A model to predict the Dothistroma spray programme

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Abstract

A model to predict the Dothistroma spray programme was developed by testing the effect of rainfall, raindays, and inoculum in previous season on the percentage of susceptible area sprayed in individual years from 1966 to 2002 at Kaingaroa and Kinleith. For both data sets a multiple regression using average monthly rainfall from November-February (including October or March rainfall if 200 mm or more), total raindays of at least 0.1 mm from November-February, and the percentage of susceptible area sprayed in the previous season to predict area sprayed gave reasonable results. The Kaingaroa data set gave an R^2 of 0.53 and for Kinleith R^2 = 0.70. Some of the unexplained variation was attributable to incomplete or inaccurate input data, management decisions influencing area sprayed, and, possibly, exceptional climatic events such as a wetter and warmer than average September or April.

Further work to enhance the model should be carried out. This includes refining the input data, adding more observations, testing other combinations of predictive variables, and establishing disease progress field trials. Such enhancements should result in a model sufficiently robust to predict accurately the size of spray programmes and in turn reduce costs associated with over- or under-estimating supplies needed to service the programme.

Introduction

The Dothistroma Control Committee is responsible for purchase of bulk lots of copper fungicide and spray oil, letting contracts for aerial application and keeping financial accounts for the Dothistroma control programme. Copper fungicide and oil has to be ordered well in advance of the start of the spray programme, before the annual aerial survey has been conducted. A model that accurately predicts next season's disease levels would be invaluable to the Committee by avoiding additional expense that may be incurred by over- or under-estimating supplies needed for the forthcoming season. Individual forest companies would also benefit by being able to accurately budget Dothistroma control costs for the next financial year.

Dothistroma disease progression is governed by initial inoculum, rainfall, temperature, and silviculture. Some work on predictive modelling was carried out in the late 1970s using Kinleith and Kaingaroa disease and rainfall data. A highly significant relationship was found (R^2=0.87) for a multiple regression using the parameters summer rainfall and summer raindays to predict susceptible area sprayed at Kinleith. However, only 11 observations were available and a larger sample is needed before one could be confident of predictions from the model.

Combinations of continuous variables (e.g. rainfall, raindays, inoculum in previous season) were tested for their contribution to a predictive multiple regression model. This report describes the methods used and the results. The best-fit models are provided.

Methods

Climate data (rainfall and raindays at 0.1 mm and 1.0 mm) were fitted to disease level and percentage of susceptible area sprayed data. Information from plantations in two regions (Kaingaroa and Kinleith) was gathered from a variety of sources.

For Kaingaroa, data were obtained from:

1. Records held at Forest Research from early work carried out by Denis Albert of NZFP and continued by Bou van der Pas and Lindsay Bulman (1966-1979).

2. Records held at Forest Research from John Knowlton and Judy Gamble of NZFS (1979-80)

3. Various NZFS records of areas sprayed and correspondence from 1971-78.

4. Dothistroma survey data from 1973-1986.

5. Stand record system data of Dothistroma spraying from Dave Lowry, Forestry Corporation (1987-1992).

6. Various computer files of area sprayed and survey data from Mark Forward and Nigel Heron of FCF (1995-2002).

7. Susceptible area data from (1) and Doug McNab, Hugh Goodacre, and Kevin Cooney of FCF.

8. Climate data were obtained from NIWA, NZ Meteorological Service reports, and Mark Forward and Nigel Heron of FCF.

For Kinleith, data were obtained from:

1. Records held at Forest Research from early work carried out by Denis Albert of NZFP and continued by Bou van der Pas and Lindsay Bulman (1966-1979).

2. Table 1 from Andy Dick's 1989 paper (1966-88).

3. Dothistroma Control Committee reports (1971, 1972, and 1981).

4. Sharon Watkins of CHH (1982-2002).

5. Climate data were obtained from NIWA, NZ Meteorological Service reports, and Sharon Watkins.

Spray data

A great deal of time was spent validating the data. In some cases the stated hectares sprayed in Kaingaroa in individual years varied depending on the source of the data. Differences were generally the result of minor species (*Pinus nigra* and *P. ponderosa*) being included in sprayed hectares data in one source and not the other, or from areas double sprayed being counted twice. Hectares sprayed from 1987/88 to 1992/93 were taken from the stand record system as no other records were available. Area sprayed in 1993/94 and 1994/95 were estimated from Dothistroma Trust Account figures, and in the 2000/01 season were estimated by summing the area where disease levels were assessed at 20% or higher, as no actual area sprayed data were available. For Kinleith, differences arose from other regions being included in the sprayed hectares data (i.e. Matahina, King Country, Pureora).

