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Effectiveness of preventing flowering of hawthorn in protecting pear orchards from fire blight infection

HENK J. SCHOUTEN[1]

Department of Phytopathology, Wageningen Agricultural University, P.O. Box 8025, 6700 EE Wageningen, the Netherlands

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Abstract

Since 1984 when a new Ministerial Regulation on fire blight came into force, there have been 20 'protected regions' in the Netherlands, where nurseries of rosaceous plants, and pear and apple orchards are extra protected against fire blight. This policy is also necessary to meet the requirements of the European Community (EC) on fire blight. Two of the measures in the protected regions are the prohibition of flowering of the native hawthorn (*Crataegus monogyna* and *C. laevigata*), and destruction of blighted plants. In the unprotected regions, flowering is allowed, and destruction of blighted plants is limited to a zone of 500 metres around orchards.

For three years, the effectiveness of preventing flowering of hawthorn in protecting pear orchards against fire blight infection was studied in the field. Five test areas of about 3 km × 3 km were chosen with hawthorns and pear orchards. Two of these areas were in protected regions and three in unprotected regions. The more than 50 000 hawthorns in the areas were grouped into 1125 sites of hawthorn. The 126 orchards larger than 0.2 ha contained about 180 000 trees.

During the three years light to moderate epidemics of fire blight were observed in the regions. Fire blight occurred in 2.3 % of the non-flowering sites and 19.8 % of the flowering (or fruiting) sites at least once in 1987, 1988 or 1989. The prohibition of flowering for hawthorn in protected areas was rather well implemented, so that in protected areas a smaller proportion of sites of hawthorns had fire blight (4.1 %) than in unprotected areas (14 %). Moreover, there were fewer sites per square kilometre in the protected areas (13) than in the unprotected areas (26).

In protected areas, 53 % and in unprotected areas 59 % of the pear orchards had fire blight during 1987, 1988 or 1989. The difference was not significant. The first reason for the ineffectiveness of the preventing of flowering prevention in hawthorn to control fire blight in pear orchards was the inadequate hygiene of the pear orchards in both types of region. If it be assumed that a new focus is most probably initiated by the nearest existing focus, the second reason was that fire blight hardly spread from hawthorn to pear in the period of this study. Spread of fire blight within pear orchards and between pear orchards occurred frequently.

Additional keywords: Crataegus monogyna, Crataegus laevigata, Erwinia amylovora, Pyrus communis, epidemiology, bacterial disease, spread.

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[1] Present address: Centre for Plant Breeding and Reproduction Research (CPRO-DLO), P.O. Box 16, 6700 AA Wageningen, the Netherlands

Introduction

Fire blight, caused by the bacterium *Erwinia amylovora* (Burrill) Winslow et al., is a serious disease of pomaceous plants. It is destructive to pear trees and less so to apple trees, hawthorn and several other members of the Rosaceae. In the Netherlands, fire blight was not found until August 1966, when a focus was discovered on an island in the south-west of the country. Immediately, strict measures of eradication were undertaken, which implied total destruction of the orchards with fire blight, and removal and burning of all hawthorns on the island. More than 21 km of hawthorn hedges and about 175 000 solitary bushes of hawthorn were destroyed. In 1971, fire blight was discovered again in the south-west on another island, but also in the north-west of the Netherlands. Another eradication programme was started, but the disease spread gradually all over the Netherlands despite this effort (Meijneke, 1967; 1984).

A policy of containment was initiated in 1984 with a Ministerial Regulation (Netherlands, 1984): 20 'protected regions' were created (Fig. 1). The objective was to meet the EC requirements on fire blight for products from nurseries and to protect nurseries, and pear and apple orchards in these regions against fire blight as far as possible. Only inside the protected regions is it permitted to produce nursery plants susceptible to fire blight. In order to 'ensure' that these protected regions are free from fire blight, the Plant Protection Service there inspects all susceptible plants several times a year, including those in nurseries and private gardens, except pear and apple trees in orchards. Diseased plants have to be destroyed as soon as possible. The responsibility for inspection and removal of fire blight from orchards is mainly left to the fruit growers. The native hawthorn (*Crataegus monogyna* and *C. laevigata*) is not allowed to flower in the protected regions, as its blossom is the main point of entry

Fig. 1. 'Protected regions' in the Netherlands (Netherlands, 1984).

