Boxwood Blight Infection Risk Model
A disease caused by *Calonectria pseudonaviculata* (Fungi: Ascomycota)

Infection Risk Model Documentation for USPest.org
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Model Access Links

This model has been released and is available at the USPest.org multi-pest modeling website:
https://uspest.org/risk/boxwood_app
(newer interface intended for mobile devices; latest version includes an option for "push" email notifications, see https://uspest.org/wea/Boxwood_blight_model_instructions.pdf for a "how to use" guide); see also:

https://uspest.org/risk/models?mdl=bxwd_s
(older interface integrated with 150+ other USPest.org "MyPest Page" models. Note bxwd_s stands for "boxwood blight – susceptible varieties")

The synoptic version of this model, which uses Google maps and links current risk level color-coded pins to the full model (older interface) for each available weather station, is available at:
https://uspest.org/risk/boxwood_map

Abstract

The invasive pathogen, *Calonectria pseudonaviculata* causes boxwood blight on susceptible cultivars of boxwood, *Buxus sempervirens* and related species. Models to predict infection and severity of this disease are urgently needed. As part of the OIPMC/USPest.org commitment to build tools that can help mitigate the impact of established and invasive pests in the US, an infection risk model was developed in order to better predict environmental conditions conducive to infection. Version 3.0 of this model was developed from numerous sources: 1) data from the thesis by Gehesquière (2014) for two varieties of *Buxus*; *B. sempervirens* (Common or American boxwood), which has been classified as susceptible, and *B. sempervirens var. Suffruticosa* (English or true dwarf boxwood), which was found to be among the most highly susceptible varieties assessed (LaMondia 2019), 2) publications by Avenot et al. (2017, 2021), and Weiland et al. (2022), and 3) end-user feedback and incidence report analysis.

Introduction

Boxwood blight is caused by the invasive pathogen, *Calonectria pseudonaviculata* (*Cps*; synonym *Cylindrocladium buxicola*). This disease has spread to most US states through transport of boxwood plantings. The potential world distribution based on climate suitability studies was recently published by Barker et al. (2022). Infection can occur at temperatures as low as 44°F and as high as 84°F. Initial infections are often caused by surviving microsclerotia when conditions are suitable for sporulation, and rain splash may be a factor. Local spread is usually through contact with the sticky spores produced by secondary infections. Long distance spread is usually through shipment of infected plants, which may be asymptomatic. Fungicidal control is sometimes used to prevent and curtail mild infections, whereas destruction of plants may be required for severe infections. Infection risk models which integrate favorable temperatures with estimates of leaf wetness may be used to help time preventative fungicidal treatments, and to determine times when to expect symptoms to appear.

Model Description

The model makes use of a convention often used for infection risk models, “degree-hours (DH) during periods of leaf wetness (LW)”, which basically says that we accrue infection risk units based on temperature response if there is sufficient moisture in the environment. This convention requires an estimate of leaf wetness, whether from leaf wetness sensors that may be connected to weather stations, or from an algorithm that derives the estimate from other weather parameters. For more on this see the section below, “Leaf Wetness Estimation”. The temperature response of *Cps* is combined from four major studies: Gehesquière (2014), Avenot et al. (2017), Avenot et al. (2021), and Weiland et al. (2022). We scaled the latter three studies to match the response rate of the former for compatibility with version 1.0 of our model, which was initially based on the earlier study. Degree-hour calculations for this model are based on a linear piecewise-regression model (Fig. 1), converted to a table lookup approach to infection degree-hours (Appendix I).

As the infection process depends upon moisture expressed as estimated leaf wetness, as with most other models using this convention, a dry period of some estimated interval is needed to stop and force a resetting of accumulated infection units (degree-hours) to zero. While laboratory studies by Avenot et al. (2017) showed that interval may be as short as 2-3 hr, this value was calibrated to greater than 5 hr based on end-user feedback and case-study analysis. This value seems reasonable, and must be slightly conservative, since boxwood canopies can be very dense, and drying under field conditions would be expected to take longer than under laboratory conditions.

