Model for Yield Loss Determination of Bacterial Blight of Field Beans Utilizing Aerial Infrared Photography Combined With Field Plot Studies

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ABSTRACT

A model for the assessment of yield losses from bacterial blight (caused by *Xanthomonas phaseoli*) of field beans is described. The model uses a yield-loss factor of 38 determined from the average yield loss in 2-year field-plot trials, combined with results on the incidence of bacterial blight in commercial bean fields as determined by aerial infrared photographic surveys conducted in 1968, 1970, and 1972 in Ontario. Losses for the field-bean crop in Ontario varied from a high of over 1,251,913 kg (46,000 bu) in 1970, to a low of 217,724 kg (8,000 bu) in 1972.

Phytopathology 65:942-948

Additional key words: *Phaseolus vulgaris*, disease-loss assessment, remote sensing, epidemiology.

In recent years, interest in determining losses in crops has received more attention following the 1967 FAO-sponsored International Symposium in Rome that recommended the development of more precise methodology for disease-loss assessment. Subsequently, the FAO manual on the evaluation and prevention of losses by insects, pathogens, and weeds was published in 1971 (1). Most methods in the plant pathology section of the manual outline typical methodology involving field experiments to characterize the relationship between disease and yield loss. A specific disease is assessed at regular intervals during the growing season using growth-stage and disease-assessment keys, and yields of healthy and diseased plots are taken. After the development of a suitable method, field surveys are made using the appropriate assessment method. Yield losses are determined by extrapolating from the relationship between disease intensity and yield loss established in the field-plot experiments. Methodology of this type has its limitations, particularly in the survey aspect, because of the manpower required to cover vast areas of cropped land.

Because of climatic conditions, most Canadian field bean production is confined to southwestern Ontario. This area, together with areas of Michigan, is ideal for infection by the bacterial blight organism, *Xanthomonas phaseoli* (E. F. Sm.) Dows. The pathogen is seed-borne, which early in the season provides infected seedlings from which secondary infection in the field is rapid under favorable environmental conditions.

For a number of years (4, 5, 10), field surveys have been carried out on the incidence of bacterial blight in southwestern Ontario. From observations and experience, we know that the disease has a consistent pattern of development through the growing season. Initial foci appear the last week of July. In the period 10 to 15 August disease symptoms in the foci are optimum for recognition. Yield losses occur within discrete foci that are present by approximately 16 August. Secondary spread of the pathogen after this time does not play any appreciable role in yield losses.

The approach to control is the elimination of seed-borne infection. The Pedigreed Bean Seed Program, now operating in Canada, was initiated following severe epiphytotics of bacterial blight in 1961 and 1962 (4, 5). Breeder seed is now imported from Idaho and California to initiate the program. This seed is usually disease-free or contains only low levels of infection because of unfavorable conditions for blight in those areas and rigid field inspection. Seed from this parent stock is distributed to selected growers in Ontario for seed production in .8094-hectare (2-acre) plots and the crop is monitored for bacterial blight by plant pathologists at least twice during the growing season. Plots with any diseased plants are discarded for pedigreed-seed production. This practice has helped control the disease in subsequent generations, but small amounts of infection in the Breeder seed in certain years have produced undetected field infection. Seed from Breeder-seed plots produces Certified bean seed in three generations.

In this present work, a model is described for determining yield losses from bacterial blight of field beans (*Phaseolus vulgaris* L.). The model utilizes information from field-plot experiments at Ottawa to determine a yield-loss factor, integrated with data from aerial surveys, using infrared-sensitive film, conducted in 1968, 1970, and 1972 to determine the incidence of bacterial blight in commercial bean fields in representative areas of southwestern Ontario. The methodology for the determination of blight in commercial fields was described earlier (7, 8). Aerial surveys were conducted in southwestern Ontario in two intensive bean-growing areas near Chatham in Kent County, and near Hensall in Huron County, Ontario. The surveys provided a precise measure of the incidence of bacterial blight in bean fields in these areas.

Methodology to determine the percentage of blight on a field-to-field basis is necessary to ascertain the effectiveness of the Pedigreed Bean Seed Program in reducing blight in an area, but yield losses cannot be determined from this information. Yield losses in a specified area are necessary to ascertain the economic effect of the program.

