

# A computerized warning system for fire blight control

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**Summary** — A warning system for the control of fire blight in pear and apple has been described. It is based upon the determination at the local level of a climatic potential (CP), and an inoculum potential (IP). These potentials are combined in order to estimate an overall level of risk. A recommended control measure is associated with this risk. Among the inputs required, climatic data, forecast of certain climatic parameters and precise information about the disease situation in the plot and its surroundings are essential. The warning system is computerized, and has been devised for use with an IBM-PC personal microcomputer; its availability to growers and plant protection services is presently under study.

**bacterial disease / warning system / *Malus* = apple / *Pyrus communis* = pear / *Erwinia amylovora***

**Résumé** — Un système d'avertissement informatisé pour la lutte contre le feu bactérien. La lutte contre le feu bactérien est rendue particulièrement difficile par l'irrégularité des infections provoquées par la bactérie responsable (*E amylovora*). Dans une semblable situation, un système d'avertissement constitue une aide déterminante. Le système proposé prend en compte au niveau de la parcelle 2 des facteurs de la variabilité de la maladie : le climat et le niveau d'inoculum. Un potentiel climatique (PC) (tableaux I, II, III) est déterminé en fonction du climat auquel le verger a été soumis depuis le 1<sup>er</sup> février de l'année en cours et à partir des prévisions du temps à 2 j (températures, pluie). Un potentiel d'inoculum (PI) (tableaux IV, V, VI) est établi notamment d'après les connaissances du développement local de la maladie dans le passé, et de son activité observée actuelle. Il est tenu compte également de la phénologie de l'hôte; 3 périodes sont considérées : préfloraison (stades D à E<sub>2</sub>), floraison (E<sub>2</sub> à G), postfloraison (après le stade G). En postfloraison, l'état physiologique de l'hôte doit être précisé (croissance, présence de floraison d'été). La combinaison de ces potentiels, spécifique à chacune de ces périodes permet la définition d'un conseil de lutte, gradué en 3 niveaux (ne pas intervenir, réaliser une visite du verger, traiter chimiquement) (tableaux VI, VII, VIII). Ce système, d'utilisation simple, est prévu pour fonctionner sur un micro-ordinateur compatible PC. Il demande, pour donner satisfaction, que plusieurs conditions soient réunies : en particulier une étude climatique préalable de la zone est nécessaire, de même que la disponibilité de prévisions météorologiques adaptées. De plus, une connaissance locale des conditions dans lesquelles se développe le feu bactérien (sensibilité variétale, vecteurs, plantes hôtes secondaires, fertilisation) reste indispensable. Les 3 produits utilisables dans la lutte en France (fluméquine, cuivre, phosétyl-aluminium) peuvent être associés à l'utilisation de ce système d'avertissement, dont la diffusion auprès des arboriculteurs et des services de la protection des végétaux est en cours d'étude.

**bactériose / lutte raisonnée / *Malus* = pomme / *Pyrus communis* = poire / *Erwinia amylovora***

## INTRODUCTION

One of the obstacles to a satisfactory control of bacterial diseases is the lack of regularity of infections over the years. This is particularly true in the case of fire blight caused by *Erwinia amylovora*, a classical bacterial disease of pear, apple

and ornamental (Pomoideae) in Europe and North America. A warning system aimed at providing in a help in the adjustment of control measures is probably one of the answers to this specific difficulty.

It has been shown by several authors in the United States and in Europe (Mills, 1955; Powell,

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1965; Thomson *et al*, 1975; Billing, 1976, 1978a) that climatic factors are of key importance in determining the severity of fire blight for a given year. Several approaches have been proposed or suggested which attempt to describe the activity of the disease from the assessment of several factors (field, plant, and climatic factors) (Thomson *et al*, 1977; Billing, 1978b, 1988; Beer *et al*, 1984; Billing and Paulin, 1990; Steiner, 1990a, b).

Approaches proposed by Billing (Billing, 1979, 1980a, b), though relatively simple to use are probably the most comprehensive. In several countries Billing's original system (BOS) (Billing, 1984) has been repeatedly shown to give satisfactory results, either used on a day-to-day basis, or applied to past weather and disease data (Billing, 1980a; Meijneke and van Teylingen, 1981; Paulin *et al*, 1983; Bazzi *et al*, 1984; Sobiczewski, 1984; Bonn, 1987).

We describe here a warning system for fire blight, based on the combination of a climatic potential (CP) with an inoculum potential (IP). CP is determined by data derived from BOS, associated with forecasts of meteorological parameters; IP is estimated mainly from knowledge of the local past history of the disease. A report on a preliminary version of this system has already been published (Jacquart-Romon *et al*, 1987).