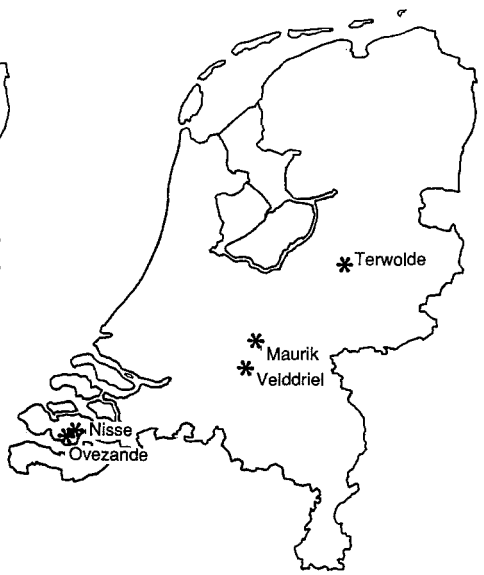

Fig. 2. The five areas.

for the bacterium (Wilson et al., 1987). Prevention of flowering of hawthorn in the vicinity of orchards and nurseries therefore lowers the risk that these hawthorns become a source of infection for orchards and nurseries (Billing, 1981). Flowering can be prevented by cutting down the bushes of hawthorn at least once in three years or by clipping the hedges of hawthorn annually. Outside the protected regions, regular inspection for fire blight is restricted to zones of 500 metres around orchards. Hawthorn is allowed to flower in these unprotected regions, but diseased plant parts have to be destroyed in the zones.

For consideration of conservation of nature and landscape, the containment policy is strongly criticized. In particular, the prohibition of flowering for hawthorns aroused much opposition. Unfortunately, little quantitative information is available on, for instance, the effect of flowering hawthorns on incidence of fire blight in orchards and nurseries. This particular aspect of the official policy, though reasonable on first sight, lacks scientific justification and support. To gain insight into the effect of the prevention of flowering of hawthorns, the incidence of fire blight in hawthorns and pear orchards in protected regions was compared with the incidence in unprotected regions, thus providing policymakers with quantitative information. Several members of the Rosaceae are susceptible to fire blight, but the disease is established primarily in hawthorns and pear trees in the Netherlands. Other host species were taken into account only if they had fire blight. The growing of potential host plants in nurseries is only allowed in protected regions, so that a comparison to potential host plants in nurseries in unprotected regions is impossible. In this study attention was focused on hawthorns and pear orchards.

Materials and methods

Five areas with hawthorns and pear orchards were chosen (Fig. 2). Two of these areas were situated in large protected regions and the other three in unprotected regions. Each area was about 3 km × 3 km. The 50 940 hawthorns in these five areas were grouped into 1125 'sites of hawthorns' as defined in Table 1. The state of each site of hawthorns was characterized by number of hawthorns per site, presence of blossom or berries, presence of fire blight, and co-ordinates on Ordnance Survey maps, scale 1 : 10 000. All sites were inspected three times a year in 1987, 1988 and 1989, and changes of state were noted.

Similarly, all pear orchards were drawn in on the 1 : 10 000 maps. In addition, 1 : 2500 maps were made of these orchards, using magnifications of the Ordnance Survey maps. In the winter of 1987-1988, the owners of all 135 pear orchards were visited to investigate the orchards' histories concerning fire blight. Of these 135 pear orchards, 126 were larger than 0.2 ha. The pear growers were visited again in 1988 and 1989, three times a year in order to note their observations with respect to number and place of diseased trees. The foci were marked on the orchard maps and their co- ordinates determined. Each focus was characterized: new or old (Table 1), number of diseased trees per focus, subdivided into trees that showed symptoms for the first time, and trees that had also been diseased before. The orchards contained about 190 000 trees. The average size of the orchards in the protected areas was 1.1 ha and in the unprotected areas 1.2 ha.

