Project title:	MORPH disease models – extracting algorithms from the MORPH software
Project number:	
Project leader:	Rosemary Collier, University of Warwick
Report:	Final report, July 2018
Previous report:	None
Key staff:	Richard Reader
Location of project:	University of Warwick
Industry Representative:	
Date project commenced:	1 October 2017
Date project completed (or expected completion date):	31 March 2018

DISCLAIMER

While the Agriculture and Horticulture Development Board seeks to ensure that the information contained within this document is accurate at the time of printing, no warranty is given in respect thereof and, to the maximum extent permitted by law the Agriculture and Horticulture Development Board accepts no liability for loss, damage or injury howsoever caused (including that caused by negligence) or suffered directly or indirectly in relation to information and opinions contained in or omitted from this document.

The results and conclusions in this report are based on an investigation conducted over a one-year period. The conditions under which the experiments were carried out and the results have been reported in detail and with 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.

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.

Rosemary Collier

Associate Professor

University of Warwick

Signature ..... Date .....

[Name]

[Position]

[Organisation]

Signature ..... Date .....

Report authorised by:

[Name]

[Position]

[Organisation]

Signature ..... Date .....

[Name]

[Position]

[Organisation]

Signature ..... Date .....

CONTENTS

GROWER SUMMARY

Headline

Algorithms for six of the disease forecasting models in MORPH have been extracted from the software and are available for development in new formats.

Background

The MORPH software is very old and as newer versions of WINDOWS appear it is becoming harder to sustain. The aim of this project was to extract the algorithms for six of the disease forecasting models in MORPH so that these would be available to others for development into new formats.

Summary

The algorithms were extracted for the following models:

- Alternaria (Dark leaf spot - *Alternaria brassicae*)
- BOTIPI (*Botrytis squamosa*)
- Milioncast (Downy Mildew – *Peronospora destructor*)
- Ringspot (*Mycosphaerella brassicicola*)
- White Blister (*Albugo candida*)
- White Blister 2 (*Albugo candida*)

Financial Benefits

The major benefit of this project is that the algorithms will not be lost even if the MORPH software fails.

Action Points

The algorithms are available to the industry for development in new formats.

SCIENCE SECTION

Introduction

The MORPH software is very old and as newer version of WINDOWS appear it is becoming harder to sustain. The aim of this project was to extract the algorithms for 6 of the disease forecasting models in MORPH so that these would be available to others for development into new formats.

Materials and methods

The algorithms were extracted from the MORPH software by Richard Reader who was one of the MORPH team when MORPH was supported by Defra. The information extracted is summarised below.

The algorithms were extracted for the following models:

- Alternaria (Dark leaf spot - *Alternaria brassicae*)
- BOTIPI (*Botrytis squamosa*)
- Milioncast (Downy Mildew – *Peronospora destructor*)
- Ringspot (*Mycosphaerella brassicicola*)
- White Blister (*Albugo candida*)
- White Blister 2 (*Albugo candida*)

Results

The output from the project is presented below.

Alternaria (*Alternaria brassicae* – Dark Leaf Spot)

Introduction

The Alternaria model consists of two models: - a model of potential disease infection used for crop walking and a model of disease progress used for spray timing. If Alternaria has not been observed the crop walking model is run. This provides an estimate of whether conditions have been observed that would have been conducive for infection and hence suggests whether the grower should do a crop walk. If Alternaria has been observed, then the disease progress model is run which provides a prediction for when sprays should be applied to control the disease.

Weather Inputs

1. Air Temperature ˚C
2. Leaf Wetness mV
3. Rainfall mm
4. Humidity %

User Inputs

1. Planting Date
2. Date of last Crop Walk
3. Dark Leaf Spot seen (Y/N)
4. Spore Production and Activation Level (default 25)
5. Date for Onset of Lower Leaf Senescence (default 31/08)
6. Spray Date (unused)
7. Spray Product (unused)

Outputs

Crop Walking

There are two sets of output for the crop walking model.

The first a set of graphs of the infection score, daily minimum and maximum temperatures and the number of hours of leaf wetness, i.e. hours with leaf wetness above 200mV.

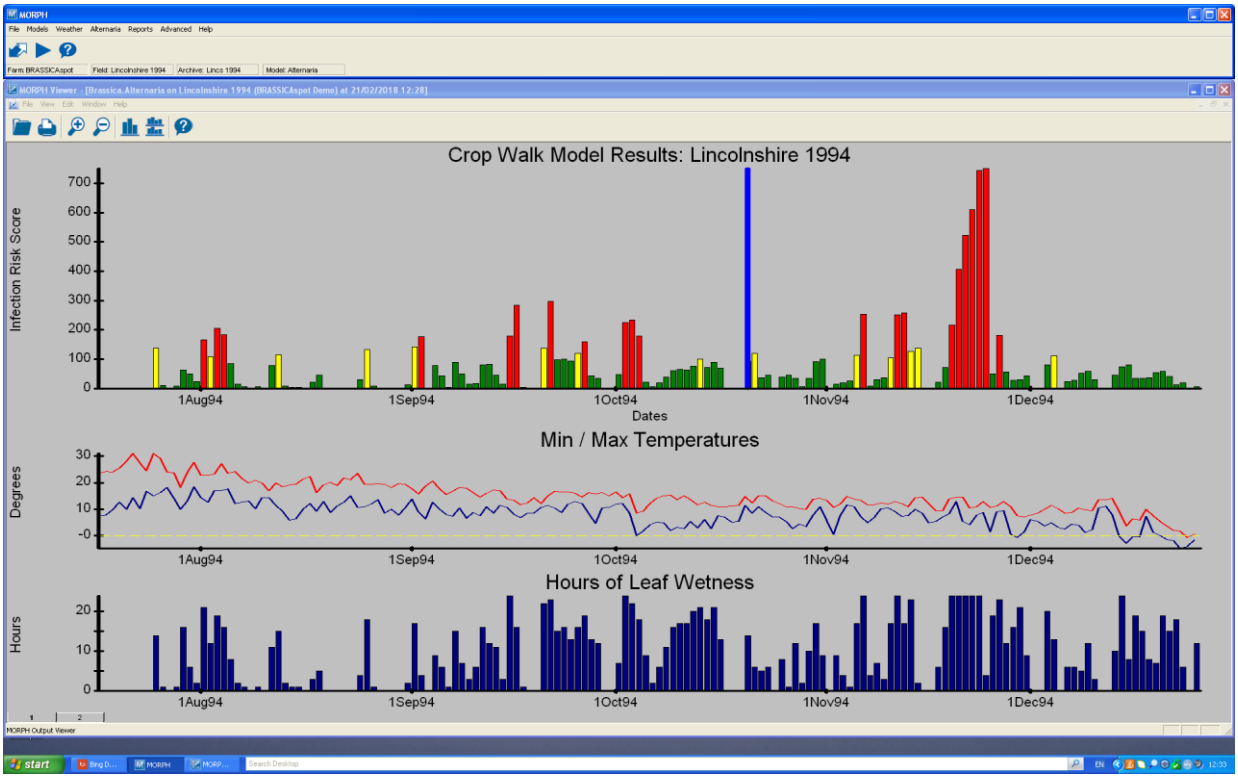
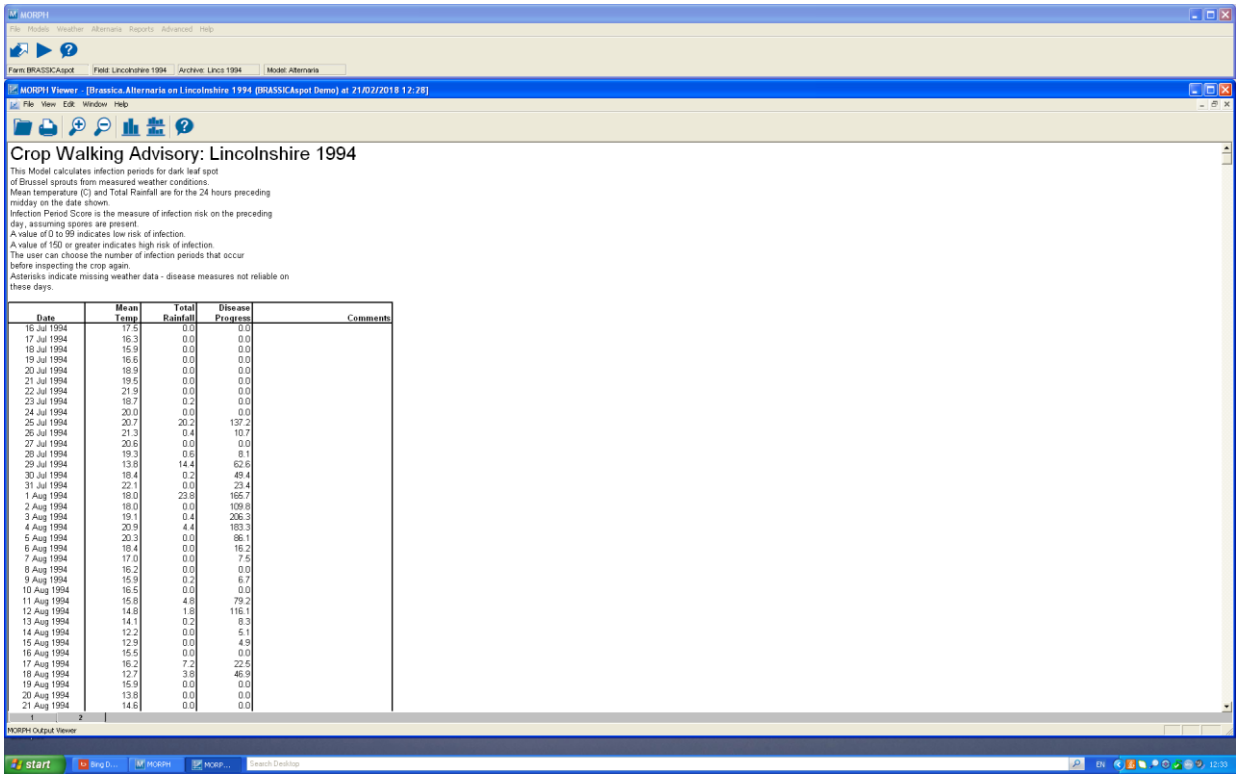


Figure 1 Graphs of disease score, maximum & minimum temperatures and hours of leaf wetness

The second a table of the mean daily temperature, total rainfall and infection score



Crop Walking Advisory: Lincolnshire 1994

This Model calculates infection periods for dark leaf spot of Brussel sprouts from measured weather conditions.
Mean temperature (C) and Total Rainfall are for the 24 hours preceding midday on the date shown.
Infection Period Score is the measure of infection risk on the preceding day, assuming spores are present.
A value of 0 to 99 indicates low risk of infection.
A value of 150 or greater indicates high risk of infection.
The user can choose the number of infection periods that occur before inspecting the crop again.
Asterisks indicate missing weather data - disease measures not reliable on these days.