Once the spray data were gathered and validated as far as possible with the records available, for Kaingaroa and Kinleith complete data of hectares sprayed, and susceptible area, from 1966 to 2002 were held. Disease level data from 1970-87, 1995-96, and 1999-2000 were available from Kaingaroa but not from Kinleith. At Kaingaroa in the 1995/96 spray season 81% of the susceptible area was sprayed, despite three relatively dry, or average rainfall, previous summers. Such a large spray programme is inexplicable and was excluded from the analysis.

Climate data

The NIWA data contained a number of missing observations and were supplemented with NZFS, FCF, and CHH meteorological data. At Kaingaroa the stations and years' data used in the analysis are shown in Table 1.

Table 1 – Stations and years' data used in the Kaingaroa analysis.

Station	**Monthly Rainfall**	**Raindays 1.0 mm**	**Raindays 0.1 mm**
Kaingaroa NIWA	1965-87, 1989-92	1965-87, 1989-92	1965-87, 1989-92
Kaingaroa FCF	1976-86	1976-86	1976-86
Murupara NIWA	1965-87	1965-87	1965-87
Murupara FCF	1976-87	1976-87	1976-87
Galatea 1 NIWA	1965-73, 1974-76, 1977-80, 1990-91	1965-73, 1974-76, 1977-80, 1990-91	1965-73, 1974-76, 1977-80, 1990-91
Galatea 2 NIWA	1966-70, 1973-81, 1982-2002	1966-70, 1973-81, 1982-2002	1966-70, 1973-81, 1982-2002
Galatea 3 NIWA	1987-89	1987-89	1987-89
Galatea FCF	1993-94, 1995-2002	1993-94, 1995-2002	1993-94, 1995-2002
Rerewhakiitu NIWA	1977-78, 1997-2000, 2002	1977-78, 1997-2000, 2002	1977-78, 1997-2000, 2002
Goudies FCF	1993-94, 1995-2002	1993-94, 1995-2002	1993-94, 1995-2002
Waiotapu FCF	1976-86	1976-86	1976-86
Wairapukao FCF	1976-86	1976-86	1976-86
Matea FCF	1993-98, 1999-2002	1993-98, 1999-2002	1993-98, 1999-2002

At Kinleith, NIWA data (raindays 1.0 mm, and raindays 0.1 mm) were available for Kinleith from 1967-90; at Tokoroa from 1999-2001; and at Mangakino from 1999-2000. Rainfall data were available for Kinleith from 1967-90; at Tokoroa from 1999-2002; and at Mangakino from 1996-2002. These data were supplemented by rainfall and rainday 0.1 mm data from CHH for Kinleith from 1982-2002. Data from all stations were averaged to provide monthly mean data.