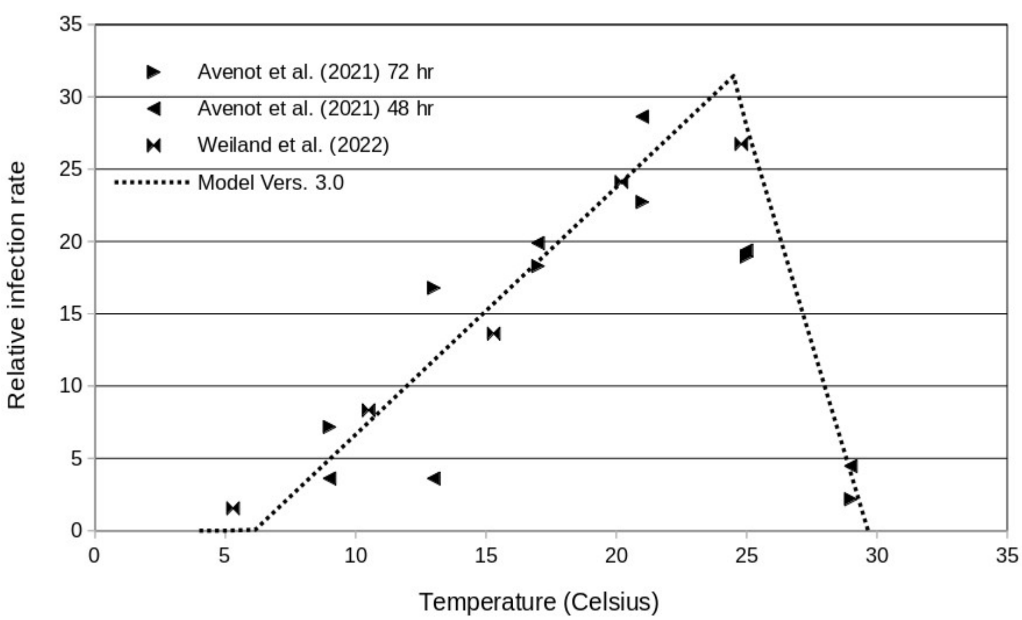

Fig. 1. Boxwood blight relative infection rate versus temperature, under conditions causing leaf wetness. Model version 3.0 (a degree-hour model) was developed using results from Avenot et al. (2017, 2021) and Weiland et al. (2022), both scaled to and combined with results of Gehesquière (2014).

Degree of Infection Models

The model also calculates the relative degree of infection over longer intervals of leaf wetness, which would result from repeated infection cycles for this compound infection disease, as reported by Gehesquière (2014). From his results (Tables 6.7 & 6.8), we regressed the number of leaf lesions per plant (reflecting the number of infections) vs. DH during leaf wetness periods. From these results, two models of disease build up were then fit to the data (Fig. 2):

B. semp.: Degree of infection (#lesions/plant) = 0.0175 x DH – 1.0881; r^2 = 0.92
B. s. v. Suff.: Degree of infection (#lesions/plant) = 0.0552 x DH – 3.1860; r^2 = 0.82

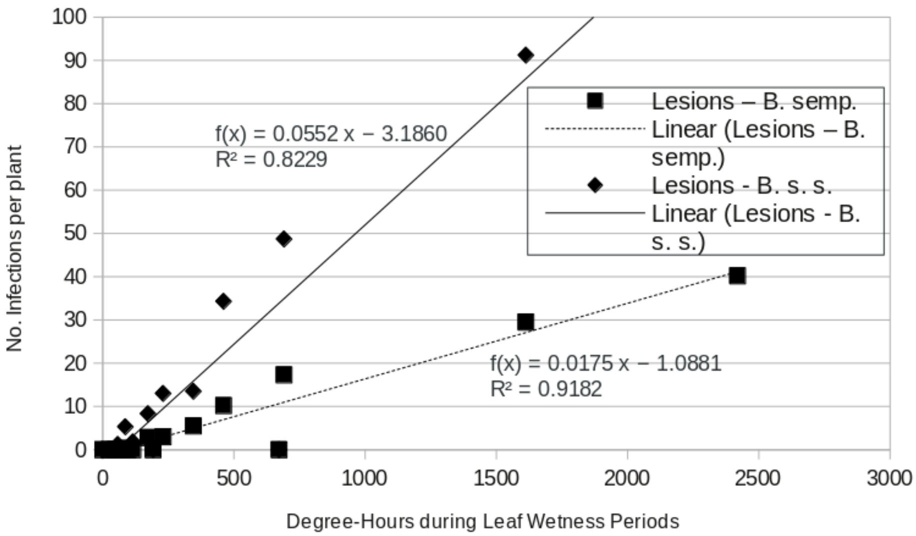

Fig. 2. The relationship between degree-hours during leaf wetness periods and infection severity, for *Buxus sempervirens* (B. semp.) and for *Buxus sempervirens* "Suffruticosa" (B. s. s.). Adapted from Gehesquière (2014, Tables 6.7 & 6.8).