Date	Mean Temp	Total Rainfall	Disease Progress	Comments
16 Jul 1994	17.5	0.0	0.0	
17 Jul 1994	16.3	0.0	0.0	
18 Jul 1994	15.9	0.0	0.0	
19 Jul 1994	16.6	0.0	0.0	
20 Jul 1994	18.9	0.0	0.0	
21 Jul 1994	19.5	0.0	0.0	
22 Jul 1994	21.9	0.0	0.0	
23 Jul 1994	18.7	0.2	0.0	
24 Jul 1994	20.0	0.0	0.0	
25 Jul 1994	20.7	20.2	137.2	
26 Jul 1994	21.3	0.4	10.7	
27 Jul 1994	20.6	0.0	0.0	
28 Jul 1994	19.3	0.6	8.1	
29 Jul 1994	13.8	14.4	62.6	
30 Jul 1994	18.4	0.2	49.4	
31 Jul 1994	22.1	0.0	23.4	
1 Aug 1994	18.0	23.8	165.7	
2 Aug 1994	18.0	0.0	109.8	
3 Aug 1994	19.1	0.4	206.3	
4 Aug 1994	20.9	4.4	183.3	
5 Aug 1994	20.3	0.0	86.1	
6 Aug 1994	18.4	0.0	16.2	
7 Aug 1994	17.0	0.0	7.5	
8 Aug 1994	16.2	0.0	0.0	
9 Aug 1994	15.9	0.2	6.7	
10 Aug 1994	16.5	0.0	0.0	
11 Aug 1994	15.8	4.8	79.2	
12 Aug 1994	14.8	1.8	116.1	
13 Aug 1994	14.1	0.2	8.3	
14 Aug 1994	12.2	0.0	5.1	
15 Aug 1994	12.9	0.0	4.9	
16 Aug 1994	15.5	0.0	0.0	
17 Aug 1994	16.2	7.2	22.5	
18 Aug 1994	12.7	3.8	46.9	
19 Aug 1994	15.9	0.0	0.0	
20 Aug 1994	13.8	0.0	0.0	
21 Aug 1994	14.6	0.0	0.0	

Figure 2 Table of daily mean temperature, total rainfall and disease and infection score

Spray Timing

There are three possible sets of output from the spray timing model.

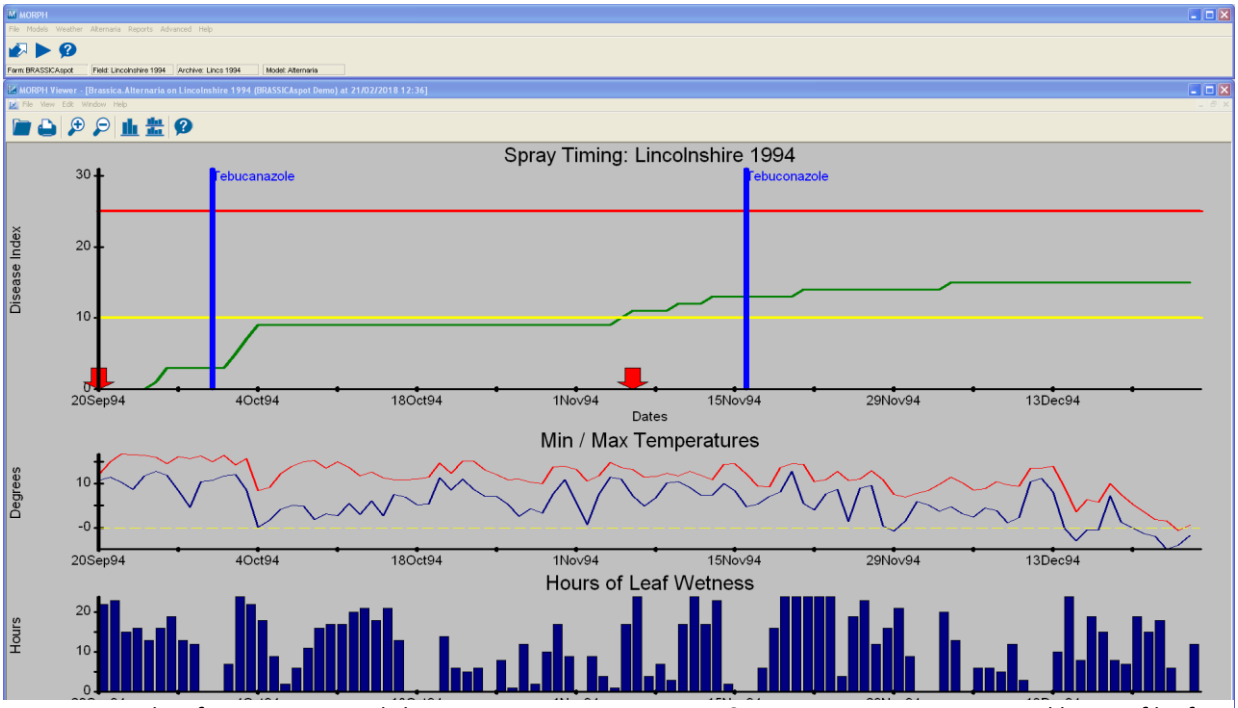


Figure 3 Graphs of progress towards lesion appearance, maximum & minimum temperatures and hours of leaf wetness

The first output for most of the season is set of graphs showing the progress towards appearance of new lesions together with the daily maximum & minimum temperatures together with the total hours of leaf wetness. Lesions are predicted to occur when the disease score reaches 10. The time of new lesion appearance is marked on the x-axis together with the timing of any sprays applied and the products used.

Later in the season if the disease score exceeds 25 then a bar chart is displayed which shows days when both sporulation and infection are predicted rather than the meteorological data.

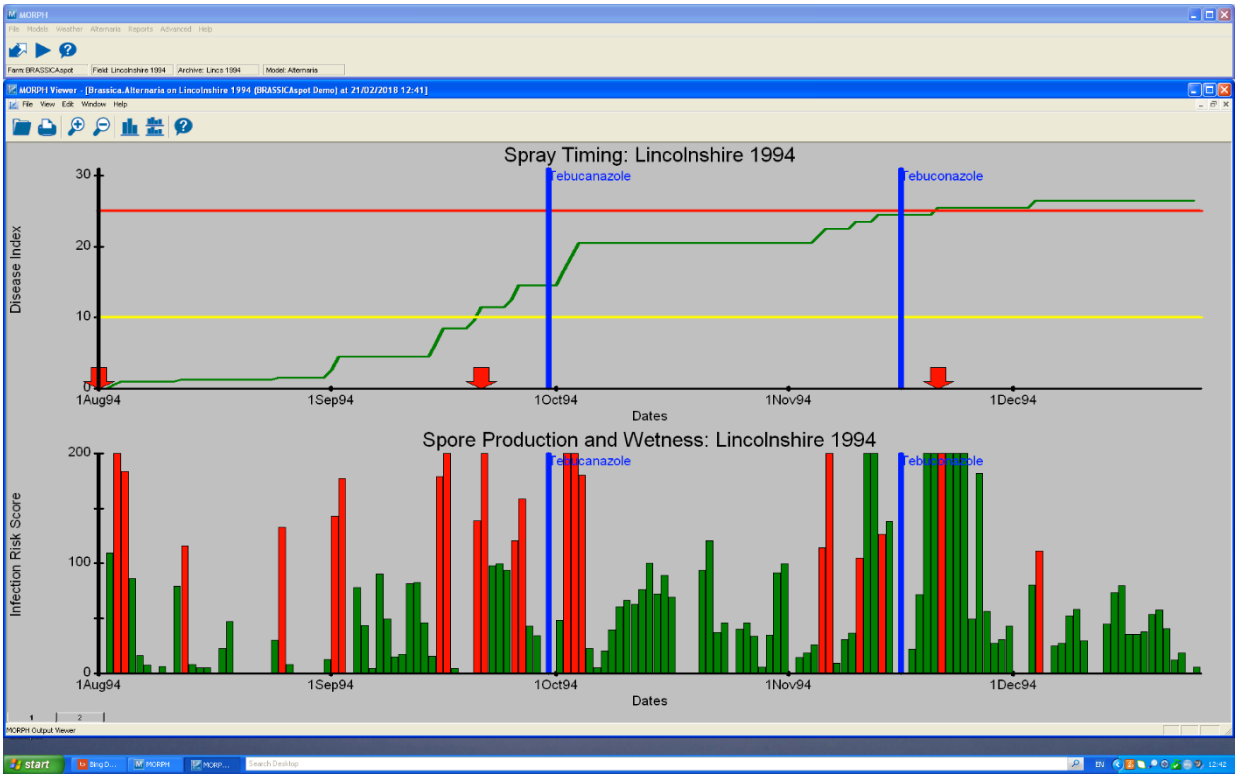
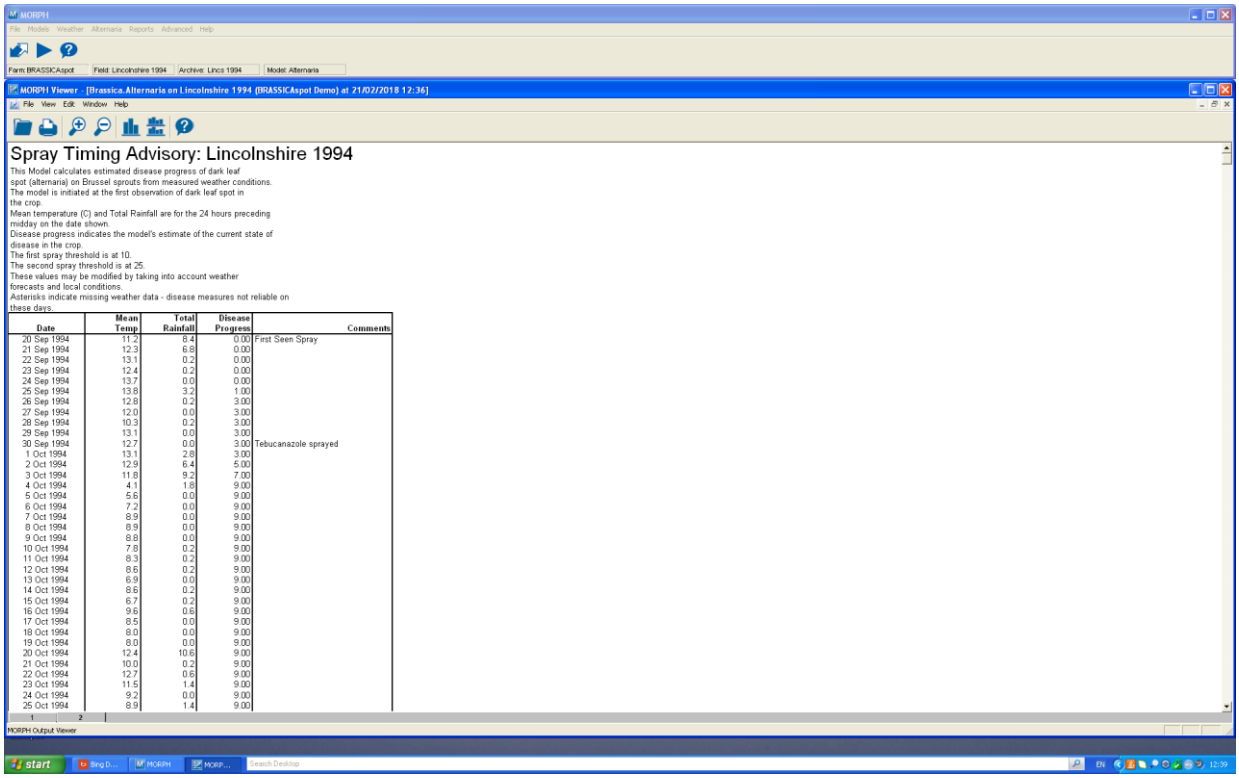


Figure 4 Graphs of lesion appearance and infection risk

The final output is a table of the mean daily temperature, total rainfall and progress towards the disease thresholds of 10 and 25.