MATERIALS AND METHODS.—*Field tests.*—A randomized block consisting of 12 plots of field beans, cultivar Sanilac, each measuring 9 × 12 m (30 × 40 ft) was established in the field in 1971 and 1972. Two treatments were used. One consisted of six uninoculated control plots, and the other six were inoculated with a mixture of isolates of *Xanthomonas phaseoli* that causes common blight, and *Xanthomonas phaseoli* f.sp. *fuscans* that causes fuscous blight. Inoculation was accomplished approximately 3 weeks after planting by spraying plants in the 3- to 4-leaf stage with an aqueous suspension of the two organisms with a knap-sack sprayer. Each row received 154 ml of aqueous suspension.

Each plot contained 13 rows of beans sown 5 cm (2 inches) apart in each row giving, with maximum emergence, 204 plants per row and 2,652 plants per plot.

TABLE 1. Yields of Sanilac bean plots infected with bacterial blight

| Year and treatment | Yield (kg per plot) for replicates | | | | | | | |
	I	II	III	IV	V	VI	MEAN	F value
1971								
Healthy	20.8	21.05	20.55	22.91	18.6	22.36	21.05	
Infected	13.83	11.02	13.61	12.47	15.56	13.15	13.28	47.76*[b]
1972								
Healthy	19.05	24.72	10.09	27.44	15.08	22.68[a]	19.84	
Infected	8.07	14.42	14.88	13.97	8.98	11.61	11.99	8.39*

[a] A plot yield of 22.68 kg is equivalent to a yield of 3190.95 kg per ha.

[b] * Indicates significant difference between means for healthy and infected plots, $P = 0.05$.
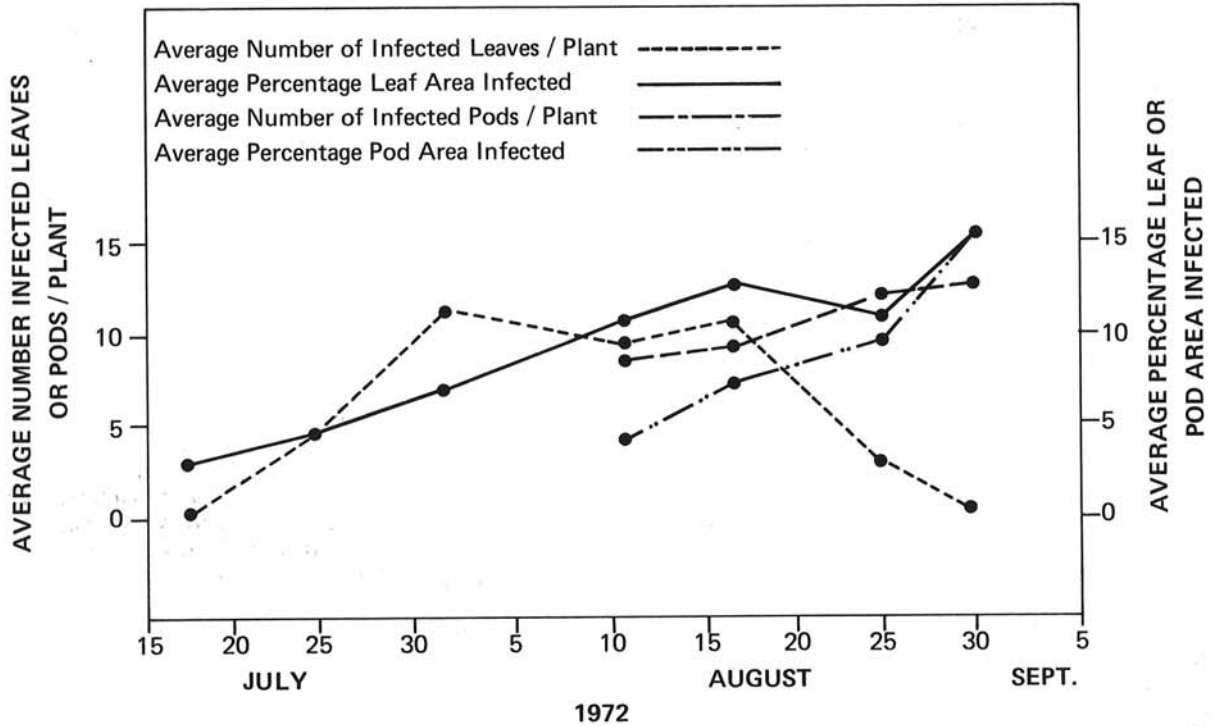
Fig. 1. Progress of bacterial blight in field plots as recorded by weekly disease assessments through the growing season.