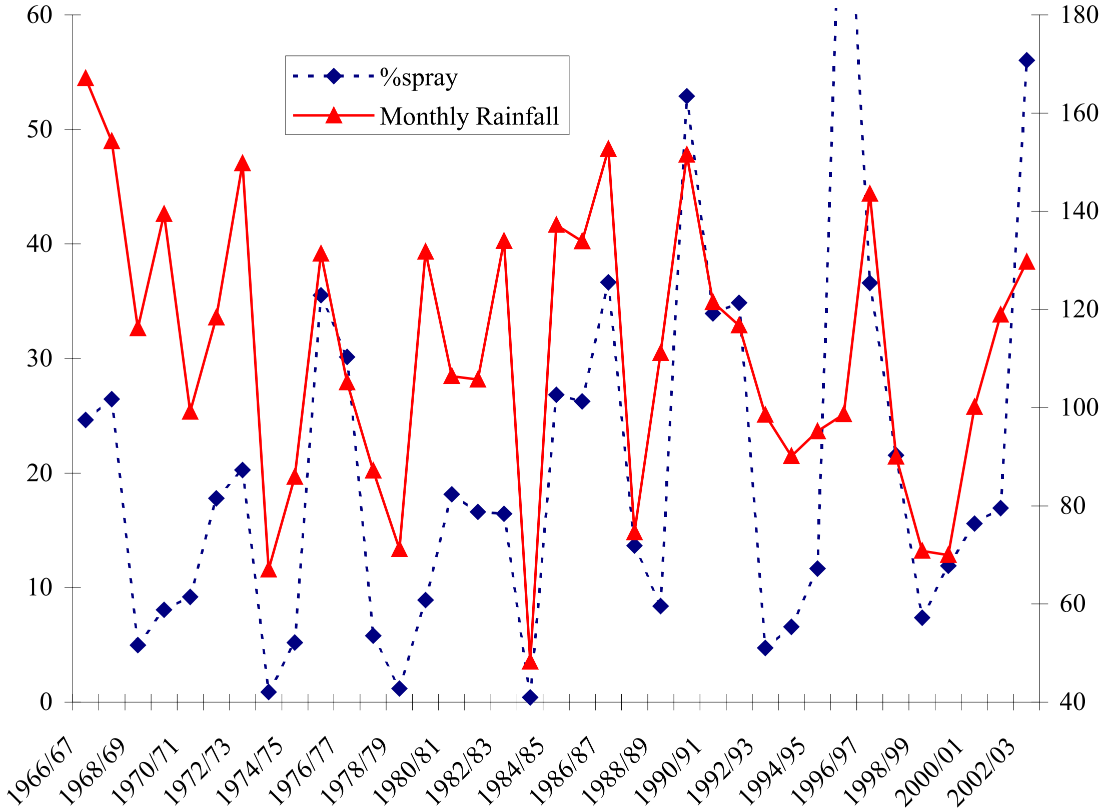
Data analysis

Because there were incomplete records of disease levels at Kaingaroa, and no records of disease levels at Kinleith, the percentage of susceptible area sprayed was the primary response variable tested in the model. The percentage sprayed was related to total rainfall from November to February of the previous season; raindays at 1.0 mm and 0.1 mm (at Kinleith only raindays at 0.1 mm were used as some years' 1.0 mm data were not available); and the percentage of area sprayed in the previous season. Average summer rainfall was included as an additional variable whereby monthly rainfall from November to February was averaged, and if rainfall was 200 mm or higher in October or March then that month's value was also included in the mean value. Similar procedures for rainday data were not carried out. A stepwise multiple regression using a SAS package determined significant variables. Kaingaroa and Kinleith data were analysed separately.

Results

The best fit models were obtained using average rainfall, raindays, and percentage area sprayed the previous season. The relationship between average rainfall and sprayed area is shown in Figure 1 (regression $R^2 = 0.41$).

Figure 1 – Percentage of susceptible area sprayed and average rainfall over the previous Nov-Feb (including October or March rainfall if 200 mm or more) at Kaingaroa.



For Kaingaroa both average rainfall and raindays at 0.1 mm were significant predictors of sprayed area, and the inclusion of percentage area sprayed in the previous season increased the R^2 from 0.472 to 0.532 with area sprayed in the previous season being significant at $p = 0.052$. The model outputs were:

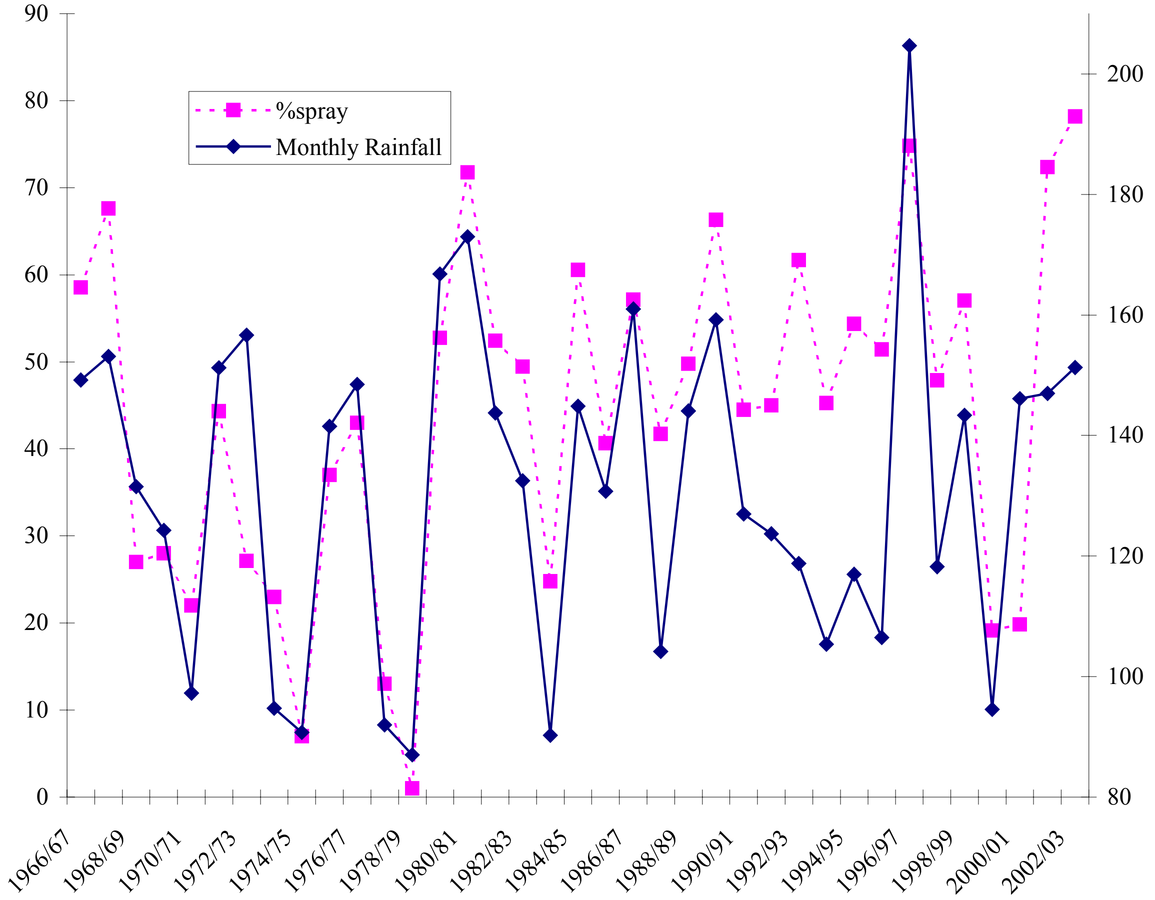
Variable	Estimate	Std Error	Type II SS	F Value	Pr > F
Intercept	-33.252	11.40	921.42	8.51	0.0063
Meanrain	0.201	0.079	698.06	6.45	0.0160
Raindays0.1	0.660	0.329	435.70	4.03	0.0531

And with the inclusion of percentage area sprayed in the previous season:

Variable	Estimate	Std Error	Type II SS	F Value	Pr > F
Intercept	-36.923	11.05	1105.21	11.16	0.0021
Meanrain	0.196	0.076	665.34	6.72	0.0143
Raindays0.1	0.667	0.315	444.05	4.48	0.0421
Prevspr	0.205	0.102	402.05	4.06	0.0524

At Kinleith the fit of the model was better, but the same variables were significant, with the proviso that raindays at 1.0 mm were not available and therefore not tested. The relationship between average rainfall and sprayed area is shown in Figure 2 (regression $R^2 = 0.50$).

Figure 2 – Percentage of susceptible area sprayed and average rainfall over the previous Nov-Feb (including October or March rainfall if 200 mm or more) at Kinleith.



For the combination of average monthly rainfall and raindays at 0.1 mm the R^2 was 0.665, increasing to 0.703 after area sprayed in the previous season was added. The inclusion of average monthly rainfall including October and March values if rainfall in those months was 200 mm or higher significantly improved the model. When average monthly rainfall was excluded, and only total Nov-Feb rainfall, raindays at 0.1 mm, and previous spray were used as predictors the R^2 of the model decreased from 0.703 to 0.607 and previous spray became not significant.