Spray Timing Advisory: Lincolnshire 1994

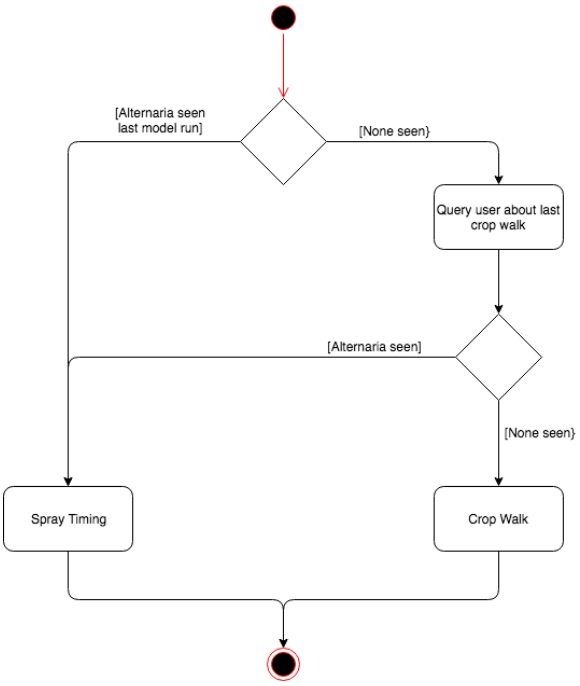
This Model calculates estimated disease progress of dark leaf spot (alternaria) on Brussel sprouts from measured weather conditions.
The model is initiated at the first observation of dark leaf spot in the crop.
Mean temperature (C) and Total Rainfall are for the 24 hours preceding midday on the date shown.
Disease progress indicates the model's estimate of the current state of disease in the crop.
The first spray threshold is at 10.
The second spray threshold is at 25.
These values may be modified by taking into account weather forecasts and local conditions.
Asterisks indicate missing weather data - disease measures not reliable on these days.

Date	Mean Temp	Total Rainfall	Disease Progress	Comments
20 Sep 1994	11.2	8.4	0.00	First Seen Spray
21 Sep 1994	12.3	6.8	0.00	
22 Sep 1994	13.1	0.2	0.00	
23 Sep 1994	12.4	0.2	0.00	
24 Sep 1994	13.7	0.0	0.00	
25 Sep 1994	13.8	3.2	1.00	
26 Sep 1994	12.8	0.2	3.00	
27 Sep 1994	12.0	0.0	3.00	
28 Sep 1994	10.3	0.2	3.00	
29 Sep 1994	13.1	0.0	3.00	
30 Sep 1994	12.7	0.0	3.00	Tebucanazole sprayed
1 Oct 1994	13.1	2.8	3.00	
2 Oct 1994	12.9	6.4	5.00	
3 Oct 1994	11.8	9.2	7.00	
4 Oct 1994	4.1	1.6	9.00	
5 Oct 1994	5.6	0.0	9.00	
6 Oct 1994	7.2	0.0	9.00	
7 Oct 1994	8.9	0.0	9.00	
8 Oct 1994	8.9	0.0	9.00	
9 Oct 1994	8.8	0.0	9.00	
10 Oct 1994	7.8	0.2	9.00	
11 Oct 1994	8.3	0.2	9.00	
12 Oct 1994	8.6	0.2	9.00	
13 Oct 1994	6.9	0.0	9.00	
14 Oct 1994	8.6	0.2	9.00	
15 Oct 1994	6.7	0.2	9.00	
16 Oct 1994	9.6	0.6	9.00	
17 Oct 1994	8.5	0.0	9.00	
18 Oct 1994	8.0	0.0	9.00	
19 Oct 1994	8.0	0.0	9.00	
20 Oct 1994	12.4	10.6	9.00	
21 Oct 1994	10.0	0.2	9.00	
22 Oct 1994	12.7	0.6	9.00	
23 Oct 1994	11.5	1.4	9.00	
24 Oct 1994	9.2	0.0	9.00	
25 Oct 1994	8.9	1.4	9.00	

Figure 5 Table of dailt mean temperature, total rainfall and disease score

Model Description

The choice of which model to run is made by the following process:



Crop Walk

The Crop Walk model does not produce a forecast but rather attempts to determine whether suitable conditions for infection have occurred in the preceding days. It runs from planting date to the latest weather record. For the Crop Walk model a day is assumed to run from 12:00 to 12:00. Crop Walk model produces an infection score. If this score is below 100 there is a low risk of infection, if it is between 100 and 150 there is a medium risk of infection and if it is greater than 150 then there is a high risk of infection. If conditions are favourable, then this score is carried forward from one day to the next.

A base hourly infection rate is calculated as

$$BaseInfRate = 1.329524 + 0.53204T$$

where T is air temperature and 0°C < T < 26°C air temperature and leaf wetness are not missing.

This base rate is then multiplied by a maximum infection rate given by

$$MaxInf = \frac{67.82291 - 0.00034366 * 1.56290^{T} + 1.6498T}{100.0}$$

To give an infection rate of

$$InfRate = BaseInfRate * MaxInf$$

The daily infection score is calculated by the following pseudocode.

```
infectionScore = 0
foreach day
    foreach readingInADay
        if 0 < T < 26 and leafWetness >= 0.2
            infectionScore = infectionScore + infRate
        else if T < 8 and VPD < 2.0 // pause infection
            continue
        else // reset infection
            infectionScore = 0
    store infectionScore
```

An infection score below 100 is a low risk of infection, between 100 and 150 is a medium risk of infection and greater than 150 is a high risk of infection.

Spray Timing

For the Spray Timing model, a day is assumed to run from 12:00 to 12:00. The model runs from planting date to the latest weather record. The model produces a disease index for

chance of sporulation. Crossing thresholds of 10 and 25 indicate that the crop should be sprayed.

The disease index is formed by accumulating individual daily scores from each initial observation of new lesions. The daily score is given by

$$DI = IS * I\mathrm{P}$$

Where *IS* is the daily Infection Score and *IP* is the Inoculum Potential.

The Infection Score, *IS*, is derived from the daily crop walk infection score where

```
if cropWalkScore >= 150
IS = 2
else if cropWalkScore >=100
IS = 1
else
IS = 0
```

The Inoculum Potential, *IP*, is derived from the daily Spore Production, *SP*, as follows

```
if before summer onset of leaf senescence
if SP > 100 for previous 5 days
if total rainfall today > 5
IP = 0.5
else
IP = 0.25
else if
IP = 0
else if mean temperature for previous 4 days < 7.5
if SP > 100 for previous 5 days
if total rainfall today > 5
IP = 1
else if total rainfall today > 2.5
IP = 0.5
else
IP = 0
else
if SP > 100 for previous 5 days
IP = 1
else
IP = 0
```

The daily Spore Production, *SP*, is derived from the Spore Rate, *SR*, where

$$SR = -21.1648 + \frac{29.0272}{\left(1.0 + 19.0 * e^{-0.522228*(\mathrm{T}-7.08706)}\right)^{\frac{1}{19.0}}}$$

and T is air temperature by the following where VPD is Vapour Pressure DEficit

```
SP = 0
sporeScore = 0
timeDry = 0
foreach day
```



```
foreach readingInADay
 SR = max(SR * timestep, 0)
if (temperature and humidity not missing) && VPD <= 2.0
sporeScore += SR
                          timeDry = 0
else if (temperature and humidity not missing) && VPD > 2.0
sporeScore +=SR
timeDry++
else
sporeScore = 0
timeDry++
SP = max(SP, sporeScore)
store SP
```


BOTIPI (*Botrytis squamosa*)

Introduction

The BOTIPI model comprises three models. The first model predicts the timing of the first spray for a Summer or Winter emerging crop. Following the predicted date of the first spray the remaining models produce sporulation indexes for the subsequent release of conidia. These are the Sporulation Index Value, SIV, and Inoculum Potential Index, IPI. The second and third models only predict the likely occurrence of sporulation and make no attempt to predict infection.

Weather Inputs

1. Air Temperature °C
2. Humidity %
3. Leaf Wetness mV
4. Rainfall mm

User Inputs

1. Model start date
2. Advice Date
3. Summer IPI_2 switch day (default 42)
4. Winter IPI_2 switch day (default 134)
5. Emergence dates

Outputs

The output from the BOTIPI model consists of two sets of graphs and two summary tables. The first set of graphs shows output from the model for a Summer crop for each of the emergence dates or the model start date, if there are no emergence dates. The Cumulative Disease Severity Index (CDSI) is shown until it reaches a score of 21. This score is the spray threshold and is marked with a red line. An earlier warning line is marked when the CDSI reaches a score of 15. After this date a bar graph shows the Infection Production Index (IPI), coloured red, yellow or green according to the value (0, 1, 2) of the Daily Infection Value (DINFV) when the IPI is greater than 7.

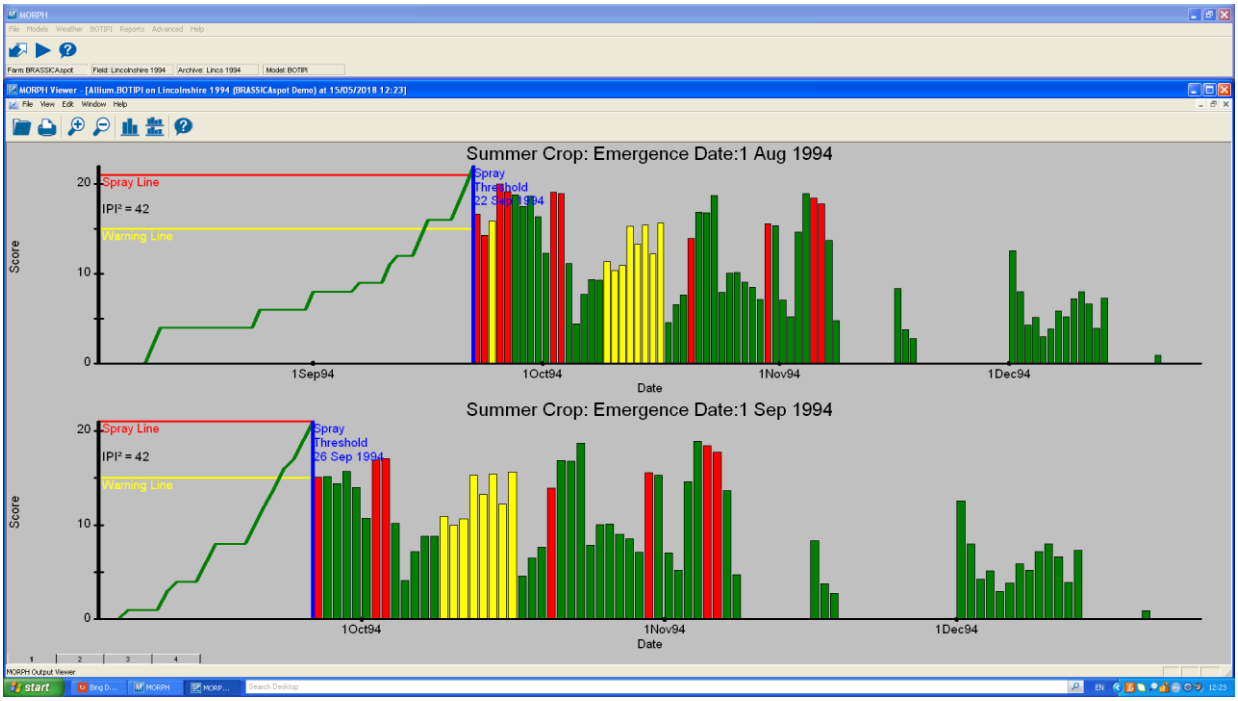


Figure 6 Summer Crop

This second set of graphs is the same as the first but using the Winter IPI switch day rather than the Summer IPI switch date.