The data thus gathered were organized in databases, manipulated by means of PASCAL programmes, and analyzed statistically.

Table 1. Definitions.

Site of hawthorns:	A solitary hawthorn (*Crataegus monogyna* or *C. laevigata*) or a group of hawthorns, with a maximum distance of 50 metres between the hawthorns (e.g. a hedge or a mixed planting). If a site is longer than 100 metre, it is split into two or more sites.
Focus in pear orchard:	One pear tree or a group of adjacent pear trees with fire blight. Diseased trees belong to different foci when these trees are separated by five or more healthy trees within a row or by one or more healthy rows.
Focus in hawthorn:	Any site of hawthorns with fire blight.
New focus:	A focus, discovered for the first time.
Old focus:	A previously discovered and still existing focus. Though an attempt was made to remove the focus at first discovery, the attempt failed according to later inspection.

Results

Fire blight in hawthorn. According to the Ministerial Regulation on fire blight, hawthorns were not allowed to flower in protected regions. The Regulation was rather well implemented (Table 2), since in the protected areas 19 % of the sites of hawthorns flowered abundantly and 9 % had some flowers, whereas in the unprotected areas a much higher proportion of the sites of hawthorns flowered (61% and 10 %, respectively; Table 2).

Flowering had a clear effect on incidence: using the data of all five areas, protected and unprotected, 19 % of the flowering sites were blighted and out of the non-flowering sites only 2 % showed fire blight in 1987, 1988 or 1989. In each test area, the effect of flowering was obvious (Table 3). The frequencies of Table 3 were subjected to categorical data analysis (Grizzle et al., 1969) using flowering and test area as input variables and fire blight as response variable. This multivariate statistical analysis

Table 2. Frequencies and proportions of sites of hawthorns in protected and in unprotected areas, August 1989. Flowering scale: − = no flowers or berries; ± = few flowers or berries; + = a moderate or large number of flowers or berries per site.

Area	Flowering				Proportion flowering (+) in %
	−	±	+	Σ	
unprotected	261	85	534	880	61
protected	176	23	46	245	19
Σ	437	108	580	1125	

Table 3. Frequencies of blighted and flowering sites of hawthorns in the five test areas. For flowering scale and time, see Table 2. When sites showed no fire blight, the flowering (or fruit bearing) refers to August 1989. When sites were blighted, flowering refers to the inspection time when fire blight was detected. Flowering had a positive, highly significant effect ($P < 0.001$) on fire blight in sites of hawthorns.

Protected areas:	Fire blight	Flowering			Unprotected areas:	Fire blight	Flowering		
		− or ±	+	Σ			− or ±	+	Σ
Maurik	−	104	12	116	Terwolde	−	261	220	481
	+	0	2	2		+	5	23	28
	Σ	104	14	118		Σ	266	243	509
Overzande	−	87	32	119	Velddriel	−	39	79	118
	+	3	5	8		+	0	8	8
	Σ	90	37	127		Σ	39	87	126
					Nisse	−	26	136	162
						+	3	80	83
						Σ	29	216	245

revealed that flowering had a highly significant effect ($P < 0.000\ 1$) on fire blight in sites of hawthorns.

Table 4 shows that the sites of hawthorns in the protected areas had fire blight less frequently than those in the unprotected areas. Probably, this is caused by the prohibition of flowering for hawthorn in the protected areas, as non-flowering hawthorns are less susceptible than than flowering sites. On average, there were 13 sites of hawthorns per square kilometre in the protected areas and 26 in the unprotected areas. In the unprotected areas there were ($0.14 \times 26 / (0.041 \times 13) =$) 7 times more diseased sites per square kilometre than in the protected areas. Together about 525 hawthorn bushes out of the 51 000 involved in this research were blighted during the years of research, which is 1.0 %. Up to this point, the Ministerial Regulation was successful. However, its objective is not primarily the hygiene of hawthorns, but the protection of orchards and nurseries, and of export markets for nursery products.

