

μMETOS and MetWin II the Potato Late blight models

μMETOS and MetWin II are calculating three different models to assess the risk of potato late blight infections. Smith Periods and Infection periods following the Model of Fry are calculated to indicate possible infection periods. The *Phytophthora infestans* negative prognosis following Ullrich und Schrödter is calculated to assess the increase in inoculum during the growing season. Accumulated Fry Infection periods are offering the possibility to assess the need of a fungicide application.

Smith Periods

Model Developer and Citation: Smith, L.P. 1956. Potato blight forecasting by 90% humidity criteria. Plant Pathology 5:83-87.

Sensor location: Off-site, at regional weather stations.

Input variables: Minimum temperature and hourly relative humidity.

Calculated variables: Number of hours of relative humidity 90% or higher.

Model description: Smith criteria: Two consecutive days with minimum temperature of 10 C (50 F) with at least 11 hours of relative humidity 90% or higher are favorable for the development of *Phytophthora infestans* on potato. 10 hours of relative humidity at the second day are indicated as 90% of Smith period.

Action threshold: Initiate treatments when first 100% Smith period has been fulfilled.

Model validation: This model is currently under validation in England and Wales (Hims et al., 1995). Preliminary results indicate that spray programs guided by the Smith criteria achieved a comparable degree of control as calendar based spray programs. In high risk areas for late blight, the model advised the same number of sprays as the routine spray program, but in low risk areas it advised 3 to 5 fewer sprays.

Model representation in μMETOS and MetWin II: The μMETOS is showing one asterix if 90% of a Smith period is reached and two asterix if 100% of a Smith period is reached. MetWin II is graphing three lines one is representing 90% of Smith period, the next is representing 95% of Smith period and the last is representing 100% of Smith period.

Infection Periods following Fry

Model Developer and Citation: Fry, W.E., Apple, A.E., and Bruhn, J.A. 1983. Evaluation of potato late blight forecasts modified to incorporate host resistance and fungicide weathering. Phytopathology 73:1054-1059.

Bruhn, J. A. and Fry, W. E. 1981. Analysis of potato late blight epidemiology by simulation modelling. Phytopathology 71: 597-601.

Sensor Location: Within crop canopy.

Environmental Input Variables: Daily rainfall (mm), hourly average temperature and relative humidity.

Calculated Variables: Number of consecutive hours with relative humidity greater than or equal to 90%, at five intervals of temperature (< 3, 3-7, 8-12, 13-22, 23-27 and >27 C) in 24

hour periods (from noon to noon the following day).

Input Variables: Cultivar resistance (susceptible, moderately susceptible or moderately resistant).

Model Description: This forecast model was derived from two simulation models. One model describes weather effects on fungicide distribution and amount. The second model describes effects of host resistance and weather on development of *Phytophthora infestans* on potato. Do the fact that the fungicide part was developed for one single fungicide (chlorothalonil) MetWin II and μ METOS are not using the model describing the weather effects on fungicide. The model assessing the effects of weather conditions on Potato Late Blight is assessing the possibility and severity of *Phytophthora infestans* infection periods. This blight units are calculated according to the number of consecutive hours that relative humidity is greater than or equal to 90%, and average temperature falls within any of six ranges (< 3, 3-7, 8-12, 13-22, 23-27 and >27 C).

Blight units for the simulation forecast as determined by temperature and periods of high relative humidity

Average temperature (C)	Cultivar resistance	Consecutive hours of relative humidity $\geq 90\%$ that should result in blight units of:							
		0	1	2	3	4	5	6	7
>27	S /b	24							
	MS /c	24							
	MR /d	24							
23-27	S	6	9-12	10-12	13-15	16-18	19-24		
	MS	9	10-18	19-24					
	MR	15	16-24						
13-22	S	6					7-9	10-12	13-24
	MS	6	7	8	9	10	11-12	13-24	
	MR	6	7	8	9	10-12	13-24		
8-12	S	6	7	8-9	10	11-12	13-15	16-24	
	MS	6	7-9	10-12	13-15	16-18	19-24		
	MR	9	10-12	13-15	16-24				
3-7	S	9	10-12	13-15	16-18	19-24			
	MS	12	13-24						
	MR	18	19-24						
<3	S	24							
	MS	24							
	MR	24							

/a High relative humidity $\geq 90\%$. Blight unit estimation period is 24 hr (noon to noon).