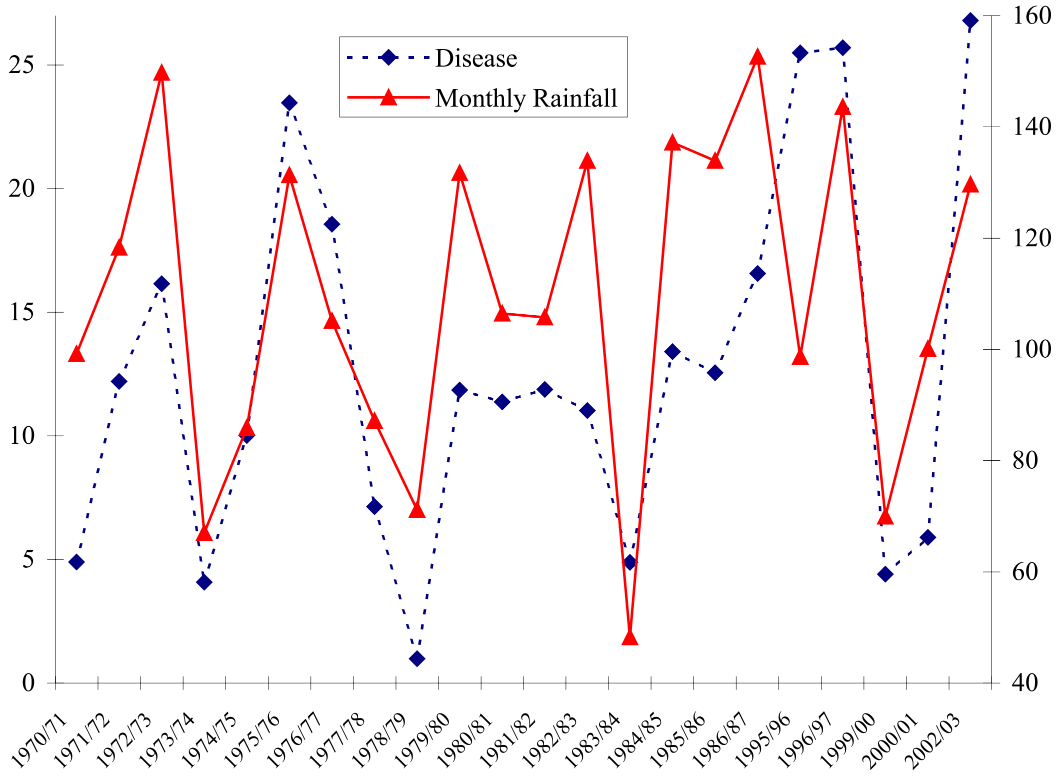
Variable	Estimate	Std Error	Type II SS	F Value	Pr > F
Intercept	-57.840	12.919	2720.15	20.04	<0.0001
Meanrain	0.349	0.080	2567.48	18.92	0.0001
Raindays0.1	1.107	0.271	2268.14	16.71	0.0003

And with the inclusion of percentage area sprayed in the previous season:

Variable	Estimate	Std Error	Type II SS	F Value	Pr > F
Intercept	-62.444	12.555	3068.79	24.74	<0.0001
Meanrain	0.371	0.077	2855.73	23.02	<0.0001
Raindays0.1	0.965	0.268	1609.28	12.97	0.0010
Prevspr	0.206	0.100	520.38	4.19	0.0486

Prediction of disease levels proved less accurate than prediction of susceptible area sprayed. Disease levels follow rainfall reasonably well during the 1970/71 to 1986/87 period (R^2 =0.545), but the 1995/96 and 2000/01 years do not conform particularly well (Figure 3). For all years the relationship of disease level and average rainfall gave R^2 = 0.419. The addition of raindays at 1.0 mm and 0.1 mm increased R^2 to 0.631. Disease level in the previous season could not be tested due to missing values.

Figure 3 – Disease level and average rainfall over the previous Nov-Feb (including October or March rainfall if 200 mm or more) at Kaingaroa.



Discussion

Because there were incomplete records of disease levels at Kaingaroa, and no records of disease levels at Kinleith, the percentage of susceptible area sprayed was analysed. However, the area sprayed is influenced not only by climatic and environmental factors but also by management decisions that may not always be based on disease severity or best spray practice. For instance, in April 1984 the Minister of Forests advised of a possible human health risk from *Dothistroma* following tests in a Sydney laboratory which showed that dothistromin was capable of causing chromosome damage in mammalian cells. Consequently, the Dothistroma Control Committee recommended for the 1984/85 spray season that all stands of *P. radiata* where disease levels were 15% or more in which workers will be operating within 12 months be sprayed. In the 1990s NZFP adopted a policy of spraying stands when disease levels were low (10-15%) in the expectation that inoculum levels would be reduced further and disease would be suppressed the following year even after a wet summer. In 1999/2000 and 2000/01 CHH decided that no double spray would be undertaken, regardless of disease levels. At Kaingaroa it appeared that stricter criteria for spraying were also applied for those seasons, as many stands assessed at 25% infection were not sprayed.