Table 4. Frequencies and proportions of sites of hawthorns with (+) and without (−) fire blight in 1987, 1988 or 1989.

Area	Fire blight			Proportion with fire blight (%)
	−	+	Σ	
unprotected	761	119	880	13.5
protected	235	10	245	4.1
Σ	996	129	1125	

Table 5. Frequencies and proportions of pear orchards (> 0.2 ha) with or without fire blight in 1987, 1988 or 1989. No significant effect ($P = 0.29$) according Fisher's exact test (right tail).

Area	Fire blight			Proportion with fire blight (%)
	−	+	Σ	
unprotected	29	42	71	59
protected	26	29	55	53
Σ	55	71	126	

Table 6. Frequencies of pear orchards (> 0.2 ha) with and without fire blight in 1987, 1988 or 1989 per area.

Test area	Fire blight		
	−	+	Σ
Maurik (protected)	14	12	26
Ovezande (protected)	1	12	13
Terwolde (unprotected)	12	17	29
Velddriel (unprotected)	9	3	12
Nisse (unprotected)	19	27	46
total	55	71	126

Fire blight in pear orchards. About 1190 (0.6 %) out of the 190 000 pear trees concerned were diseased during the research period. Pear orchards in protected areas had about as often fire blight as pear orchards in unprotected areas (Tables 5 and 6). There was no significant difference. Prohibition of flowering of hawthorn had no demonstrable effect on the occurrence of fire blight in pear orchards, in contrast to its effect on infection of hawthorn. The absence of a significant difference for pear orchards is curious and requires an explanation. Therefore foci in and around the pear orchards were analyzed.

Old foci in pear orchards. In Figure 3 plots the number of old and new foci against time. There should hardly be any old focus, as pear growers try to eliminate foci by careful pruning. Figure 3 shows, however, that there were far more old foci than new foci. Obviously, removal was not adequate. Poor hygiene explains why the proportion of pear orchards with fire blight in protected areas did not differ significantly from that in unprotected areas. Sanitation of the environment of pear orchards, though necessary to keep the inoculum pressure low, cannot protect the orchards against new infections if inadequately removed foci are present within the orchards.

Figure 3 shows that the frequency of old foci declines, but there were probably more old foci in 1989 than depicted. The graph is based on the assumption that treatment of a focus by a grower implies removal of that focus, except if fire blight be detected

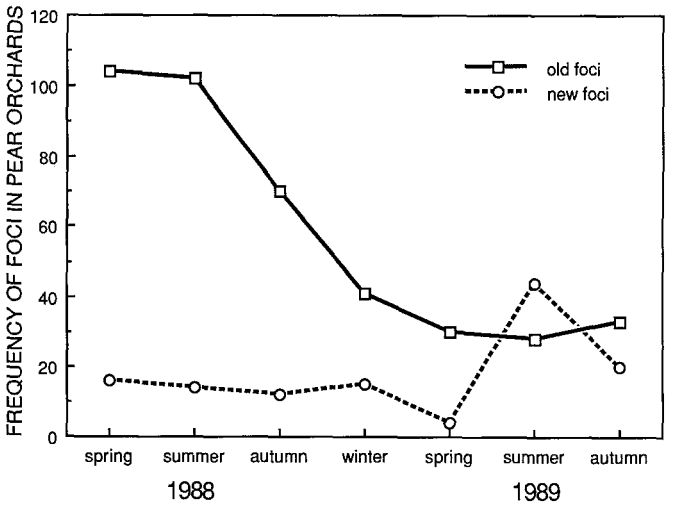

Fig. 3. Total frequencies of fire blight foci ('old' and 'new') in pear orchards over 1988 and 1989 in the areas. The terms 'old foci' and 'new foci' are defined in Table 1.

again in that group of trees later. Because the observations were discontinued after 1989, the number of foci showing fire blight again (= old foci) in 1990 is not known. So the decline in the frequency of old foci is overestimated.