Leaf Wetness Estimation

Leaf wetness as implemented at USPest.org is based upon a 0-10 scale, with 0 denoting "dry" and 1+ denoting "wet and wetter". Models implemented at this website allow the end-user to raise the threshold for "wet" to a higher value as an option. This scale was adopted based upon a no-longer-used leaf wetness sensor (hardware) specification. The requirement for hardware sensors was relieved at USPest.org after adoption of a version of the Kim et al. (2004, 2005, 2010) "fuzzy logic leaf wetness" (FLLW) algorithm, which estimates leaf wetness based on energy balance principles using hourly weather inputs of temperature, dewpoint, and wind speed. This algorithm, while extensively tested and validated (Kim et al. 2010), does not account for leaf wetness due to precipitation events. We subsequently commissioned Fox Weather, LLC to develop a "precipitation-drying leaf wetness" (FoxLW) heuristic algorithm in order to reflect hourly precipitation and subsequent leaf drying rates. Here is a summary of Fox's documentation for this algorithm:

- for rainfall at 0.05 in/hr, LW=10 for that hr
- at 0.02 in/hr: in summer LW=5, winter or at night then LW=10
- LW should end < 0.5 hr after rain ends during day, and ca. 1 hr after rain ends at night if WS=5 mph
- if WS=10 mph, then LW ends when rain ends

- LW = 0 if rain < 0.02 with WS >= 10 mph
- LW = 3 if rain > 0.01 or < 0.02 with WS <=5 mph
- if WS ranges from 5 to 10 mph, set LW to 0

The Kim et al. FLLW and FoxLW models are independent and parallel computations for a leaf wetness value: We output the highest LW of the two (they are not added together, we just take the maximum value). The boxwood blight model at USPest.org uses a default LW threshold of 1 for wet, 0 for dry.

Model Programming Details

A single low threshold temperature of 44°F is used for both young and mature leaves. First lesions (leaf spots) are predicted after 56 DH during leaf wetness periods to infection thresholds while additional lesions (degree of infection) is predicted through the formulas:

For American boxwood: no. lesions per plant = 0.0175 x DH – 1.0881
For English boxwood: no. lesions per plant = 0.0552 x DH – 3.186

These equations were only coarsely translated into ranges for the sake of showing increasing infection severity risk with prolonged accumulations of DH. These models that describe first and relative degree of infection have been implemented at the multi-pest modeling website https://uspest.org/risk/models?mdl=bxwd_s and at the boxwood blight app/webpage https://uspest.org/risk/boxwood_app. The degree of infection model is subject to interpretation of events relevant to management needs, and therefore should be reviewed especially by potential end-users of the model. The combined model currently uses the following selected events and parameters:

Summary of Parameters for Modeling Boxwood Blight :
Name of model: Boxwood blight infection risk
Model type: Non-linear degree-hours (DHs) during leaf wetness periods
Lower temp. threshold: 44°F (6.7°C)
Topt (optimal temperature): 76°F (24.4°C)
Upper temp. threshold: 86°F (30.0°C)
Leaf wetness threshold: 1 (on scale from 0 to 10)
Maximum cumulative DH: 850 (for graphs primarily)
No. of dry hours to stop the infection cycle:
more than 5.0 (this current value is based on both recent work and from case studies and end-user feedback, as model uses an hourly time step, this threshold is effectively 6.0
DHs less than first infection of young leaves (low risk of new infections)
0 - (lt. green)
DHs to first infection of young leaves (highly susc. Var.):
56 - (green)
DHs to first infection of young leaves (susc. Var.):
160 - (yellow-green)
DHs for infection resulting in: 6 lesions, highly susc. Var., 1 lesion, susc. Var:
250 - (yellow-orange)
DHs for infection resulting in: 12 lesions, highly susc. Var., 3 lesions, susc. Var:
400 - (orange-red)