TABLE 2. Yield losses in field beans due to bacterial blight in Ontario, Canada

Year	Percent area infected	Bean area (ha)	Average yield (kg/ha)	Total yield loss (kg)
1968	4.60	36,423	1,197	762,100
1970	6.60	32,780	1,526	1,255,723
1972	0.70	53,825	1,600	217,452

Rows were spaced 76 cm (30 in) apart and plots were isolated from one another by a 6-m (20-ft) border of disked soil.

Beginning with the first evidence of disease, plants were assessed at weekly intervals throughout the growing season. Twenty plants were selected and tagged in each plot, so that the same plants were assessed throughout the season. The number of infected leaves and pods were determined as well as the percentage of leaf and pod area infected at each assessment.

At harvest, the outside two-rows on each side were discarded as well as three feet of row at each end of the plots. Plots were harvested by means of a small threshing mill, and yields and 1,000-seed weights were determined.

Aerial photography.—Methods and procedures for the aerial photography used in this study were described previously (2, 3, 7, 8, 9).

RESULTS AND DISCUSSION.—*Field plot yield-loss factor.*—Yield losses in 1971 and 1972 were very consistent showing a 7.77 kg (17.13 lb) per plot loss in 1971 (36.9% yield loss) and a 7.86 kg (17.32 lb) per plot loss in 1972 (39.6% yield loss) or a 38% yield loss for the two-year trial (Table 1). The yield-loss factor of 38%

represents the percentage loss in a totally infected area. A lower F-value was obtained in 1972 because one infected plot was flooded part of the season from abnormal rainfall.

The epiphytology of the disease was followed in 1971 and 1972. In 1972, seven disease assessments were made between 17 July and 30 August (Fig. 1). The average number of infected leaves detected in the first assessment was less than one per plant. The number of infected leaves reached a maximum by the third assessment on 2 August (over 11 infected leaves per plant) and continued at that level until 17 August, the fifth assessment. Between the fifth and sixth assessments, defoliation commenced prematurely because of infection, and the more heavily infected leaves fell; thus, an average of only three infected leaves per plant was recorded. In the final assessment (30 August), an average of only one infected leaf per plant was present. Because of early defoliation, infected plots were harvested 5 September 1971 and 10 September 1972. Control plots were harvested on 11 September 1971 and 23 September 1972.