In Figure 4, the old foci are divided into two groups: old untreated foci (old foci that had not been treated during that season, although the bacterium was still present)

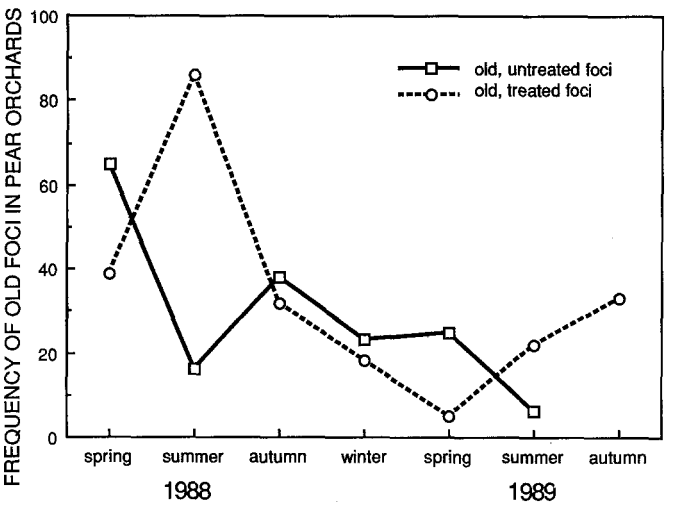

Fig. 4. Frequencies of old foci in pear orchards, 1988 and 1989. See Table 1 for definition of the term 'old focus'. Old untreated foci are old foci that had not been treated in that season; the bacterium was still present, as could be seen later. Old treated foci are old foci that had been treated by the pear grower. Note that the sum of these two frequencies equals the frequency of old foci in Fig. 2.

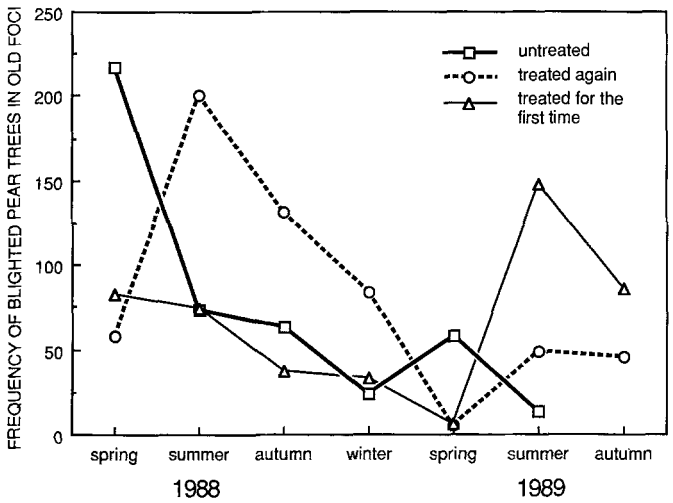

Fig. 5. Frequencies of blighted pear trees in old foci.

and old treated foci (old foci that had been treated again by the grower). First the old untreated foci will be discussed.

Some pear growers did not treat old fire blight foci for months. They usually overlooked the fire blight, but sometimes did not have time to inspect and treat again. Figure 5 shows the number of trees involved. Especially in spring, 1988 and 1989, there were many untreated diseased trees. During these springs the untreated trees might have served as sources of inoculum for flower infection in pear and hawthorn.

Many foci that had already been treated had to be treated again for either of two reasons. The first reason was that tree hygiene by pruning and sawing was not good enough, so that the bacterium remained in these trees. This group of trees is called 'treated again'. It was a large group, especially in 1988. Affected shoots and branches were removed and burned, but the bacterium had migrated deep into the trees or had infected other shoots of the same tree, and consequently the trees remained diseased. The second reason for the large number of old treated foci was that old foci expanded by infecting healthy adjoining trees. In Figure 5, these infected adjoining trees are called 'treated for the first time'. Expansion of old foci was relatively important in 1989.