## DESCRIPTION OF THE WARNING SYSTEM

### Inputs

#### Climatic data

The compiled climatic data needed are those required for BOS, and run from February 1st of the current year: daily minimal and maximal temperatures, and daily rainfall.

#### Weather forecasts

The following data regarding weather are required for the actual day of interrogation and for the day after: minimal and maximal daily temperatures; daily occurrence of rain; daily amount of rainfall, with respect to the 2.5 mm threshold: rainfall of  $\geq 2.5$  mm, or rainfall of  $< 2.5$  mm; daily occurrence of a storm. In this context, a storm in-

cludes any climatic event likely to provoke some damage on aerial parts of fruit trees; strong winds and/or heavy rain and hail are therefore included within the storm category.

### Plant growth and development

The growing period of pear or apple trees has been divided into 3 stages. On the date of interrogation, the input is as follows: the indication of the stage of development: phenological stages D, E<sub>2</sub> or G (Fleckinger, 1945), growth status of the shoots (*ie* presence of succulent shoots), occurrence of secondary blossoms in the orchard (at least 25% of the trees show at least 1 blossom).

### Activity of the disease

The available inoculum is assumed to be related to the status and proximity of symptoms of fire blight. The inputs are related to the nature of the symptoms, in time: old or recent lesions, and in space: symptoms detected in the area, in the orchard, or in the precise plot to be protected against fire blight. The term "orchard" refers to a group of plots belonging to the same farm, close to each other, and managed in a similar way by the same team of workers. A "plot" is a cluster of trees usually belonging to the same cultivar, planted in the same field.

An "active lesion" is a symptom in which the bacteria are multiplying rapidly. Because this activity is climate-dependent, some climatic inputs are taken into account during certain periods (see below).

### Outputs

The warning system is intended for use between the 1st of February and the end of July. Before phenological stage D the output is limited to a climatic analysis of the potential for fire blight activity. After stage D, additional information is provided on adequate control measures; 3 types of advice, adjusted for the local situation, are issued by the software: i), no action necessary in the plot for the control of fire blight; ii), visit the plot in order to detect (and destroy) expected recent symptoms; iii), apply a suitable spray to prevent new infections (after pruning out of parts showing symptoms).

## EVALUATION OF FIRE BLIGHT RISKS

### *Factors involved in evaluation of the risks*

The level of severity of fire blight is the result of the combination of at least 3 types of factors, linked to plant, climate and inoculum.

#### **Plant factors**

The risks of infection differ according to the tree's stage of development. In our warning system, they are considered to appear at stage D. Up to stage E<sub>2</sub> of flower bud development they remain low, because routes of infection are not easily accessible. During the blossom period (from stage E<sub>2</sub> to stage G) they are very high, the natural openings of flowers facilitating introduction of the bacteria into the plant. Afterwards the risks are limited to 2 periods associated with the growth status of the plant: shoot growth, when tips of growing shoots can be infected by the bacteria, and secondary blossom, when open flowers are present on the trees.

The variability of the risks associated with the plant is taken into account in the system that we used as a basis for the calculation of the potential activity of the disease (BOS): different climatic factors are taken into account according to the stage of growth of the plant. This is why the period of susceptibility to fire blight is divided into 3 stages: different data are considered or data are considered differently, during these periods, which are as follows: i), pre-bloom: from stage D to stage E<sub>2</sub>; ii), blossom period: from stage E<sub>2</sub> to stage G; iii), post-bloom: after stage G.

**Table II.** Determination of the climatic potential (CP) during bloom.

<i>Forecast</i>	<i>CP</i>
No end of I period	
– None of the following events is forecast	1
– PD ≥ 9, or storm, or other infection conditions	2
– 2 PD ≥ 9	3
– Storm and: PD ≥ 9 or other infection conditions, or rain ≥ 2.5 mm	3
End of I period (J – 1, J, J + 1)	
– No other event foreseen	Rank of I period + 2
– One infection condition foreseen	Rank of I period + 3

#### **Climatic factors**

The past climatic data as well as forecasts collected and processed according to BOS are used for a climatic analysis. According to this analysis and to the climatic forecast, a climatic potential (CP) is assessed for the next 2 days. This potential ranges between 1 (low climatic risk) and 4 (high climatic risk). Its determination differs according to the period described above.

During the prebloom period, temperatures play a key role in the increase of the bacterial population in overwintering lesions: water supply is not considered as a limiting factor for bacterial multiplication at this stage. Infections are linked to damaging climatic events (storm). Therefore the aim of control measures is to limit the level of available inoculum. Potential doublings of the bacterial population (PD) and end of incubation periods (I) calculated according to BOS are the basis for the scale of climatic potential (CP) shown in table I.