DHs for infection resulting in: 18 lesions, highly susc. Var., 5 lesions, susc. Var:
550 - (lt. Red)

Model assumptions:

1. The model assumes that infectious pathogen spores (inoculum) are present, and that the host is a susceptible cultivar, and it is not yet protected by fungicides.
2. The model predicts relative rates of infection; lesion estimates are only approximate
3. While spores from microsclerotia generally require rainfall to spread and initiate the infection process, the model conservatively does not require rainfall events, as spores may also be present from existing lesions.
4. These results were scaled to reflect infection rates on one highly susceptible (English boxwood) and one susceptible (American boxwood) cultivar; lower infection risk levels would be expected for less susceptible cultivars.
5. It is assumed that the plantings are exposed to ambient conditions, including that they are not under overhead irrigation and are not heavily shaded, both of which would increase risk of infection.

Use of the model at https://uspest.org/risk/boxwood_app (latest mobile-friendly version)
Model usage documentation has been placed in a separate document, see https://uspest.org/wea/Boxwood_blight_model_instructions.pdf

Model Changes and Areas for Potential Model Improvement
Versions 1.0 and 1.1 were implemented starting in 2013, with revision to 2.0 in use starting July 2018. Version 2.1 included changes added during 2019 (modify dry period to reset degree-hour accumulations from >3 hr to >5hr) and during 2020 (new version of email "push" notifications technology, show current year results compared to the previous year). Version 3.0 added infection response rates at lower temperatures down to 6.7C, and reverted to a linear response curve based on Weiland et al. (2022) and Avenot et al. (2021) results. The model has been partly validated by comparing model predictions prior to observed outbreaks in several instances. In nearly all cases, the model gave sufficient warning that infection could spread if inoculum is present. We do have reports from areas of the humid southeastern US which may indicate that leaf wetness is sometimes insufficient to predict infection, possibly due to periods very high humidity. Future updates potentially should include addition of 1) an RH threshold, 2) efficacy and residual effects of fungicides, and 3) splitting forecast predictions into several categories of boxwood cultivar susceptibility, such as resistant or tolerant, moderately tolerant, moderately susceptible, and susceptible cultivars.

If you would like to contribute to model validation, please send reports of outbreaks to: coopl@oregonstate.edu. Please include in your posting: 1) the cultivars of boxwood affected and symptoms noted, 2) the time when symptoms were first observed/noted to rapidly expand, 3) the location and a description of the setting: park or other public space, nursery, private home, etc, and 4) relevant management activities including the usage of fungicides (active ingredients, rates and timing).

Disclaimer
All data and products are provided "as is" and users assume all risk in their use. No claims are made as to the correctness or appropriateness of this information for your particular needs. No specific pest control products are intended for endorsement or use. These responsibilities and all associated liabilities rest solely with the people who interpret and implement information from this and other sources. Use all predictive information with caution - errors occur, and predictive models do not

replace the need for proper monitoring in the field. If you observe conditions that differ substantially from model predictions, please contact us to determine if the model inputs were incorrect, if the model functioning or weather data are in error, or if the model is inappropriate for your conditions.

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Appendix I

Look up table developed from Fig. 1, used to determine degree-hour (DH) boxwood blight infection risk units as a function of temperature (ºF) during periods of leaf wetness.

Temp ºF	DH
43	0.0
44	0.95
45	1.9
46	2.85
47	3.80
48	4.75
49	5.70
50	6.65
51	7.60
52	8.55
53	9.50
54	10.45
55	11.40
56	12.35
57	13.30
58	14.25
59	15.20
60	16.15
61	17.10
62	18.05
63	19.00
64	19.95
65	20.90
66	21.85
67	22.80
68	23.75
69	24.70
70	25.65
71	26.60
72	27.55
73	28.50
74	29.45
75	30.40
76	31.35
77	27.96
78	24.63
79	21.29
80	17.96
81	14.63
82	11.29
83	7.96
84	4.63
85	1.29
86	0.00

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Western IPM Center
BBIG Boxwood Blight Insight Group
NIFA