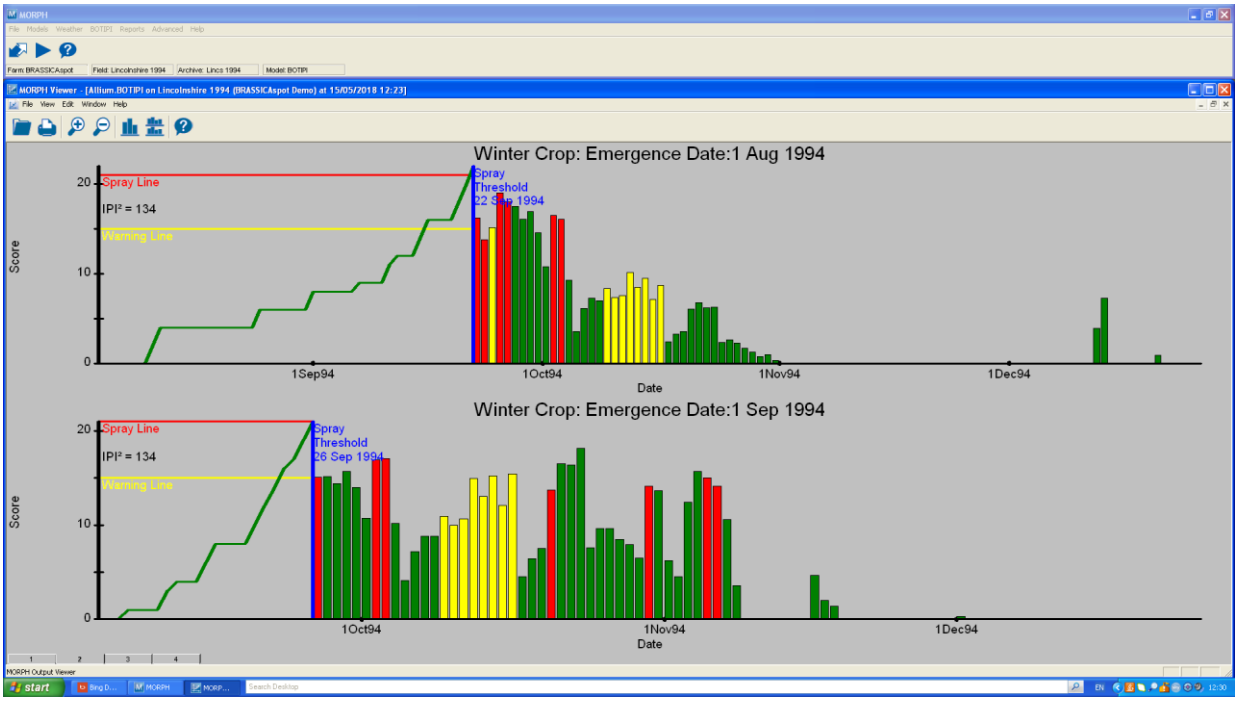


Figure 7 Winter Crop

The third output is a table of the CDSI and IPI scores for each of the previous graphs with the dates at which the spray thresholds are crossed for CDSI and colour of the bar for IPI.

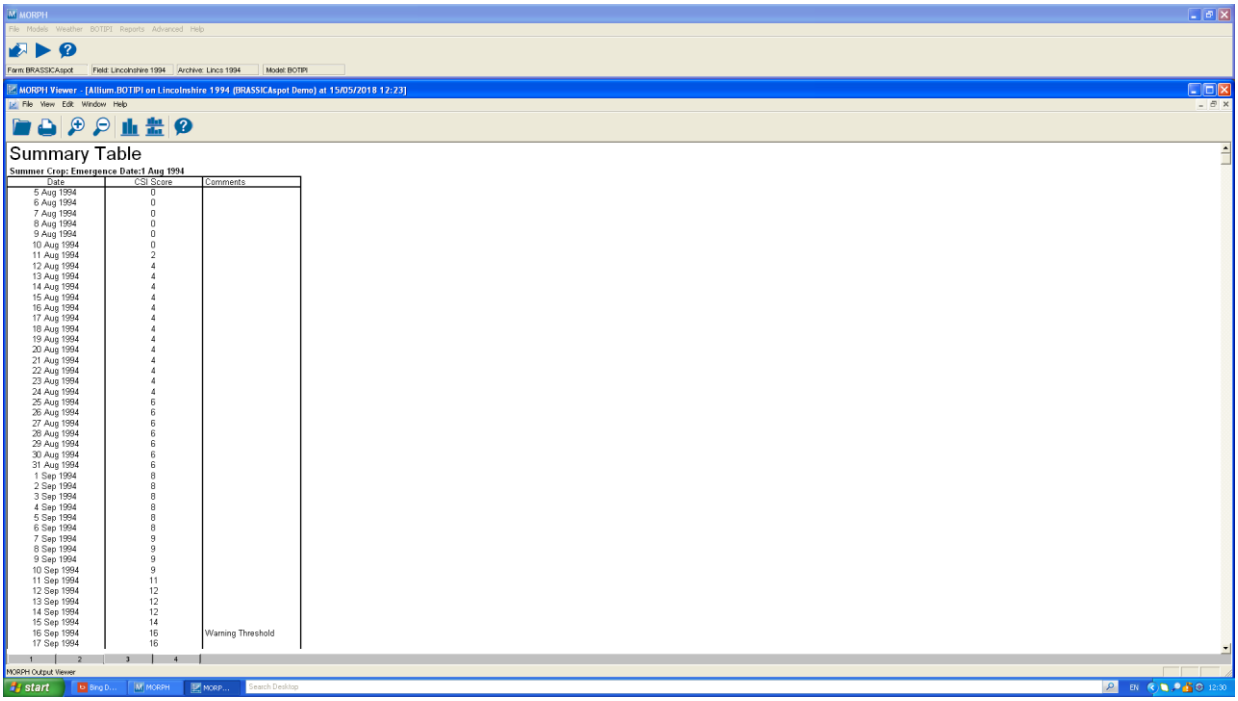


Figure 8 Graph summary table

The final output is a table of the raw output of the models comprising the Daily Inoculum Value (DINOV), DINFV, DSI, CDSI, average temperature of the wet period, the duration of the wet period, IPI and Sporulation Index Value (SIV) from the model start date to the model advice date.

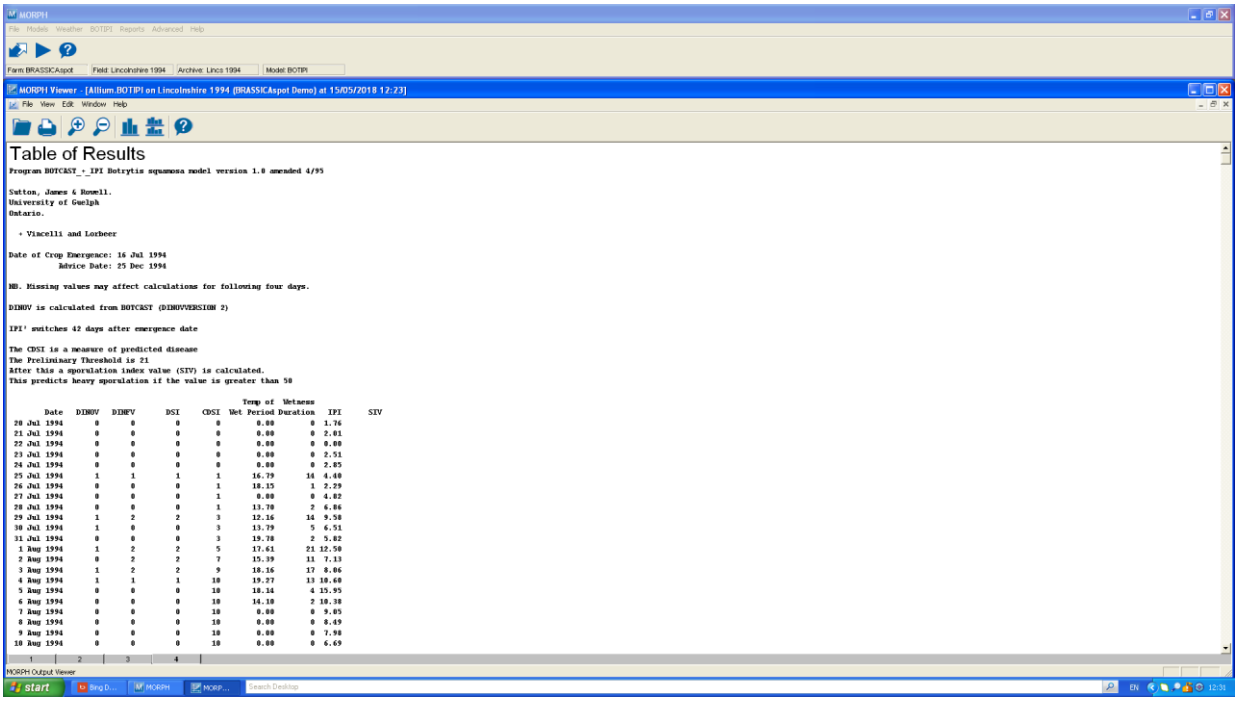


Figure 9 Raw model data

Model Description

Cumulative Disease Severity Index model

The CDSI model accumulates the daily Disease Severity Index, DSI, starting 4 days after emergence. The DSI is dependent on the Daily Infection Value, DINFV, and Daily Inoculum Value, DINOV, for the previous two days.

DINOV for day N is derived from the following set of rules

```
If bHot was true for previous 5 days including day N
        DINOV = 0
Else if nWetHours >= 12
        DINOV = 1
Else if nWetHours < 5
        DINOV = 0
Else if bWater is true
        DINOV = 1
Else if nDryHours >= 6
        DINOV = 0
ELSE
        DINOV = 1
```

DINFV is looked up from the following table where average temperature is the average air temperature from 13:00 day N-1 to 12:00 day N when the leaf wetness > 200mv and the number of hours of leaf wetness > 200mV over the same period. DINFV is 0 outside of the range of this table.

Hours of Leaf Wetness	Average Temperature ℃																						
	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	0	0	0	0
8	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0
9	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0
10	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0

11	0	0	0	0	0	1	1	1	2	2	2	1	1	1	1	1	1	1	1	1	1	0	0
12	0	0	0	0	1	1	1	1	2	2	2	1	1	1	1	1	1	1	1	1	1	0	0
13	1	1	1	1	1	1	1	1	2	2	2	1	1	1	1	1	1	1	1	1	1	0	0
14	1	1	1	1	1	2	2	2	2	2	2	1	1	1	1	1	1	1	1	1	1	0	0
15	1	1	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	1	0	0
16	1	1	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	1	1	1
17	1	1	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	1	1	1
18	1	1	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	1	1	1
19	1	1	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	1	1	1
20	1	1	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	1	1	1
21	1	1	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	1	1	1
22	1	1	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	1	1	1
23	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	1	1	1
24	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	1	1	1

If DINOV was 1 for today and yesterday, then DSI = DINFV else DSI = 0 and the CDSI for the day is calculated by adding the DSI to the previous day's CDSI. Once CDSI reaches 15 a spray warning is generated and when it reaches 21 a first spray is forecast. At this point the simulation moves on to using the Inoculum Production Index model and Sporulation Index Value model.