During the blossom period the determination of infection conditions is of the greatest importance: both rain and temperature play an important role. According to Billing (1980a), a day

**Table I.** Determination of the climatic potential (CP) during prebloom.

<i>Forecast</i>	<i>CP</i>
None of the following events	1
PD ≥ 9	2
End of I period, or 2 PD ≥ 9	3
End of I period and 2 PD ≥ 9 or storm	4

when one of the following conditions is met is likely to be an infection day:  $PD \geq 9$ ;  $PD \geq 3.5$  with rain, rain  $\geq 2.5$  mm. PD is the potential doubling of *Erwinia amylovora* in its host according to daily minimal and maximal temperature, when water is not a limiting factor. A storm may favour infection as well, whatever the temperature or amount of rainfall if there is tissue damage. The success of infection depends on the availability of bacteria: this is evaluated by the completion of incubation periods (BOS). The rank of incubation periods (I) during bloom has been pointed out as an indicator for the build up of the inoculum (Jacquart-Romon *et al*, 1984). The scale of CP during bloom is given in table II.

During the postbloom period, the climatic conditions allowing infection to taken place differ according to the route of infection (shoot or secondary flower). The scale of climatic potential is given in table III.

### Inoculum factors

Records of the disease and of its past history in the area in the orchard and/or in the plot are used as a basis for the estimation of an inoculum potential (IP) (tables IV, V). For the postbloom period, in the case where no symptoms are observed, an IP is derived from the assessment of the climatic potential activity of the disease during the blossom period and the 15 d preceding interrogation. This is: i) to stress the key role of the activity of the disease during the blossom period on further development of fire blight in the orchard; ii) to take into account the fact that certain weather conditions during bloom can pro-

mote disease activity which could remain undetected for some time, and yet be a source of bacteria for infections.

### Decision

Potentials for climatic and inoculum risks are combined differently during the 3 periods to provide an overall risk. The level or risks determines the type of control measure to be taken. The different combinations of CP with IP for prebloom, bloom and postbloom periods are given in tables VI, VII, VIII, respectively.

Sprays against fire blight must be applied before infection. They are recommended when both infection conditions are forecast, and a high level of inoculum is expected from the observations of symptoms and/or from the climatic conditions.

Visits to the orchards are aimed at cutting out symptoms: they are recommended when symptom expression can be expected from analyses of the risks, so that the grower checks the fire blight situation in his orchard at the proper period, thus avoiding useless and time-consuming surveys.

During bloom, special care is taken if pollinating insects are present: protective sprays are therefore recommended when both symptoms and insect activity are observed in the orchard.

During postbloom, in the case of infection risks due to the presence of secondary blossoms, it may be preferable to remove the flowers if this is economically feasible, instead of using a recommended spray.

**Table III.** Determination of the climatic potential (CP) during postbloom.

<i>Plant status</i>	<i>Forecast</i>	<i>CP</i>
No shoot growth	– No storm	1
	– Storm	2
Shoot growth	– No rain $\geq 2.5$ mm, or storm	1
	– Rain $\geq 2.5$ mm	2
	– Storm	3
Secondary blossom	– No rain, storm, or $PD \geq 9$	1
	– Rain $\geq 2.5$ mm, or $PD \geq 9$	2
	– Storm	3

**Table IV.** Determination of the inoculum potential (IP) during prebloom and blossom period.

<i>Observations</i>	<i>IP</i>
No fire blight in the area	1
Fire blight introduced in the area and:	
– Not detected in the orchard the previous year	2
– Detected in the orchard the previous year	3
Fire blight detected this year in the orchard and:	
– Disease activity observed before bloom	4
– Disease activity observed in the close vicinity of the plot during bloom	4
– Disease activity observed in the plot during bloom	4

**Table V.** Determination of the inoculum potential (IP) during postbloom.

<i>Observations or calculation</i>	<i>IP</i>
Young active symptoms not observed during the 15 d before the day of questioning	
– Rank reached during bloom < 2	
and – Rank reached during the last 15 d ≥ 2	2
– Rank reached during bloom < 2	
and – Rank reached during the last 15 d ≥ 2	2
– Rank reached during bloom ≥ 2	
and – Rank reached during the last 15 d < 2	2
– Rank reached during bloom ≥ 2	
and – Rank reached during the last 15 d > 2	3
Young active symptoms observed in the plot during the last 15 d and removed	3
Young active symptoms observed in the close vicinity of the plot during the last 15 d and not removed	3
Young active symptoms observed in the plot during the last 15 d and not removed	4