New foci. New foci appeared regularly in pear orchards (Fig. 3). To gain insight in the infection sources of these new foci, a 'nearest focus' assumption was formulated, in accordance with the theory of dispersal gradients (Gregory, 1968; Glasscock, 1971). The probability that a new focus originates from the nearest focus on record is supposed to be higher than the probability that it originates from a focus at a larger distance. The nearest focus was assumed to be the source of infection for the new focus. Figure 6 indicates that the major part of the new foci were nearest to foci in the same orchard, thus presumably originated from that. A much smaller part originated from foci of a neighbouring orchard, and probably only one focus in pear could be ascribed to contamination by a diseased site of hawthorns. Apparently, pear trees

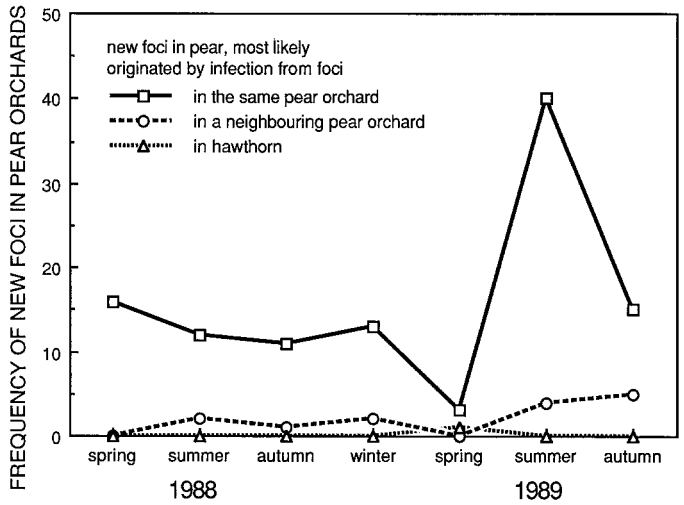

Fig. 6. Frequencies of new foci in pear orchards, 1988 and 1989. It was assumed that the nearest focus led to formation of the new focus.

were rarely contaminated by hawthorn, neither in the protected areas nor in the unprotected areas.

According to the 'nearest focus' assumption, most foci in hawthorn (Fig. 7) originated from contamination by other foci in hawthorn, but several foci in hawthorn originated from foci in pear. So fire blight spread mainly within either host genus and less between the host genera. The primary reason is probably the spatial separation of the genera: blighted pear trees were usually surrounded by healthy pear trees, and

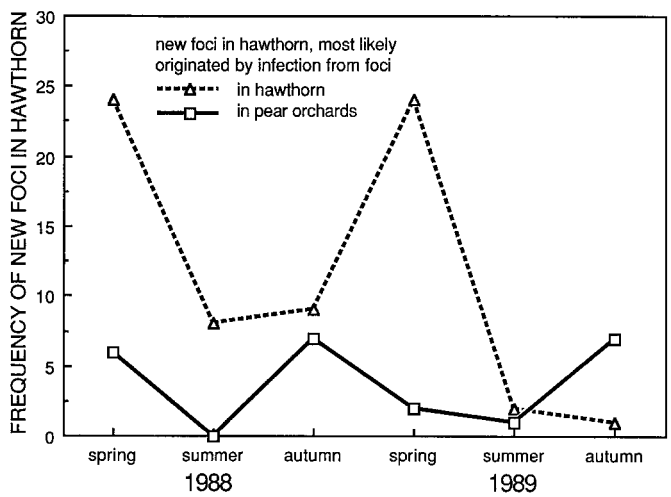

Fig. 7. Frequencies of new foci in hawthorn, 1988 and 1989. It was assumed that the nearest focus led to formation of the new focus.

blighted sites of hawthorns often by healthy sites, so that new foci may be expected first within the genus. Additional reasons might be (1) the difference in phenological development of pear and hawthorn, by which the main flowering periods only slightly overlap, (2) the flower constancy of several insects visiting flowers, such as bees (De Wael, 1988), (3) possibly some differential virulence of *E. amylovora* to different host species (Norelli et al., 1984). (4) Pear orchards are often surrounded by windbreaks, consisting of plants which are not susceptible to fire blight. Windbreaks consisting of non-host plants may hamper spread of fire blight to and from orchards.