The effect of the disease on the bean plant is shown by photographs taken from the ground at four dates between
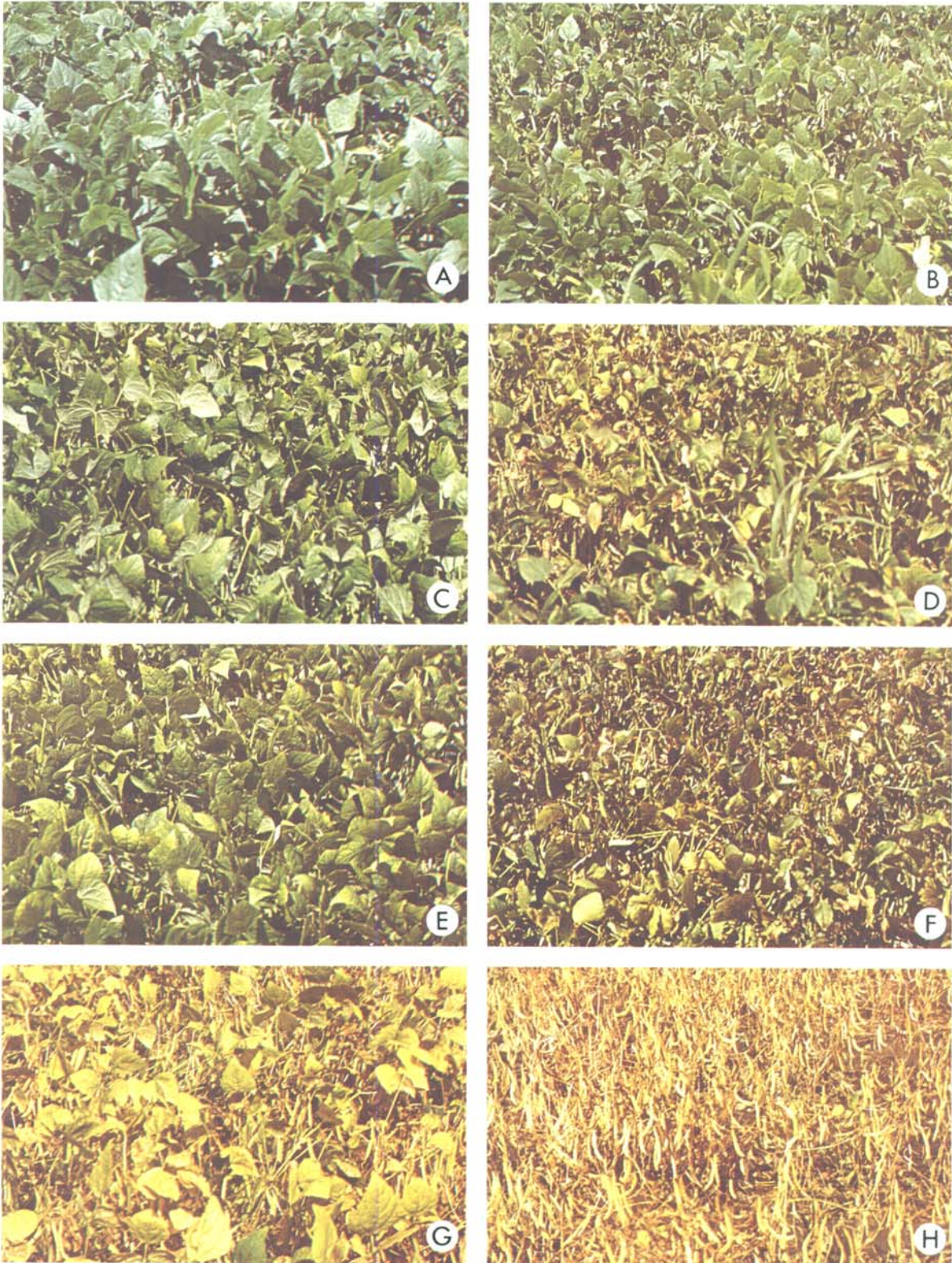
Figure 2 – **(A to H)**. Ground views of experimental plots of field beans, *Phaseolus vulgaris* L. showing comparisons between control plots (left), and plots infected with bacterial blight caused by *Xanthomonas phaseoli* (right). **(A – B)** 27 July, **(C – D)** 11 August, **(E – F)** 15 August, and **(G – H)** 29 August 1972.

27 July and 29 August 1972 (Fig. 2). These show that the disease was present on a few leaves 27 July (B), and was very apparent 11 August (D). The disease had advanced considerably by 15 August (F). By 29 August the infected plot (H) was almost defoliated, whereas the healthy plot (G) was not.

The average percentage leaf area infected increased from slightly over 3% in the first assessment to over 15% in the final assessment (Fig. 1). Despite early defoliation of heavily infected leaves, the remaining leaves contained large areas of infection. The 15% figure is low, therefore, considering that the more heavily infected leaves had fallen and could not be included in the assessments.

Pod infection was first noted 11 August with an average of five pods per infected plant. Slightly over 15 pods per plant were infected on the last assessment date, 30 August. During the same period of time the percentage pod area infected increased from 9 to 13 (Fig. 1).

From the results of the disease assessments, it seems that losses in yields were caused primarily by heavy leaf infection that caused early defoliation early in the growing season.

In 1971, there was a 17.8% weight difference between the 1,000-seed weights from healthy and infected plots (healthy 167.65 gm, vs. infected 138.84 gm). In 1972, a 10.64% weight difference occurred (healthy 154.36 gm, vs. infected 137.94 gm). In both years, the infected seed weights were almost identical, but the 1,000-seed weight was almost 8% higher in the 1971 check plots. It is apparent that the disease not only causes a reduction in the number of seed, but also a marked reduction in seed size.

The greatest differential in optical transmission densities between films of healthy and diseased plots occurred 15-20 August (2). This was determined from microdensitometer scans of transparencies obtained from exposing infrared-sensitive film aerially over the Ottawa test plots. This was supported by ground assessments that showed a maximum number of leaves per plant infected as well as maximum leaf area infected on 17 August. After this time, senescence rapidly occurred and was followed by defoliation (Fig. 1).