/b S = susceptible cultivars.

/c MS = moderately susceptible cultivars.

/d MR = moderately resistant cultivars

Decision rules about when fungicide should be applied were generated based on cumulative blight units or fungicide units since last spray. MetWin II is showing the infection periods and their severity indicated by this model in the graphik for potato late blight. μ METOS is showing the daily and hourly blight units for the three classes of susceptibility on the screen.

Cumulative blight units can be calculated with the blight unit accumulator window of MetWin II. Blight units can be accumulated with μ METOS too.

Decision rules for the simulation forecast based on accumulated blight units (Fry)

Logic statements	Cultivar resistance		
Fungicide should be applied if fungicide has not been applied within 5 days	Susceptible	Moderately susceptible	Moderately resistant
AND cumulative blight units since last spray exceed:	30	35	40

Phytophthora negative prognosis (Ullrich und Schrödter)

Model Developer and Citation: Ullrich J. and Schrodter H., 1966. Das Problem der Vorhersage des Auftretens der Kartoffelkrautfaule (*Phytophthora infestans*) und die Möglichkeit seiner Lösung durch eine Negativprognose. Nachrichtenblatt Dt. Pflanzenschutzdienst (Braunschweig) 18:33-40.

Sensor Location: The model was developed with temperature sensors mounted 2 meters above the ground.

Environmental Input Variables: Hourly temperature, relative humidity, and rainfall.

Calculated Variables: Number of hours that fit pre-defined environmental conditions, risk values, and accumulated risk values.

Model Description: This "negative prognosis" model uses measurements of temperature, relative humidity, and rainfall to predict when late blight (*Phytophthora infestans*) epidemics are not likely to occur. It has been used in Germany to predict the timing of the first treatment. Daily and accumulated risk values over a week are calculated starting at crop emergence. Risk values are calculated according to the following table:

Multiplication factor (r)	Number of hours hourly temperature averages are in this range (h), or other conditions to be met	RH or Precipitation Requirements, or other conditions to be met
0.899	10.0 - 11.9	Only count hours that co-occur with 4 or more consecutive hours at RH \geq 90% or rain \geq 0.1 mm/hr
0.4118	14.0 - 15.9	
0.5336	16.0 - 17.9	
0.8816	18.0 - 19.9	
1.0498	20.0 - 21.9	
0.5858	22.0 - 23.9	
0.3924	10.0 - 11.9	Only count hours that co-occur with 10 or more consecutive hours at RH \geq 90% or rain \geq 0.1 mm/hr
0.0702	14.0 - 15.9	
0.1278	16.0 - 17.9	
0.9108	18.0 - 19.9	
1.4706	20.0 - 21.9	
0.855	22.0 - 23.9	
0.1639	15.0 - 19.9	Do not consider RH or rain, add 7.5479 to the product of r x h
0.0468	Number of hours with average RH < 70%	Subtract 7.8624 from the product of r x h

To calculate risk values, count the number of hours (h) that the average temperature falls within the temperature range in the second column and the conditions of relative humidity or

rainfall indicated in the third column. Since there are 14 rows in the table, there should be 14 values of h, some of which may be zero. Then, multiply each of these 14 h-values by the corresponding r-value of the first column and sum up the 14 products (r x h). The sum of the products is the risk value. For example, count all hours within a week during which hourly average temperature was between 10.0-11.9 C and relative humidity was greater than or equal to 90% or precipitation was 0.1 mm/hour or greater. Then multiply that number of hours by the corresponding value of the first column (r=0.8990). Do the same procedure for the remaining 13 rows of the table and then add up all products to get the risk value.

