assessing smoulder risk. Additionally, the contamination of the trap-plant by *Botrytis* may not be visible in a way that is easy to distinguish. Contaminated plants may show the result of *Botrytis* infection after relatively long periods. There would certainly appear to be a poor relationship between spore numbers that trap-plants were exposed to and the number of lesions that developed subsequently.

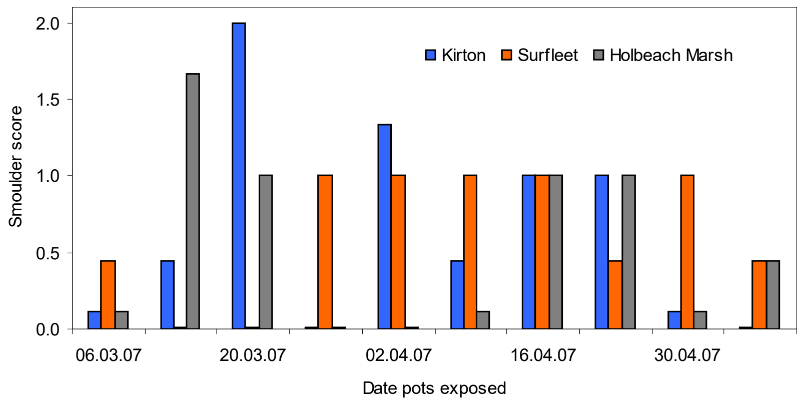


Figure 6. Smoulder scores for trap-plants with damaged leaf surfaces at three trial sites in 2007. Exposure periods started at the dates shown. The score is the mean of three replicates of the product of incidence and severity scores, recorded 3 weeks after the end of each exposure period. Only low smoulder scores were recorded on trap-plants with non-wounded leaves (data not shown), and no smoulder symptoms were recorded on non-exposed controls.

Discussion

The previous year's trials showed that the smoulder infection model had potential for predicting 'smoulder periods' when infection was likely, though it was clear more experience was needed in operating and interpreting the model. The three latest field trials described in this report confirmed this potential. The smoulder infection model produced clear peaks of smoulder activity. These trials also showed that experience is needed with using the model in order to understand how the predicted infection scores might be used in practice. Two critical levels of the infection score, higher and lower, were applied in 2007, and it appears, in retrospect, that it would be more appropriate to have used the lower, safer levels throughout: at the Holbeach Marsh site, where (in the absence of heavy rain) a high critical level was being applied, smoulder became rampant later in the season – and by the time the higher critical score was exceeded, it was hugely exceeded. Smoulder levels were high at the Kirton site also, despite the application of the lower critical score, but in this case a technical difficulty meant that a critical score early in the growing season was not actioned; in addition the site and (or) bulb stock appeared to carry a higher disease inoculum than the other sites. At Surfleet, despite using the higher critical score, disease was fairly well contained. The results suggest that using a lower critical score strategy early in the season would be essential, but later in the season a higher critical score might be used. This might have the effect of controlling disease early in the crop and matching control later in the season to the occurrence of higher risk periods. It would be important to use the most effective fungicides, and those currently available for use on narcisus are listed in Table 5.

It is important to consider some additional factors in assessing the rational need to apply fungicides. The spread of smoulder has been shown to be dependent on crop damage, whereby only damaged leaf surfaces will allow penetration by the fungus. While daffodil leaves suffer marked natural damage over the course of the growing season, for example through chafing caused by the wind, or by the breakdown of the protective cuticle through normal fungal activity, frost, flower picking and heavy rain or hail all cause damage. In the mild winter that occurred during these trials, no fungicide application was signalled as a result of frost, but all three crops were sprayed with fungicide following flower picking. At the Holbeach Marsh site, it had been planned to apply a fungicide even at a low infection score, if there had been a recent heavy rain event, but in practice this could not be tested because all rainfall was relatively mild. In 2008 it is likely that a fungicide spray will be advised following any obvious damage to the crop, plus when a low critical infection score, equivalent to 0.15, is reached.

Field trials of this type present a number of design challenges - not least of which is the uncertainty about whether any significant disease will occur at all. These trials were set up to determine whether a model-based spray programme was as good at controlling smoulder as typical growers' spray programmes. Since the essence of using a spray-timing system is timing, ideally, different timings should be compared, with other factors – number of sprays, chemicals used – remaining constant. In practice this may impose too heavy a constraint on a helpful grower who will also wish to be guided by costs, farm practices, etc., so that essentially this project has compared whole spray programmes, with different numbers of sprays and different active ingredients used, as well as different timings. Nevertheless, this year's trials indicated that using the infection model can control smoulder at least as well as using a conventional system, with the advantage of rationality (justification for using a spray) and – if fewer sprays were used – reduced cost. The above factors interact with those relating to spray timing to determine disease control. One feature of these results is that relatively crude assessments of treatment effects – for example, comparing images of contrasting plots or using a simple estimate of percentage leaf senescence – can be almost more meaningful than time-consuming assessments based on the specific (and sometimes difficult to distinguish) symptoms of the disease. Indeed, the end result of all the major narcissus foliar diseases – of white mould, fire and leaf scorch, as well as smoulder – is the premature loss of photosynthetic area.

It is planned that spray-timing advice, based on the smoulder infection model, will be made available to HDC members in 2008. It is most likely that this will be done on the basis of web-based information made available on the University of Warwick or the HDC web-sites. Subject to terms being agreed, after the conclusion of the project it is hoped that advice might be made available in a similar manner or would be sent via fax or e-mail as weekly alerts.

Since there are no convincing non-chemical methods for the control of smoulder and other foilar fungal diseases of narcissus, it is likely that a fungicide spray programme will remain the essence of foliar disease management in the short- to medium-term, so the optimisation and minimisation of spray rates and applications are important issues. Further, as white mould is no longer confined to the south-west, growers should aim at one comprehensive spray programme against the main foliar fungal diseases. Nevertheless, other aspects of Best Practice, including the use of appropriate rotations, locating first-year daffodil crops away from older crops, good bulb handling, proper hot-water treatment and sensible hygiene, should not be neglected.

Table 5. Fungicides currently used on narcissus in the UK.

Active ingredient	*Products*	*Status*	*Maximum rate*
Azoxystrobin	Amistar	LTAEU	1.0L/ha

Carbendazim	Cleancrop Curve	SOLA 1213/04	1.5ml/L
	Delsene 50 Flo	SOLA 1004/04	1.5ml/L
	IT Carbendazim	Provisional approval	0.5ml/L
	Bavistin DF	SOLA 1520/04	1.5ml/L
Chlorothalonil	Bravo 500	SOLA 1518/04	2.0L/ha
	Bravo 750	Provisional approval	2.1L/ha
Kresoxim-methyl	Stroby WG	LTAEU	0.3kg/ha
Mancozeb	Dithane 945	SOLA 1519/04	2.5kg/ha
Pyrimethanil	Scala	LTAEU	1.0L/ha
Tebuconazole	Folicur	SOLA 0430/06	1.0L/ha

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