Inoculum Production Index model

The IPI is calculated as follows.

For each day N of the simulation the following summary statistics are calculated:

nWetHours = no. of hours with leaf wetness > 200mV from 09:00 day *N*-1 to 08:00 day *N*

nHotHours30 = no. of hours with air temp >= 30˚C from 09:00 day N-1 to 08:00 day N

nHotHours27 = no. of hours with air temp >=27°C from 07:00 day N-1 to 06:00 day N

nDryHours = no. of hours with RH <=70% from 07:00 day N-1 to 06:00 day N

nHumHours = no of hours with RH >=90% from 07:00 day N-1 to 06:00 day N

dAvTemp = average air temperature from 07:00 day N-1 to 06:00 day N

bWater = true if any rainfall in period 09:00 day N-1 to 15:00 day N-1

nHotDay incremented if nHotHours27 > 12 else reset to 0

bHot1 = true if nHotHours30 >= 4

bHumday = true if nHumHours >=6

nFourDays = no. of days bHumday was true in the previous 4 days including today

The Environmental Favourability Index, EFI, calculated as

$EFI = -0.357 + 0.077*dAvTemp - 0.0023*dAvTemp^2 + 0.0065*nHumHours + 0.0011*nHumHours^2 + 0.0022*dAvTemp*nHumHours$

Then the IPI for day N is calculated by

If day N is before the IPI switch date

IPI = 7.83*EFI*(-0.0563 + 0.0626*N – 0.00067*N^2

Else

IPI = 11.12 * EFI

```
If nHotDay >= 2 or nFourDays < 3 or nDryHours >= 14
        IPI = 0.0
```

Sporulation Index Value model

The SIV model is only used after the spray threshold of the CDSI model has been passed. It is only shown in the raw output. The SIV model uses a lookup table reproduced below. The SIV is given by the entry in the table corresponding to the average temperature and average VPD for the previous 3 days.

VPD mb	Average Temperature ˚C																
	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
0.00	90	92	94	96	97	97	98	98	98	99	99	99	99	99	100	100	100
0.25	88	91	93	95	96	97	97	98	98	99	99	99	99	99	99	100	100
0.50	86	88	91	94	95	96	97	97	97	98	98	98	99	99	99	99	99
0.75	83	86	89	92	94	95	96	96	97	97	98	98	98	99	99	99	99
1.00	79	83	87	90	92	94	95	96	96	97	97	98	98	98	99	99	99
1.25	75	80	84	87	90	92	94	95	96	96	97	97	98	98	98	99	99
1.75	67	78	81	85	87	90	92	94	95	96	96	97	97	98	98	98	98
2.00	60	69	77	82	85	87	90	92	94	95	96	96	97	97	97	98	98
2.25	51	62	71	78	82	85	88	90	93	94	95	96	96	97	97	97	98
2.50	42	55	65	74	79	82	85	88	91	93	94	95	95	96	96	97	97
2.75	31	46	59	68	75	79	83	85	89	91	93	94	94	95	95	96	97
3.00	23	36	50	62	70	76	80	83	86	89	91	93	93	94	95	95	96
3.25	17	28	40	53	64	71	77	80	84	86	89	91	92	93	94	95	95
3.50	12	20	32	44	56	65	72	77	81	84	86	89	91	92	93	94	94
3.75	7	15	25	37	48	58	66	72	77	81	84	86	89	90	92	92	93
4.00	4	10	20	29	39	50	60	67	73	78	81	84	86	88	89	91	92
4.25	1	6	14	22	32	43	52	62	68	74	77	81	83	85	87	88	90

4.50	0	4	9	17	25	36	45	54	62	68	74	76	80	82	84	85	87
4.75	0	2	7	12	20	28	38	46	54	61	67	72	75	78	80	82	83
5.00	0	1	4	9	15	22	31	39	47	53	59	64	71	72	75	78	80
5.25	0	0	2	6	11	17	25	32	39	44	51	56	60	68	68	71	74
5.50	0	0	0	3	8	13	19	25	32	38	44	48	52	56	61	64	66
5.75	0	0	0	1	5	9	15	20	25	31	37	40	45	49	52	55	58
6.00	0	0	0	0	3	6	10	16	20	25	29	33	37	41	45	48	50
6.25	0	0	0	0	1	4	7	11	15	19	23	26	30	33	37	40	42
6.50	0	0	0	0	0	2	4	7	11	14	17	20	24	27	30	33	35
6.75	0	0	0	0	0	0	2	4	7	10	12	15	18	20	21	25	28
7.00	0	0	0	0	0	0	0	1	4	6	9	10	12	14	16	19	23
7.25	0	0	0	0	0	0	0	0	1	3	5	6	8	9	10	14	18
7.50	0	0	0	0	0	0	0	0	0	1	2	3	4	5	7	10	13
7.75	0	0	0	0	0	0	0	0	0	0	0	1	2	3	4	6	9
8.00	0	0	0	0	0	0	0	0	0	0	0	0	0	1	2	3	5
8.25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	2

Milioncast (Downy Mildew – *Peronospora destructor*)

Introduction

The Milioncast model consists of three models, for sporulation, infection and latent period. The model runs over the weather data for the previous six weeks. For the sporulation and infection models it produces a score that indicates how likely that sporulation or infection could have occurred. For each day on which it is predicted that both sporulation and infection would have occurred it runs the latent period model to predict when lesions will appear.

Weather Inputs

5. Air Temperature ˚C
6. Humidity %
7. Leaf Wetness mV
8. Rainfall mm

User Inputs

1. Latitude ° (used to calculate sunset time)

Outputs

The Milioncast output consists of a set of 3 graphs. The first is a graph of sporulation. The height this graph indicates the chance of sporulation having occurred in the previous 24 hours. Conditions have been conducive for sporulation if the bar exceeds the threshold of 4.15 is crossed. A bar is coloured red if infection has also been predicted to have occurred. The infection graph shows progress towards an infection event. Conditions have been conducive for infection if the threshold of 1.0 is crossed. The latent period graph shows

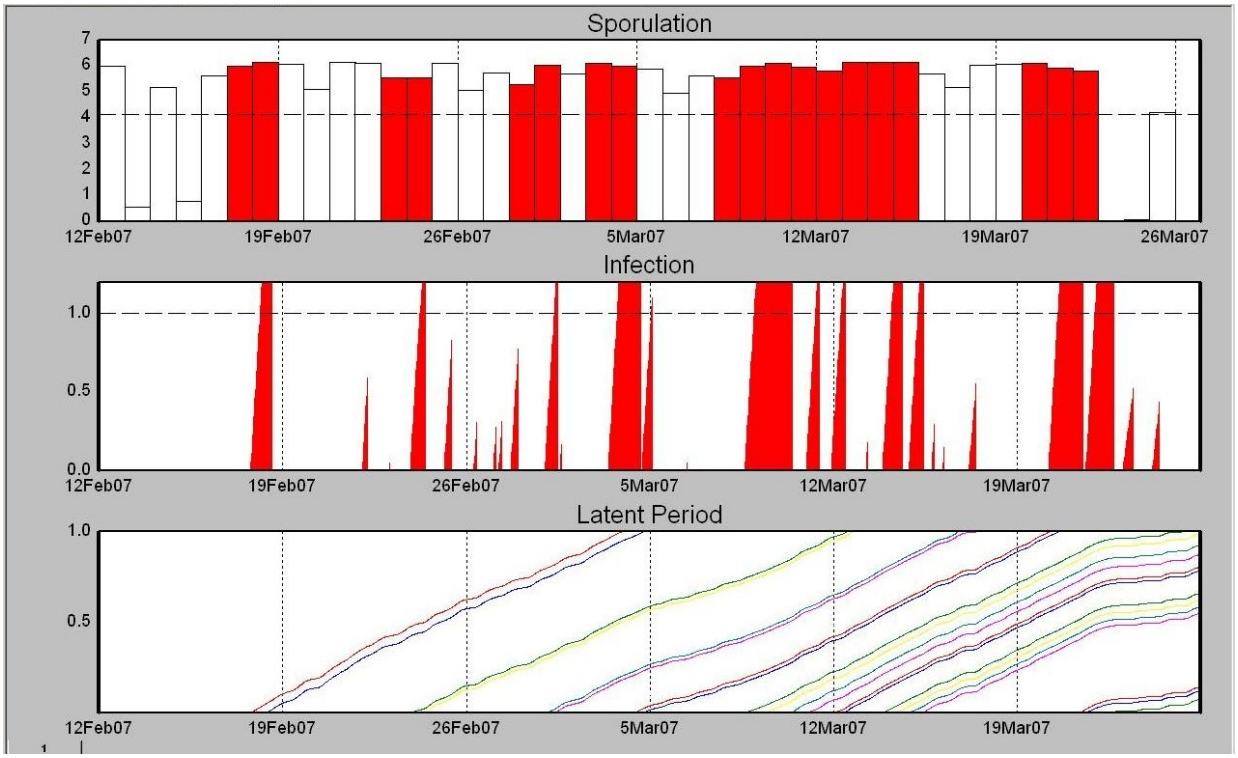


Figure 10 Graphs of Sporulation, Infection and Latent Period

progress towards lesion appearance from potential infection events on the days when both sporulation and infection were predicted. Lesions appear when the threshold of 1.0 is crossed.

Model Description

Sporulation

The sporulation model treats a day as running from 9:00am – 9:00am. It uses half hourly readings. Progress towards sporulation only occurs between sunset and 9:00am the next morning and is inhibited if it has been too warm during the afternoon, from noon to 17:30.

The sporulation score, SC, is calculated each day as follows

```
foreach reading from noon to 17:30
inhib += airTemp
```



```
mcon01 = 0.0
cumSpor = 0.0
foreach reading
if (between sunset and 9:00am) && humidity > 92
mcon01 += 0.5
conC = gammaDist(alphaC, betaC, gammaC, airTemp)
conCPrime = conC / log10(exp(1.0))
conM = 1.0 / gammaDist(alphaM, betaM, gammaM, airTemp)
conRHDeter = pow((1.0 - r), (100.0 - humidity))
conRate = (b * conCPrime * exp(exp(-exp(-b * (mcon01 -conM))) * conCPrime - exp(-b *
                  (mcon01 - conM)) - b * (mcon01 - conM))) / 2.0
cumSpor += (conRate * conRHDeter)
if inhib >= 386.7
        cumSpor = 0.0
SC = log10(cumSpor + 1.0)
```

Where gammaDist(alpha, beta, gamma, airTemp) is given by

$$gammaDist(\alpha, \beta, \gamma, T) = \frac{\gamma T^{\alpha-1} e^{\frac{-T}{\beta}}}{\beta^{\alpha}} \Gamma(\alpha)$$

With parameters

- alphaC = 2.15
- betaC = 11.95
- betaC = 212.92
- alphaM = 2.614
- betaM = 6.926
- gammaM = 4.0138
- b = 0.903
- r = 0.3968

Infection

The infection model produces an indication of whether infection could have occurred. The Infection Prediction, IP, is calculated as follows

```
if leaf wetness > 400
mcon04 = 1.0 / (2.0 * (20.26 – 1.801 * airTemp + 0.0682 * airTemp * airTemp)
else
mcon04 = 0.0
mcon05[0] = mcon04
mcon06[0]= mcon05[0]
foreach record starting at the second
        if leaf wetness > 400
                mcon04 = 1.0 / (2.0 * (20.26 – 1.801 * airTemp + 0.0682 * airTemp * airTemp)
        else
mcon04 = 0.0
mcon05[i] = mcon05[i-1] + mcon04
if mcon05[i] == mcon05[i – 1]
mcon06[i] = mcon05[i]
```



```
else
mcon06[i] = mcon06[i -1]
IP[i] = mcon05[i] – mcon06[i]
```

Latent Period

The latent period model predicts progress towards lesion appearance from a predicted infection event. An infection event happens when the sporulation score for a day exceeds the sporulation threshold during an infection period. An infection period defined by the Infection Prediction being greater than zero.