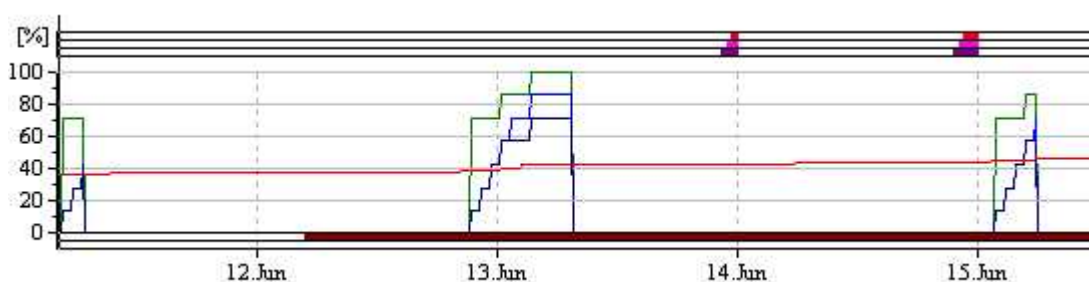
Action Threshold: Disease is expected when accumulated risk value has exceeded the threshold of 150. Users have adjusted this threshold to fit local conditions. MetWin II is showing the development of the Risk value in a different scale. The values graphed are ranging between 0 and 100. Disease is expected when the risk value is higher than 37. This is indicated by a line on the base of the graph. The Ullrich and Schrödter Value of 150 indicates a disease level of approximately 0.1% infected plants. This will be the action threshold if there is a period of several weeks to harvest. The Ullrich and Schrödter value of 270 is indicating 1% of infected plants. In the graphs of MetWin II this value is represented by 67 and indicated by a second line on the base of the graph. This value can be used as an action threshold in years where the primary inoculum of this disease is very low. This would be a year after a dry year when the planted seed carries very little inoculum. The presentation in μ METOS is similar to MetWin II. Up to the day (hour) the negative prognosis is below 150 the 0 to 100 values are shown. If this 0 to 100 value is higher than 37 (0.1% of infected plants) a asterix is shown. If the value is higher than 67 (1% infected plants two asterix are shown.

Model Validation: This model has been validated in Germany.

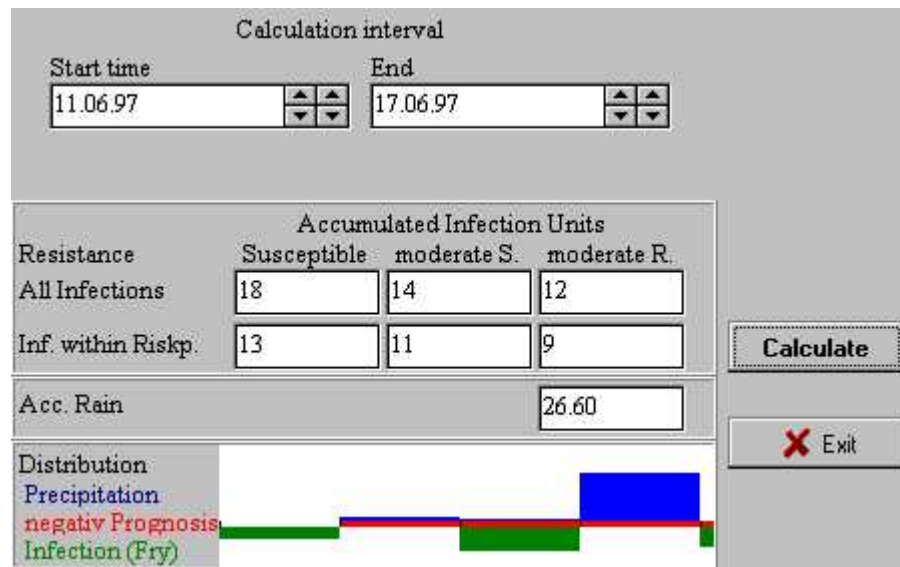
Model Implementation: This model has been implemented in Europe.

The MetWin II Potato Graphik

MetWin II shows the result of all three calculations in one graphic window. Smith periods where shown as three lines at the top of this graph. If this lines are coloured 90%, 95% and 100% of a Smith period is indicated. This is pointing out the first time when *Phytophthora infestans* had good conditions to infect the potatoes and it is indicating periods with a high disease pressure. The progress graph (0 to 100) is showing the increasing line of the Phytophthora negativ prognosis and the single possible infection events for susceptible, moderate susceptible and moderate resistant varieties calculated by the model following Fry. Fry is separating 7 different levels of infection severity. MetWin is showing this levels in a range between 0 and 100. 14 is corresponding with 1 blight unit, 28 with 2 and 100 with 7 blight units.