**Table VI.** Table of decision during prebloom period.

<i>IP</i>	<i>CP</i>			
	<i>1</i>	<i>2</i>	<i>3</i>	<i>4</i>
1	N	N	N	N
2	N	N	N	V
3	N	V	V	S
4	N	V	S	S

**Table VII.** Table of decision during blossom period.

<i>IP</i>	<i>CP</i>					
	<i>1</i>	<i>2</i>	<i>3</i>	<i>4</i>	<i>5</i>	<i>6</i>
1	N	N	N	N	V	V
2	N	N	N	N	V	S
3	N	N	V	V	S	S
4	N	N*	V*	S	S	S
5	N*	S	S	S	S	S

Tables VI, VII, VIII. N: no action required for fire blight control. V: visit the plot to detect (and remove) symptoms. S: spray with a suitable chemical, *ie* prebloom: coper compound 100 g Cu hl<sup>-1</sup>; blossom period and postbloom: streptomycin 10 g hl<sup>-1</sup>, flumequine 30 g hl<sup>-1</sup>, phosetyl Al 200 g hl<sup>-1</sup>. Orchard: group of plots included in the same farm near to one another, and managed in similar ways by the same team of workers. Plot: group of trees usually belonging to the same cultivar, grown in the same field. NB: when a single plot includes a pollinating cultivar, or is planted with a mixture of varieties, if symptoms are detected on anyone of these varieties during blossom period, note 5 for IP. Blossom period: presence of insects: very active pollinating insects noticed in the plot. Postbloom: spraying required because a storm is foreseen: to be applied only if the storm passes over the plot; storm: any climatic event which is able to cause damage to trees (true storm, hail, violent wind, heavy rain); when spraying is required on secondary blossom: it has to be kept in mind that it is preferable to remove the flowers (open and appearing). If this is not feasible, a chemical spray should be applied.

\*: spray if very active pollinating insects and symptoms are present in the orchard.

## DISCUSSION

### *Validity of the warnings*

This system has been used under different climatic situations in France over several years, either with past recorded climatic data, or with actual data and weather forecasts. Results of these experiments have been published else-

**Table VIII.** Table of decision during postbloom period.

IP	CP		
	1	2	3
1	N	N	N
2	N	N/V*	V
3	N	V	S**
4	N	S**	S**

\* Only if secondary blossoms are present. \*\* And/or remove secondary blossoms.

where (Jacquart-Romon and Paulin, 1990). They lead to progressive improvements of the system which are included in this version. Other experiments are still in progress (Lecomte, personal communication). The general trends are the following:

- the warnings supplied by the system are in accordance with observed activity of the disease;
- when the results of different spray schedules have been compared (Jacquart-Romon and Paulin, 1990; Lecomte, personal communication), the advantage has constantly been in favour of the schedule based on computer warnings (fewer sprays for equal efficacy) as compared with a calendar-based schedule (3 sprays to protect the entire blossom period),
- on several occasions, the warning to visit an orchard has been found to be especially useful in allowing early detection of unpredictable symptoms (through an examination of rain and temperature data). These early detections are of the utmost interest when followed by a trimming-out of symptoms, because they may stop the inoculum supply for further infections during the rest of the year.

### Conditions of use

The computer program has been devised for use on a compatible IBM PC personal microcomputer, a type of machine which is readily available and found in most places. Nevertheless, several conditions must be met before the proposed warning system can be used satisfactorily.

### Relation between climate and fire blight

Several traits of our system are partly based on BOS. It should be underlined that a preliminary study was first carried out at several sites in France over a period of several years (past and actual climatic data), in order to obtain information on the validity of this system under our climatic conditions (Boué, 1984; Callu, 1984; Lecomte *et al*, 1984; Paulin *et al*, 1987). Such a study is probably essential before any attempt is made to use the warning system; although BOS has provided useful indications on fire blight development in several countries outside France (Poland, Canada, Belgium, The Netherlands) the same rules and parameter values may not be applied without adaptation in certain climates.

### Agreement between weather forecasts and actual climatic data

Forecasts required to operate the system are included in a standard meteorological forecast except for the amount of rain. A special difficulty may arise with this rain-fall assessment, which is more difficult to predict than the simple occurrence of rain. This is the reason why the software includes an automatic test for alternative values regarding quantity of rain, and provides different warnings resulting from these values.

The available forecasts must be relevant for the site where the orchard to be protected is placed. This can be assessed quite easily through comparison between data collected in the orchard and information provided by the weather stations over several years. Climatic studies at the microclimate scale allow local meteorologists to provide forecasts relevant for the orchard.