Relationship of yield loss data from field plots to bacterial blight in bean fields as determined by aerial photography.—The incidence of bacterial blight was estimated as 4.6%, 6.6% and 0.70% (6) in 1968, 1970, and 1972, respectively (Table 2). Field incidence was determined from aerial photographs that were interpreted for blight followed by area-scanning procedures. In this manner the amount of blight was determined on an area [hectare (ha)] basis (3, 9). Extensive ground-truth studies were conducted which verified the photographic interpretations. The photography was conducted 11-15 August in the three years.

Part of the aerial photographic survey was conducted in the area surrounding Hensall, Ontario [48.3 km (30 miles) north of London, Ontario] where, in 1972, 65 bean fields consisting of 614.74 ha (1,519 acres) were photographed and interpreted. This area is representative of the bean-producing areas of Ontario and bacterial blight incidence on a year-to-year basis here is similar to that in other sections of southwestern Ontario where 98% of Canadian field beans are grown.

Yield losses for Ontario can be determined using the yield-loss factor of 38% obtained from the field-plot data, multiplied by the predicted yield in kilograms (the yield that would normally be obtained from this area if no blight were present) of seed in the blighted areas of each field. The predicted yield can be obtained by determining the total infected area (ha) for Ontario, multiplied by the average yield per hectare for the province.

Using data from the Hensall area as representative of Ontario field bean production, yield losses (YL) can be determined for 1968, 1970, and 1972 for Ontario using the yield loss factor 38% and the results of the aerial infrared-photographic surveys in the following equation:

$$YL = AI \times ABP \times AvY \times YLF$$

where AI = area infected in a specific year, expressed as a percentage; ABP = area (ha) in bean production in a specific year; AvY = average yield in kg/ha in a specific year; and YLF = yield loss factor, expressed as a percentage. [Acreage in bean production (ABP) and average yields (AvY) were obtained from Statistics Canada, Field Reporting Series, Catalogue 22-002, Nov. 1968 - Nov. 1972].

An example would be for 1968:

$$YL = AI \times ABP \times AvY \times YLF$$
for 1968 the values were, respectively:

$$YL = \left(\frac{4.6}{100}\right) \times 36{,}423 \times 1{,}197 \times \left(\frac{38}{100}\right) = 762{,}100 \text{ kg.}$$

Field bean yields have increased in Ontario from 1,197 kg/ha (17.8 bu/acre) in 1968 to 1,600 kg/ha (23.8 bu/acre) in 1972 (Table 2), and acreage cultivated varied from a low of 32,780 ha (81,000 acres) in 1970 to a high of 53,825 ha (133,000 acres) in 1972. Yield losses due to bacterial blight were highest in 1970, 1,255,723 kg (46,140 bu) and using a conservation value of $0.367 (Canadian) per kilogram for field beans, losses in 1970 approached a half-million dollars, but decreased sharply to $80,000 (Canadian) in 1972.

The yield losses, as expressed in dollars, are conservative as the $0.367 (Canadian) per kilogram figure is low based on current prices of field beans especially for pedigreed seed production which comprises 10% of the total acreage. Although the yield-loss factor was developed in Ottawa, a distance of over 480 km (300 miles) from the Hensall area, climatic conditions are almost identical. For the month of August, the six-year mean-daily, maximum, and minimum temperature varied less than ±1 C. Precipitation averaged 1.27 cm (0.5 inches) greater at Ottawa and R.H. was 4% greater at Hensall than Ottawa.

This approach to determining severity levels of blight, yield losses, and the acreage involved, by utilizing aerial photography with subsequent image analysis, is beyond the scope of conventional disease surveys. It was shown (2) that, although photographic density differences between healthy and stressed plants did not parallel the progress of infection in the Ottawa test plots, they did indicate a 5-day period in the growing season when maximum optical density differences could be expected. In the Hensall area, this period happened to coincide with

a time when ground haze may degrade the photographic results. In the three years represented in this study, excellent photographs were obtained. There is a distinct possibility, however, that in any given year this might not be possible during the five-day period that we have designated as having the optimum photographic potential; i.e., that time during the growing season when the crop provides its greatest canopy and chlorophyll content, and the disease symptoms provide maximum contrast to healthy areas in the field.

The model reported herein has practical application in monitoring a disease-control program. Hopefully, it will be a prototype for other disease-management systems.

It appears that the Pedigreed Bean Seed Program is effective with less than one percent of the crop infected in 1972. Further surveys will determine if this trend continues, and the value of the Pedigreed Bean Seed Program.

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