The model first finds the beginning and end of each infection period using the Infection Period score from the infection model.

For each day that the Sporulation Score has exceeded the sporulation threshold of 4.15 it checks to see if infection could have happened. Infection has happened if one of conditions is true.

1. An infection period has started before 09:00 on the sporulation day and the infection prediction score has crossed the threshold of 1.0 by the earlier of 02:00 the next day or the end of the infection period. The latent period starts at 09:00 on the sporulation day.
2. An infection period starts after 09:00 on the sporulation day and before 02:00 the next day. The latent period starts when the infection period starts.

For each latent period that has been discovered progress toward lesion appearance is calculated by accumulating the following function from the start of the latent period until the current time.

```
latent = 0
foreach record from latent period start to now
latent = latent + gammaDist(alphaL, betaL, gammaL, T) * timestep
```

where

- alphaL = 4.92
- betaL = 5.69
- gammaL = 3.479

Lesion appearances occurs when the latent period progress reaches 1.0.

Ringspot (*Mycosphaerella brassicicola*)

Introduction

The Ringspot model predicts the timing of new lesion appearance and hence the release of inoculum. It is used to time the application of fungicide sprays. Although the size of lesions seen is an input to the model it is unused. Additionally, although spray events are marked on the output graph no use is made of this information by the model itself.

Weather Inputs

1. Air Temperature ˚C
2. Leaf Wetness mV

User Inputs

1. Fresh Visible Lesion Date
2. Visible Lesion Size [Small, Medium, Large] (unused)
3. Spray Date (unused)
4. Spray Product (unused)

Outputs

There are two sets of output from the Ringspot model.

The first is a set of graphs consisting of the cumulative progress towards sporulation of the fastest 5% of spores from each new observation of lesions accompanied by graphs of minimum & maximum temperatures and hours of leaf-wetness. The date at which the sporulation progress threshold of 1.0 is crossed is marked on the x-axis. The sporulation progress graph also includes the timings of any sprays that have been applied and the products that were used.

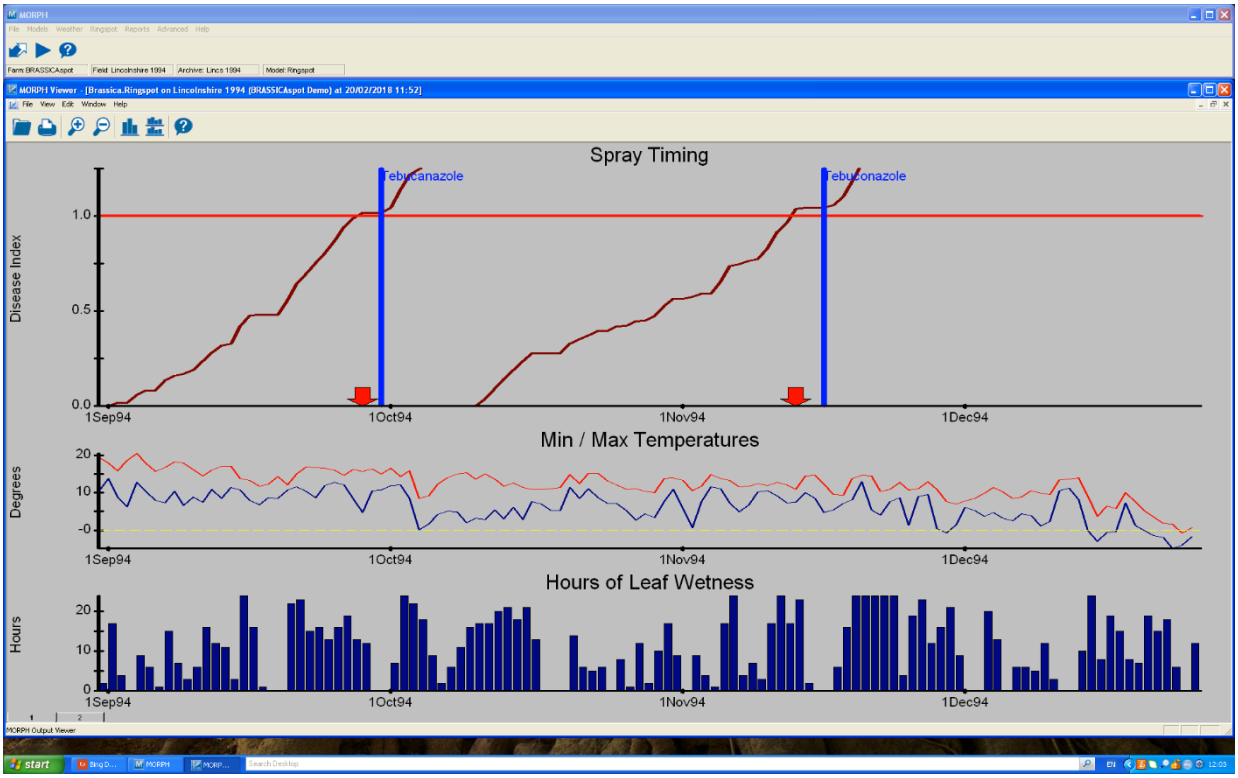


Figure 11 Graphs of sporulation progress, minimum & maximum temperatures and leaf wetness

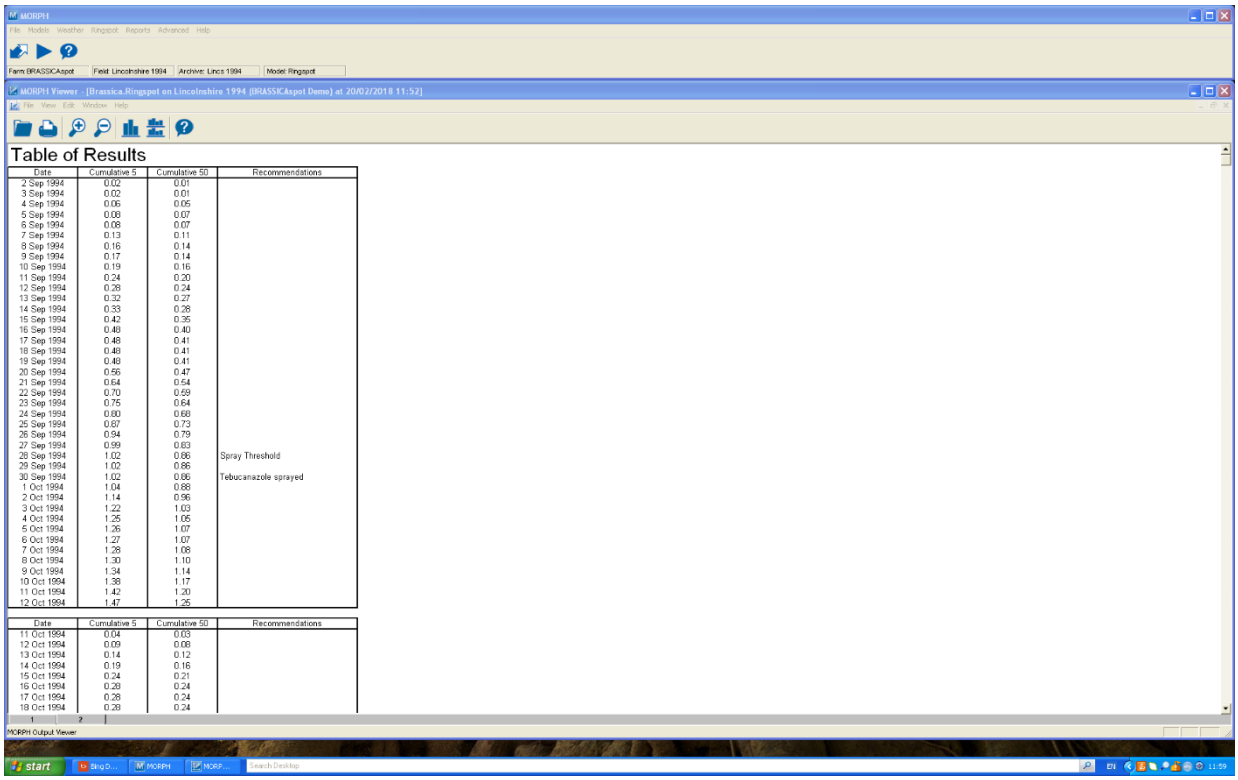


Figure 12 Table of sporulation index

The second is a table of daily cumulative sporulation score for both the 5% & 50% fastest spores for each new observation of lesions until the 50% case reaches a score of 1.25. The

date that the threshold of 1.0 is crossed for the 5% percentile and the date of any sprays is marked in the comments column.

Model Description

The disease progress model models the appearance of new lesions from an infection event. Each date that visible lesions are observed as being present by the user is used as the starting date for a new infection event. The mean hourly development rate is given by

$$rate50 = \frac{0.0196 + 0.0058T}{24}$$

where T is air temperature when T is between 0˚C and 20˚C and leaf wetness > 0.2. The rate of the fastest 5% is given by

$$rate5 = \frac{0.0199 + 0.0046T}{24}$$

where T is air temperature when T is between 0˚C and 20˚C and leaf wetness > 0.2.

The model predicts that a spray should be applied when the cumulative 5% infection rate exceeds 1.0, i.e. the fastest 5% of spores will have produced new lesions.

White Blister (*Albugo candida*)

Introduction

The White Blister model simulates the possibility of infection by *Albugo candida*. The model does not provide a forecast as such but rather determines whether suitable conditions for infection have occurred over the previous 24 hours. As such it can be used to provide a recommendation for crop walking to see whether infection has actually occurred.

Weather Inputs

1. Air Temperature ˚C
2. Leaf Wetness mV

User Inputs

1. Planting Date

Outputs

There are three sets of output from the White Blister model.

The first is a group of three graphs which consist of a bar chart showing the infection score. The bars are coloured red, amber and green to show high medium and low risks of infection. A graph of the maximum and minimum daily temperatures and the hours of leaf wetness, i.e. hours with leaf wetness sensor > 200mV.

The second is a table of the daily mean air temperature, total rainfall and infection score for the 5% & 50% fastest spores.

The final output is a summary of each of the WET, DRY and MISSING periods. For each period the length of the period, mean temperature, maximum VPD, total rainfall, maximum hourly rainfall and infection score for each of the fastest 5%, 20% & 50 spores.