The graph above is showing a fulfilled Smith period at June 14th and at June 15th. The progress graph is showing the value of the negative prognosis ranging between 35 and 42. The 0.1% level of disease frequency in field is fulfilled during this period, what is indicated by the line in the bottom of the graph. The 1% margin is not fulfilled. There is no second line on the bottom of this graph. 3 infections of different severity are indicated by the model followint Fry during the graphed period. The accumulated blight units for this period showed in the screen shout beside. The accumulated Infection Units for all Infections in this time interval are: 18 for susceptible varieties,



14 for moderate susceptible varieties and 12 for moderate resistant varieties. The accumulated Infection Units for the part of the time interval when negative prognosis was higher than 150 (0.1% of infected plants) are: 13 for susceptible varieties, 11 for moderate susceptible varieties and 9 for moderate resistant varieties. None of them is higher than the thresholds of 30 for susceptible varieties, 35 for moderate susceptible varieties and 40 for moderate resistant varieties. The accumulated precipitation during this period was 26.6 mm. The main rain event was on day four of this period. The main infection event was on day three.

The presentation of the models for *Phytophthora infestans* on potato with the μ METOS

Three different displays are representing the Potato Late Blight. One display is showing Smith periods and negative prognosis. Smith periods are represented by asterix. One asterix is showing 90% of a Smith period, two asterix are showing 100% of a Smith period. The negative prognosis is shown in values between 0 and 100 up to the time the value of 37 is reached. The value of 37 is representing 0.1% of infected plants. Now a asterix is shown. If the negativ prognosis shows the value for 1% infected plants two asterix are displayed.

Fry infection periods for susceptible, moderate susceptible and moderate resisteant varieties are shown in a second display. This values can be accumulated for every period of time to assess for the action treshold.

The presentation of Potato Late Blight in μ LINK PC-Software

This presentation is similar to the MetWinII graphs.

Tomato Downy Mildew (*Phytophthora infestans*)

Tomato Downy Mildew is caused by the same pathogen than Potato Late Blight. In some cases therefore the same models are used for both pathogens. In the case of μ METOS and MetWin II we are showing Smith Periods for both pathogens. Together with the Smith Periods and the Blight Units following Fry μ METOS and MetWin II are showing the results of the IPI model. This models shows the time were no disease risk occurs and when the disease risk period starts. Data representation in μ METOS, μ Link and MetWin II is similar to potatoes.

The IPI-model for Tomato Downy Mildew

Model Developer and Citation: Bugiani, R., Cavanni, P. and Ponti, I. 1993. An advisory service for the occurrence of *Phytophthora infestans* on tomato in Emilia-Romagna region. Bulletin OEPP/EPPO 23: 607-613.

Cavanni, P., Ponti, I. and Marinelli, M. 1990. A forecasting model for late blight of tomato. Informatore Fitopatologico 40:17-25 (in Italian)

Ponti, I., Cavanni, P, Mazzini, F. and Libe, A. 1985. Verification of forecasting criteria for late blight of tomato. Informatore Fitopatologico 35:13-21 (In Italian).

Sensor Location: Off-site, at regional weather stations.

Environmental Input Variables: Daily temperature, rainfall, and relative humidity.

Calculated Variables: Average daily temperature in C (T_{av}), daily minimum temperature, average daily relative humidity (RH_{av}) and 24 and 48 hour rainfall accumulation (R).

Pathogen: Number of sporangia trapped and disease observed in untreated plots placed in strategic locations throughout the tomato growing areas.

Model Description: This model generates infection potential indexes (IPI) that predict the most probable inoculum increase of *Phytophthora infestans* in the environment. In Italy, IP indexes are used along with indicator plants plus spore traps to warn farmers about when to start spraying. The model does not give recommendations about subsequent fungicide applications.

To calculate daily IPI, relative indexes for T_{av} , RH_{av} and R are calculated independently and combined by multiplying the T index by either the R index or the RH index. IPI only needs to be calculated when days have $T_{min} > 7$ C, T_{av} 9-25 C, total rainfall > 0.2 mm or $RH_{av} > 80\%$. Favorable weather conditions for *Phytophthora infestans* produce a positive IPI. Functions for index calculations are:

$$T_{Index} = (-2.19247 + 0.259906 T - 0.000139 T^3 - 6.095832 \cdot 10^{-6} \times T^4) Fc.$$

$$Fc = \text{correction factor} = 0.35 + 0.05 \times T_{min}$$

$$T = \text{daily average temperature (C)}$$

$$RH_{Index} = -34.9972725 + 0.751 RH - 0.003909 RH^2 \text{ (see note below)}$$

$$RH = \text{daily average relative humidity.}$$

$$R_{index} = 0.006667 + 0.194405 R + 0.0002239 R^2.$$

$$R = \text{rainfall (mm) accumulated during the last 48 hours.}$$

Note: The RH_{Index} as shown in Bugiani, et al. (1993) erroneously shows the constant (-34.9972725) as a positive number. After reviewing the other papers, it has been changed to the negative constant shown here.