The forecast of a general situation does not allow prevision of the occurrence of a stormy episode at any given site. To tackle this difficulty, it is recommended that the spray be applied only after the storm. Deckers and Porreye (1984) showed that such a "post-storm" spraying remained useful if applied immediately after the storm. The level of spraying efficacy was severely reduced if > 24 h had elapsed between storm and application of the spray.

### Collection of data

The climatic data needed to operate the system are easy to collect, the ideal place to obtain them

being the orchard. These data are required daily, and therefore a suitable device such as an automatic weather station connected to the telephone network could be very useful. Frequent visits to orchard are requested for determination of the inoculum potential.

### ***Inoculum level***

Although there is no direct experimental evidence for the relationship between visible symptoms and availability of bacteria, the description of the symptoms in the orchard remains the only reliable procedure to determine the inoculum level. Consequently it is essential to detect and examine the symptoms, and to collect as much data as possible on the local history of the disease. In addition, a survey of the orchard first in winter and then just before the beginning of the growth period is an absolute requirement.

Nevertheless, it may sometimes be difficult to decide whether or not lesions support bacterial multiplication. Further improvement may be expected in the precise definition of the localization of the symptoms (area, farm, plot) as well as in the knowledge of "infectivity" of the lesion (old overwintering lesion vs young extending symptoms). Besides, the determination of IP does not take into account the amount of visible symptoms. This is probably too simple an assessment of the inoculum level, but we have not been able to practically improve this input.

### ***Possibility and efficacy of interventions***

Finally, it should be pointed out that there is no need to operate a warning system if visits or sprays cannot be undertaken; the latter must be performed as soon as possible (within 24 h) after warnings have been issued.

Chemicals for spraying against fire blight are now available (Garrett, 1990): streptomycin, where registered (USA, Canada, New Zealand, The Netherlands), flumequine (Firestop) in France and Belgium, copper compounds everywhere, when the risk of phytotoxicity can be controlled. Other compounds are likely to be available soon (*ie* Phosetyl-Al, Aliette). It is essential to be prepared to apply at least one of them when beginning to use the warning system, even though only the warning for visits and symptom-detection already provides very useful assistance in fire blight control.

The period during which the chemical remains effective after it has been sprayed on the plant is variable; it depends on the characteristics of the chemical, the phenological stage of the plant, and the climate. It is generally accepted that a cumulative 25 mm rainfall is enough to wash out a chemical from the plant surface. This threshold is taken into account in the warning system. Furthermore, tree growth results in the exposure of new, unprotected sites on the surface of leaves and other organs. The following intervals between sprays are therefore recommended: 3 d during the period of fast opening of flowers, 5 d during the steady blossom period, and 15 d during postbloom.

### **CONCLUSION**

The value of such a computerized system lies in the balance between inputs and the outputs. Inputs must be relevant, precise, but at the same time easy to collect at the proper scale (*ie* the orchard level), reliable and inexpensive to obtain. Outputs must provide an obvious advantage when compared with any other method of decision.

In the warning system presented here, it seems that these requirements are satisfactorily met, although it is likely that improvements can be obtained through further experimentation and observations on the disease. Besides, the system as it stands does not use the available data on shoot and blossom susceptibility of pear and apple trees (Thibault and Le Lezec, 1990). The integration of this data in the warning system would undoubtedly improve its accuracy.

The Billing approach (BOS) used as a basis for our warning system has been revised recently (Billing, 1990) as BRS; the underlying rationale is similar, but several changes have been made, mainly concerning calculation of PD values from temperatures, which affect the length of incubation periods, and the climatic conditions required for infections (temperature- and/or rain-based). BRS has not been tested as a basis for our warning system. Nevertheless, experiments are presently being carried out in several places in France comparing BRS and BOS. The threshold values for temperature and rain taken into account in the warning system are checked by the agreement of BOS with the epidemiological data on fire blight in France: the incorporation in the warning system of concepts based on BRS would imply the evaluation of new ade-

quate thresholds. This could be relevant in conditions where BOS does not give satisfactory results.

The information required by the software is picked up on the local scale: this applies for climatic as well as for inoculum potentials. "Local" can be defined as the plot or the orchard, or a homogeneous group of orchards of the same variety in an area where climatic features are fairly constant. Similarly, climatic forecasts will not be relevant for very wide areas: these facts imply that the proposed system is not devised for large areas, such as a production zone. On the contrary, it must be used at the orchard level. Under these conditions, it will provide simple but efficient help in the control of fire blight, thus avoiding mistakes and giving clear guidelines on what is likely to be the best strategy of control to follow in a given orchard. Its commercial availability to growers and plant protection services is presently under study.

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