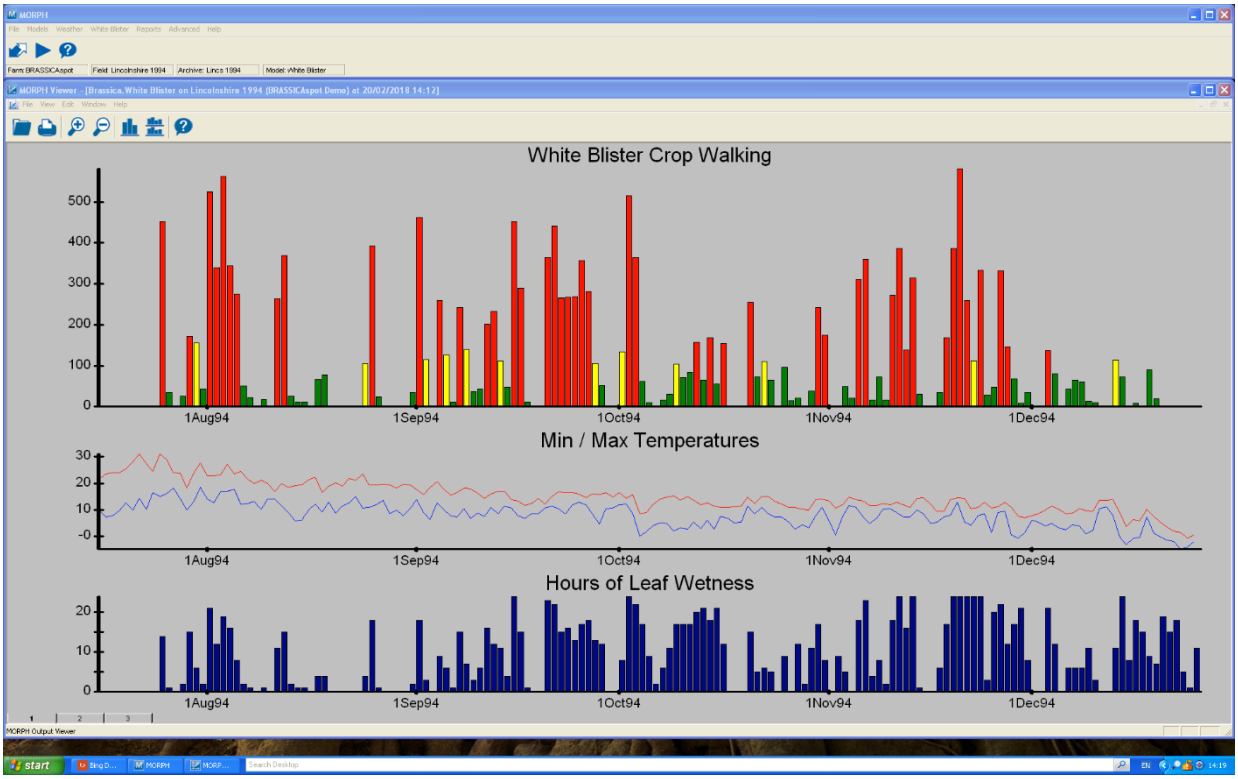
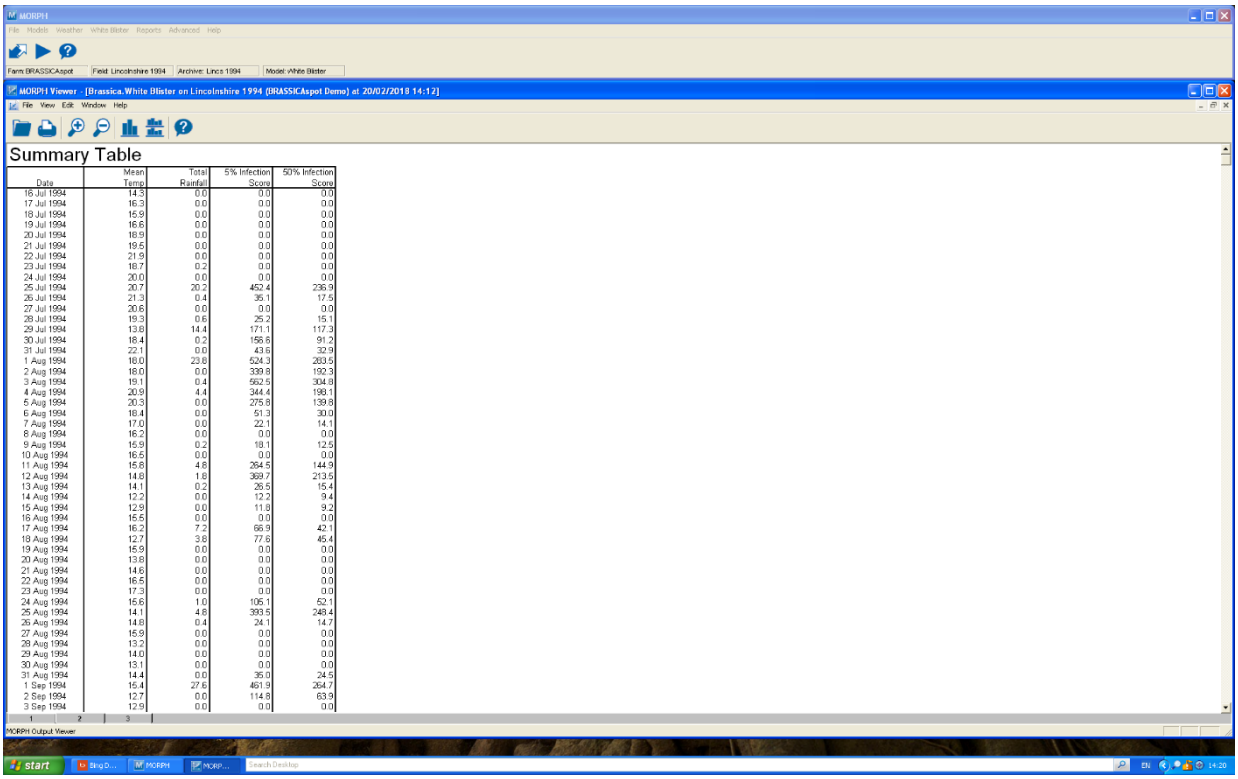


Figure 13 Graphs of infection score, maximum & minimum temperatures and hours of leaf wetness.



Date	Mean Temp	Total Rainfall	5% Infection Score	50% Infection Score
16 Jul 1994	14.3	0.0	0.0	0.0
17 Jul 1994	16.3	0.0	0.0	0.0
18 Jul 1994	15.9	0.0	0.0	0.0
19 Jul 1994	16.6	0.0	0.0	0.0
20 Jul 1994	18.9	0.0	0.0	0.0
21 Jul 1994	19.5	0.0	0.0	0.0
22 Jul 1994	21.9	0.0	0.0	0.0
23 Jul 1994	18.7	0.2	0.0	0.0
24 Jul 1994	20.0	0.0	0.0	0.0
25 Jul 1994	20.7	20.2	452.4	236.9
26 Jul 1994	21.3	0.4	35.1	17.5
27 Jul 1994	20.6	0.0	0.0	0.0
28 Jul 1994	19.3	0.6	25.2	15.1
29 Jul 1994	13.8	14.4	171.1	117.3
30 Jul 1994	18.4	0.2	156.8	91.2
31 Jul 1994	22.1	0.0	43.6	32.9
1 Aug 1994	18.0	23.8	524.3	283.5
2 Aug 1994	18.0	0.0	339.8	192.3
3 Aug 1994	19.1	0.4	562.5	304.8
4 Aug 1994	20.9	4.4	344.4	198.1
5 Aug 1994	20.3	0.0	275.8	139.8
6 Aug 1994	18.4	0.0	51.3	30.0
7 Aug 1994	17.0	0.0	22.1	14.1
8 Aug 1994	16.2	0.0	0.0	0.0
9 Aug 1994	15.9	0.2	18.1	12.5
10 Aug 1994	16.5	0.0	0.0	0.0
11 Aug 1994	15.8	4.8	264.5	144.9
12 Aug 1994	14.8	1.8	369.7	213.5
13 Aug 1994	14.1	0.2	26.5	15.4
14 Aug 1994	12.2	0.0	12.2	9.4
15 Aug 1994	12.9	0.0	11.8	9.2
16 Aug 1994	16.5	0.0	0.0	0.0
17 Aug 1994	16.2	7.2	66.9	42.1
18 Aug 1994	12.7	3.8	77.6	45.4
19 Aug 1994	15.9	0.0	0.0	0.0
20 Aug 1994	13.8	0.0	0.0	0.0
21 Aug 1994	14.6	0.0	0.0	0.0
22 Aug 1994	16.5	0.0	0.0	0.0
23 Aug 1994	17.3	0.0	0.0	0.0
24 Aug 1994	16.8	1.0	106.1	52.1
25 Aug 1994	14.1	4.8	393.5	248.4
26 Aug 1994	14.8	0.4	24.1	14.7
27 Aug 1994	15.9	0.0	0.0	0.0
28 Aug 1994	13.2	0.0	0.0	0.0
29 Aug 1994	14.0	0.0	0.0	0.0
30 Aug 1994	13.1	0.0	0.0	0.0
31 Aug 1994	14.4	0.0	35.0	24.5
1 Sep 1994	16.4	27.6	461.9	264.7
2 Sep 1994	12.7	0.0	114.8	63.9
3 Sep 1994	12.9	0.0	0.0	0.0

Figure 14 Table of meteorological data and infection scores

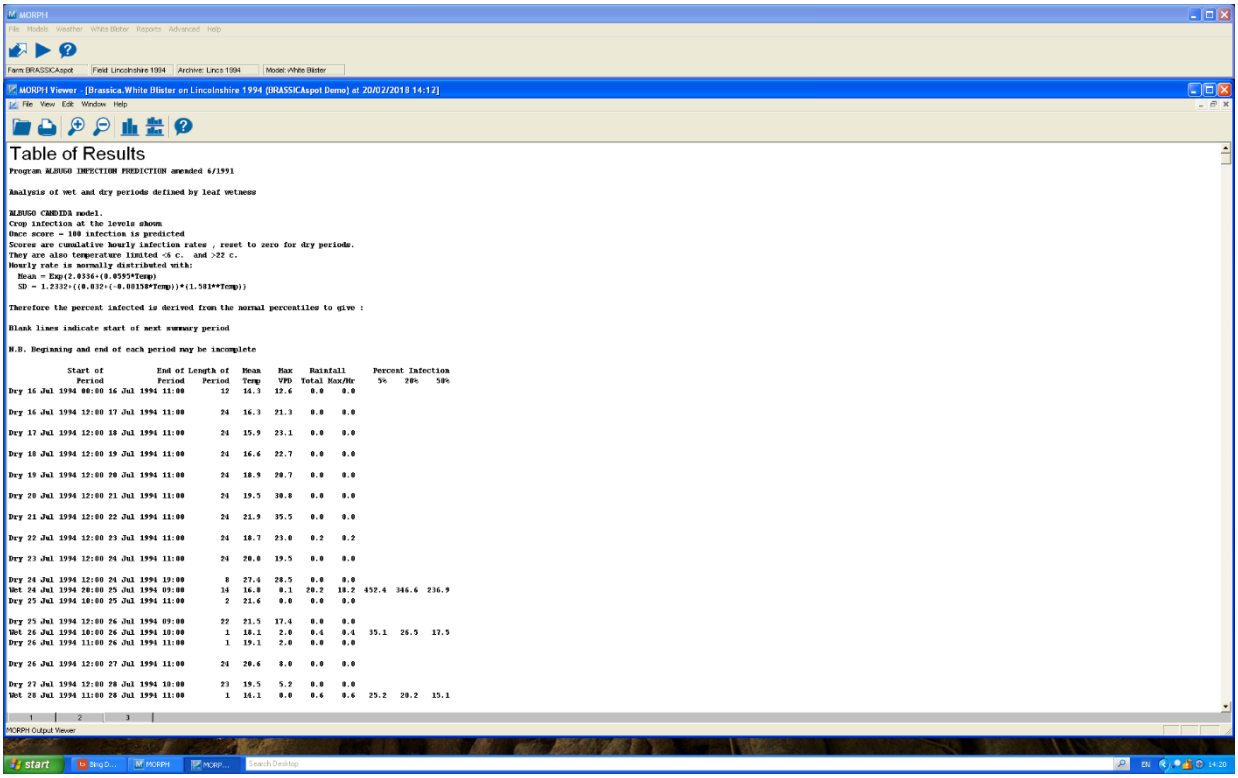


Figure 15 Summary of infection periods

Model Description

The model has three states MISSING, WET and DRY. It enters the MISSING state if the leaf wetness is missing for an hour. It enters the WET state when leaf wetness is over a threshold of 200 mV and the DRY state when the leaf wetness drops below this threshold. It produces a summary at each change of state and at 11:00 each day.