Other sources of error arose from incomplete or inaccurate data. The susceptible area sprayed for some individual years varied considerably depending on the source of the data. For instance, in the 1983/84 spray season CHH records stated that 27,541 ha were sprayed but Dick (1989) stated 19,138 ha were sprayed. In 1984/85, Dick (1989) stated that 58,833 ha were sprayed at Kinleith yet other CHH records state that

45,457 ha were sprayed. Dick (1989) stated that 16,162 ha were sprayed at Kinleith in 1971/72 but this figure included 1,835.7 ha sprayed at Matahina Forest (from Dothistroma Control Committee spray schedules). The total susceptible area was also difficult to determine on occasion. It would have been preferable to conduct an analysis of the effect of rainfall on disease levels as the variation associated with management decisions would be removed. However, this approach was not possible as Kinleith data were not available and some Kaingaroa disease assessments were missing. Also, some of the disease level data from the 1990s are suspect because both crop trees and followers were assessed and it was not clear whether an assessment of "0" for followers indicted that *Dothistroma* was not present, or that followers were not present.

The climate data were also incomplete. No station had records for all years and mean values from all stations where data were available were used. However, some inaccuracy would have been introduced by the inclusion of data from wetter or drier than normal sites for some years and not others.

Despite the inaccuracy of some of the data and the fact that percentage of susceptible area sprayed is influenced by non-environmental factors the models represented reasonable levels of explained variation with R^2 values of 0.53 and 0.70 for Kaingaroa and Kinleith, respectively. Sprayed area and susceptible area data from CHH over the 1990s included not only Kinleith but also other parts of the CHH estate, and it is highly likely that data from Kinleith alone would have resulted in an improved model. It is also likely that the inclusion of average raindays using October and March values, if 17 raindays or greater, would also reduce unexplained variation.

Traditionally, total rainfall from November to February inclusive has been used to predict the spray programme in the following season. The inclusion of October or March values if these months had above average rainfall (arbitrarily taken at 200 mm or higher) is a new approach and it worked well. The R^2 of the Kinleith model increased from 0.607 to 0.703 when average monthly rainfall was selected in preference to total rainfall. This finding is not unexpected as Gadgil (1974) found that day/night temperatures of 20°C/12°C produced the most infection when four combinations were tested in laboratory conditions. Gilmour (1981) found that moderate infection occurred at Kaingaroa in March during periods of high rainfall. Some infection occurred in October but over the three-year period of the study October rainfall was low. Mean maximum and minimum temperatures in October and March are, respectively, 15.9°C /5.1°C and 20.2°C /8.8°C at Kaingaroa and 15.9°C /6.5°C and 20.9°C /9.9°C at Kinleith (NZ Met. Service 1978). It is possible that infection could also occur during an exceptionally warm and wet April, in particular, or September.

The inclusion of raindays at 0.1 mm also improved the accuracy of predictions. For Kinleith, R^2 increased from 0.50 to 0.66 with the inclusion of raindays. For Kaingaroa the respective increase with the addition of raindays was 0.41 to 0.47.

The variables average rainfall from November to February (including October and March where appropriate), raindays, and previous area sprayed should be used in the predictive models for Kaingaroa and Kinleith. With refinement of the input variables it should be possible to develop a model sufficiently robust to allow confident predictions of the size of next season's spray programme.

Recommendations and future work

It is recommended that Dothistroma prediction models use the following variables to predict the size of next season's spray programme:

- Average monthly rainfall from Nov-Feb (including October or March rainfall if 200 mm or more)
- Total raindays of at least 0.1 mm from November-February
- The percentage of susceptible area sprayed in the previous season

The following future work that may enhance the models should be carried out:

- Refine input data to increase the accuracy of the models by:
    - obtaining more climate data
    - differentiating Kinleith and other regions in the CHH data
    - obtaining actual sprayed area data for Kaingaroa in the 1993/94, 1994/95, and 2000/01 seasons.

- Add more observations to the model from other large areas where *Dothistroma* is common, such as Pureora, King Country, or Tahorakuri.

- Test the effect of including March and October rainday values when appropriate

- Test the effect of including March but excluding October rainfall and rainday values

- Test the effect of temperature and, in particular, combinations of temperature and rainfall parameters

- In years where management decisions <u>are known</u> to have influenced the percentage of area sprayed, percentage area sprayed should be adjusted to more closely reflect the area sprayed had those decisions not been taken

- Field trials could be established in a variety of sites where monthly assessments of Dothistroma disease levels are carried out and climate observations made, in order to validate the model by monitoring disease progression under differing climatic conditions.

The field trial work is being considered for inclusion in the FRST bid for 2003-08 as it is fundamental research that will aid our understanding of the ecology of pest and disease systems as regulated by site factors and climate.

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