Discussion

Statistics. In a strict formal sense, one basic assumption underlying the statistical analyses has not been met. Sites of hawthorns and pear orchards within an area are not statistically independent, because of spread of fire blight among the orchards and the sites. Moreover, soil profile and watertable varied according to area, so that 'protection' was not the only differentiating factor. Because of these inevitable inadequacies, the statistics used must be seen as descriptive rather than explanatory. Explanations were given by biological reasoning at different explanatory levels (area - pear orchard - focus - tree).

Containment. The objective of this study was to test the effectiveness of flowering prohibition for hawthorn, as formulated in the Ministerial Regulation on fire blight 1984, thus providing the policy makers with quantitative information. That information is needed for a regulation on fire blight that balances damage to nature and landscape against damage to crops. In this study, special attention was given to the strongly criticized prohibition of flowering of hawthorn in protected regions.

For hawthorn, the prohibition of flowering appeared to be effective. The proportion of diseased sites of hawthorn in protected areas was much smaller than in unprotected areas. The objective of the flowering prohibition, however, is not primarily protection of hawthorns, but of orchards and nurseries. Unfortunately, the flowering prohibition for hawthorn did not appear to be effective in the control of fire blight in pear orchards. Pear orchards in protected areas had about the same incidence of fire blight as pear orchards in unprotected areas. The primary reason is the unsatisfactory hygiene of the pear orchards. The bacterium had established itself in pear orchards in a focal pattern, and removal of the bacterium from the foci by means of pruning and sawing away affected tree parts seemed to be difficult. The secondary reason for the ineffectiveness of the flowering prohibition to control fire blight in pear is that hardly any focus in pear originated from diseased hawthorns. A small proportion of the foci in pear probably originated from foci in neighbouring pear orchards, but most foci were initiated by foci in the same pear orchard. Flowering prevention of hawthorn was not found to be effective in control of fire blight in pear orchards during the period of study.

The results presented here contrast with growers' experiences during the early years of the epidemic of fire blight in the Netherlands and the official reports of that time that all pointed to hawthorn as active infection sources of fire blight in pear, as found elsewhere by Glasscock (1971) and Bech-Andersen (1973). The cause of the discrepancy is not known. Possibly the following items contributed:

(1) When fire blight is not endemic in pear, diseased hawthorns may play a major role in introduction of fire blight into pear. Glasscock (1971) and Baumm (1985) provided circumstantial evidence that diseased hawthorns, which bordered on healthy pear and apple orchards, served as sources of inoculum when there were severe hail storms during shoot growth of pear or apple. When fire blight is endemic in pear, diseased hawthorns are relatively less threatening to pear, as the disease spreads more frequently within pear orchards and between pear orchards than from hawthorns to pear orchards.
(2) Since 1971, officers of the Plant Protection Service have intensively inspected the hawthorns in all infected areas and since the early 1980s only in the protected regions and in the 500-metre zones around orchards in the unprotected regions, so that fire blight in hawthorns has been detected in good time and removed. Probably, this early removal of fire blight in hawthorn usually prevented spread of the disease to pear orchards.
(3) The climatic conditions during the three years of study were not particularly conducive for fire blight. They were years of moderate fire blight. The present study does not permit generalization to years particularly favourable to spread of fire blight.

The study does point to the need for better hygiene and eradication of fire blight in pear orchards.

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Note added in press

Partly through this research, the Ministerial Regulation on fire blight was changed on 13 March 1991 (Netherlands, 1991). The flowering prohibition for hawthorn has been repealed all over the Netherlands. The protected regions are reduced to the areas where host plants of fire blight are grown in nurseries. The intensive fruit-growing areas without nurseries are excluded from the protected regions. The 500-metre zones around orchards in unprotected regions are not inspected anymore by officers of the Plant Protection Service, but inspection is left to the fruit growers themselves. Within protected regions, hawthorns and susceptible ornamentals, as well as orchards, are inspected for fire blight by the Plant Protection Service for protection of nurseries.

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