If the period is WET than a 50% infection score is calculated for the period. The raw mean hourly infection rate is given by

$$IR = e^{2.03362+0.05953*T}$$

between 6˚C and 22˚C and its' standard deviation by

$$SD = 1.23253 + (0.01370 - 0.00158 * T) * 1.58180^{T}$$

between 6˚C and 20˚C.

These raw values are then scaled by the maximum infection proportion in controlled environment, given by

$$MIP = -33.27006 + (69.82128 - 2.77033 * T) * 1.10049^{T}$$

to give a scaled rate of

$$scaled\ IR = IR * MIP$$

with an SD of

$$scaled\ SD = SD * MIP$$

The 5% and 20% infection scores are calculated from the 50% score as

$$scaled\ IR\ 20\% = scaled\ IR + 0.84 * scaled\ SD$$

and

$$scaled\ IR\ 5\% = scaled\ IR + 1.65 * scaled\ SD$$

The hourly rates and SDs are accumulated over the period to give a mean infection scores for the period and their associated SDs. If the 50% infection score exceeds 100 then the infection risk is critical and crop walking should take place. If the 5% infection score exceeds 100 the infection risk is at warning level.

White Blister 2 (*Albugo candida*)

Introduction

The White Blister 2 model is an extension of the White Blister model. It consists of two models. The crop walking model of the White Blister model and a disease progress model. Although the size of lesions seen is an input to the model it is unused. Additionally, although spray events are marked on the output graph no use is made of this information by the model itself.

Weather Inputs

1. Air Temperature ˚C
2. Leaf Wetness mV

User Inputs

1. Planting Date
2. Fresh Visible Lesion Date
3. Visible Lesion Size [Small, Medium, Large] (unused)
4. Spray Date (unused)
5. Spray Product (unused) Outputs

Outputs

There are two sets of output from the White Blister 2 model.

The first is a set of graphs showing the infection score from the White blister model and the progress towards new lesions appearing from previous infection events. The date at which the 5% fastest lesions appear is marked, i.e. when the disease index reaches 1.0, together with the timing of any sprays with the product used.

The second optional output is a summary table of the daily mean temperature, total rainfall and hours of leaf wetness together with the daily and cumulative progress towards lesion appearance for the fastest 5% & 50% of lesions.

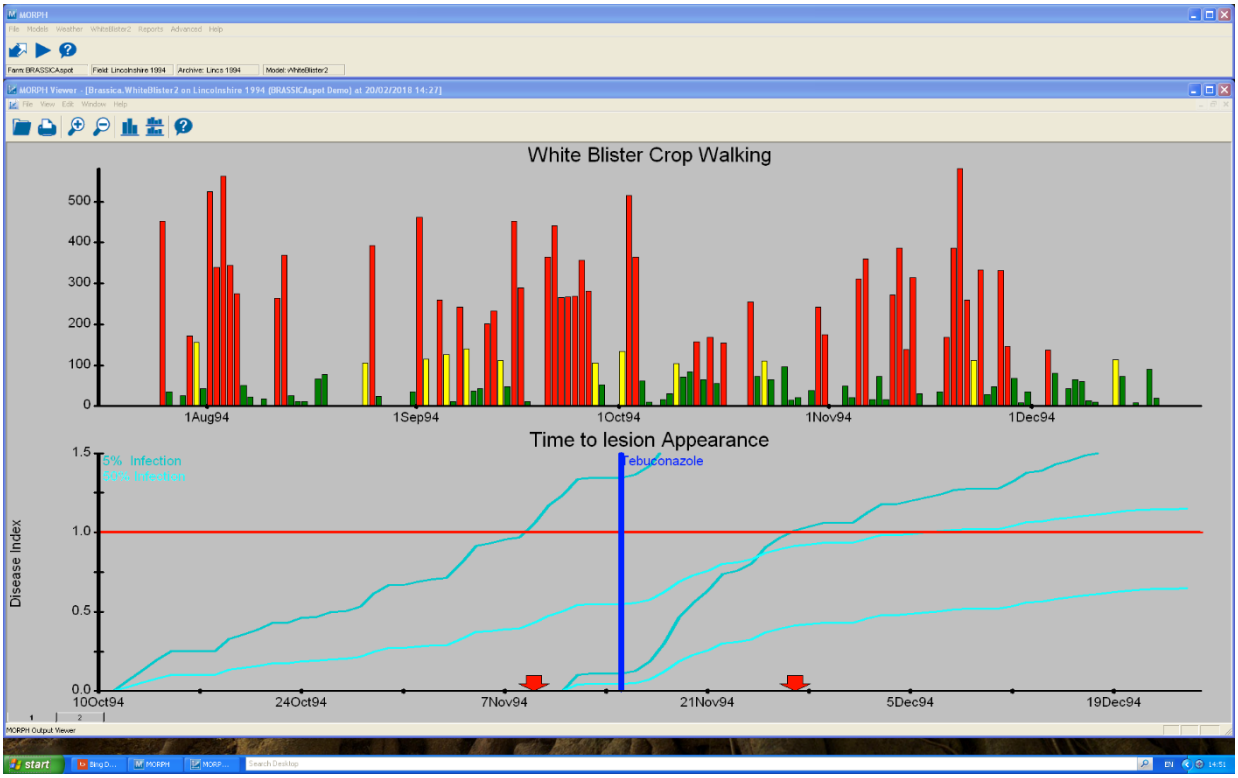


Figure 16 Graphs of infection risk and lesion appearance

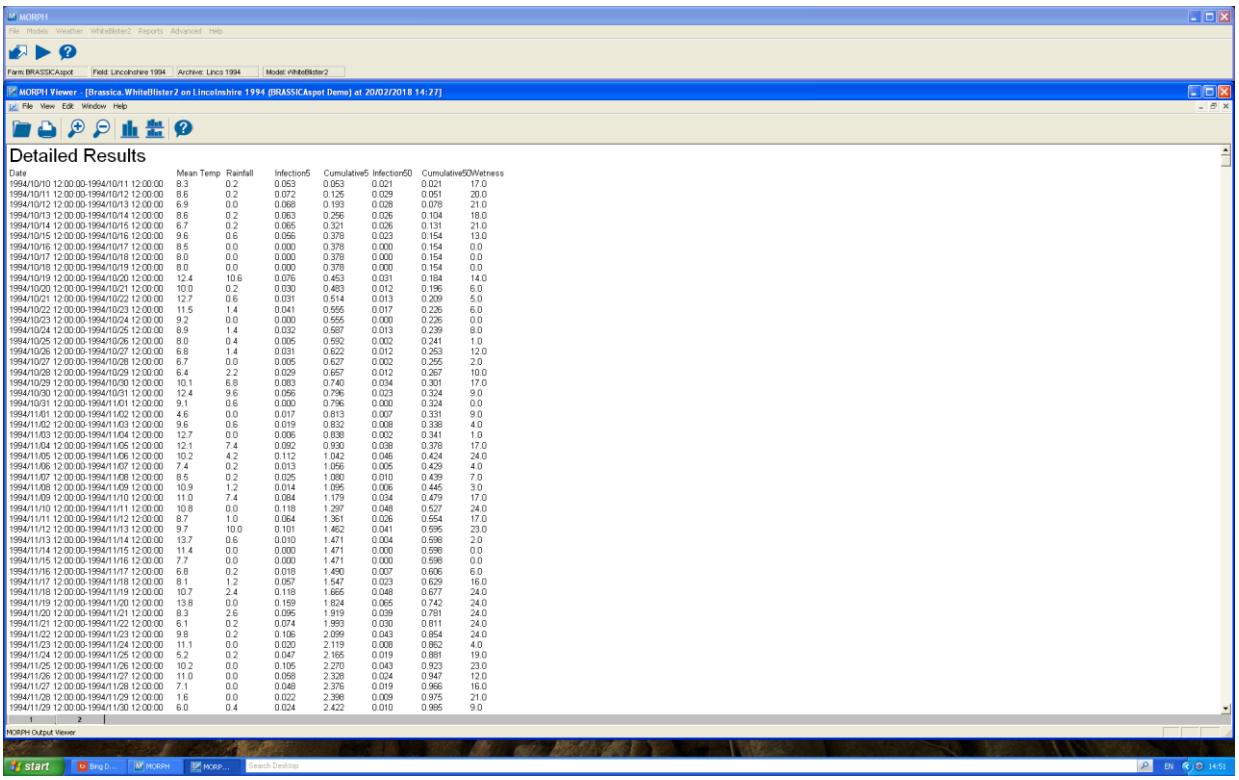


Figure 17 Summary table of meteorological data and progress to lesion appearance

Model Description

Crop Walk

See White Blister Model

Spray Timing

The disease progress model models the appearance of new lesions from an infection event. Each date that visible lesions are observed as being present by the user is used as the starting date for a new infection event. The mean hourly development rate is given by

$$rate50 = \frac{0.01557 * 1.1091^{T}}{24}$$

where T is air temperature when T is between 0˚C and 20˚C and leaf wetness > 0.2. The rate of the fastest 5% is given by

$$rate5 = rate50 * (1 + 1.65 * 0.884)$$

Appendix

Vapour Pressure Deficit (VPD)

VPD is calculated using the formula

$$VPD = \left(1 - \frac{RH}{100}\right) * e^{2.302585 * \left(9.24349 - \frac{2305}{T} - \frac{500}{T^2} - \frac{100000}{T^3}\right)}$$

where RH is relative humidity and T is air temperature.

Discussion

The MORPH software is very old and as newer versions of WINDOWS appear it is becoming harder to sustain. The aim of this project was to extract the algorithms for six of the disease forecasting models in MORPH so that these would be available to others for development into new formats. Thus none of the information above can be used directly by growers and advisors but it is now available for incorporation into other decision support systems.

Acknowledgements

We thank the AHDB for funding this work.