The cumulative daily IPI over a defined period is used by the model to evaluate late blight risk.

A network of unsprayed plots of 100 m² are planted in strategic locations with a susceptible tomato cultivar (Heinz) and used to record and follow late blight epidemics. These plots are scouted weekly and used to report late blight attacks in advance.

Spore traps installed at the ground level are used to monitor sporangia of *Phytophthora infestans* in the air every two hours throughout the tomato growing season. Rapid increase of the amount of sporangia collected has been positively correlated with the occurrence of the first symptoms during the next few weeks.

Cumulative IPI plus disease data from unsprayed plots and populations of sporangia are considered together to recommend control strategies for specific areas.

Action Threshold: IPI values below 15 indicate no risk of disease according to historical data from Emilia-Romagna, Italy. An IPI above 15 indicates high risk of disease and is used to determine when fungicides should start being sprayed, but the model does not give any recommendations about further treatments. This threshold is still being evaluated where it was developed. Model developers recommend adjustment of threshold for specific locations. Data from spore traps and disease in unsprayed plots should also be considered.

Model Validation: Cavanni, P., Ponti, I. and Marinelli, M. 1990. A forecasting model for late blight of tomato. *Informatore Fitopatologico* 40:17-25. (In Italian).

Ponti, I., Cavanni, P., Mazzini, F. and Libe, A. 1985. Verification of forecasting criteria for late blight of tomato. *Informatore Fitopatologico* 35:13-21. (In Italian).

Model Implementation: This model has been implemented since 1990 by a Regional Plant Protection Service of Emilia-Romagna. Tomato growers have achieved a 50% reduction in fungicide sprays by following this model's recommendations.

Bugiani, R., Cavanni, P. and Ponti, I. 1993. An advisory service for the occurrence of *Phytophthora infestans* on tomato in Emilia-Romagna region. *Bulletin OEPP/EPPO* 23: 607-613.

Current Limitations of Model: The model provides a risk index of initial disease but gives no recommendations about subsequent spray timing.

To provide correct recommendations, the model, which is driven by weather data, should be combined with data from unsprayed tomato plots and sporangia traps.

Future Directions of Model: The action threshold is considered provisional. Specific action thresholds could be developed for specific locations after a period of model evaluation.

Onion Downy Mildew

MetWin II, μ METOS and μ Link are showing the results of DownCast a *Peronospora destructor* model designed by Hildebrand and Sutton.

DownCast predicts Sporulation positively when the following conditions obtain:

1. Mean hourly temperatures smaller than 24°C from 8:00 to 20:00 on the previous day
2. Relative humidity higher than 95% from 2:00 to 6:00 with no interruption longer than 30 minutes
3. Temperature at night 4°C to 24°C
4. No rain after 1:00

DownCast outputs a qualitative result for the following day, which is represented as a bar in MetWin II and μ Link and as an asterisk in the μ METOS display.

***Botrytis Squamosa* on Onions**

The sporulation *Botrytis Squamosa* is forecasted by a model designed by Vincelli and Lorbeer. This model forecasts the sporulation possibilities of the fungus at the following day. If the output value is higher than a certain level the model gives the result that a sporulation will occur. This value is influenced by climate and plant stage. Therefore it is changing for different plant stages. MetWinII, μ METOS and μ LINK are outputting qualitative results for fields older than 10 days, 20 days, 30 days and 40 days after planting. The weather influence on this qualitative factor is shown in a progress graph between 0 and 100 in MetWin II and μ Link. This progress is represented by a value between 0 and 100 in the μ METOS display.

The sporulation possibility is assessed by the number of days with moderate temperature, and the number of hours with high relative humidity during the days before. 2 days with temperature higher than 27°C for more than 12 hours are providing the fungus from sporulation. 14 hours of relative humidity lower than 70% at the day before providing sporulation. As longer a period of wet nights and as higher the temperature during this period as higher the forecasted sporulation will be.