POTATO EARLY BLIGHT EPIDEMICS AND COMPARISON OF METHODS TO DETERMINE ITS INITIAL SYMPTOMS IN A POTATO FIELD

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ABSTRACT

*The influence of an early blight epidemic on potato tuber yield was evaluated in three field experiments during 2000 to 2002 crop seasons under Viçosa, Minas Gerais state growing conditions. Through a disease severity gradient method, used four different dosages of fungicide chloratalonil were obtained four epidemic levels with severity range of D1 (maximum), plot without fungicide treatment, to D4 (minimum), plot with fully dosage fungicide commercial recommended, were obtained, which allowed for comparison of the epidemic effect on plant growth and tuber yield, and indicated the time for initiating of the first early blight (**Alternaria solani**) lesions on potato foliage The disease was predicted by using the methods based either degree days (DD) with base temperature of 7°C and physiological days (PD) having minimum, optimum and maximum temperature of 7, 21 and 30°C, respectively, accumulated during the period between planting and the first symptom appearance. Plots with higher disease levels along the gradient had significantly loss tuber yield in all trials. The highest yield reduction of 49,6; 52,7 and 58,2% occurred in D1, plots without fungicide treatment, during the years 2000, 2001 and 2002, respectively. The epidemic prediction through accumulated DD or PD did not indicate the appropriate time to initiate the epidemic control. However, the PD method that predicted the first symptoms between 240 and 333 accumulated PDs was found to be more adequate. The data revealed that green leaf area and tuber yield reduction caused by the early blight is dependent upon the disease severity. Compared to the others, the PD method appears to be most suitable to determine when the disease will establish, and thus can be recommended to initiate the disease management at 250 accumulated PDs, under disease-favorable climatic conditions.*

Key words: Degree day, physiologic day, epidemiology, forecasting.

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RESUMO

EPIDEMIA DE PINTA-PRETA DA BATATA E COMPARAÇÃO DE MÉTODOS PARA DETERMINAR O INÍCIO DOS SINTOMAS DA DOENÇA NA CULTURA DE BATATA EM CAMPO

*Três experimentos foram montados entre os anos de 2000 e 2002, em condições de campo, de Viçosa, estado de Minas Gerais, com a finalidade de avaliar o efeito de epidemias de pinta-preta (**Alternaria solani**) na produção de batata (**Solanum tuberosum**) e determinar o inicio de sintomas da pinta preta na cultura de batata. Usando o método de gradiente de severidade da doença, foram obtidas em cada experimento quatro epidemias da doença, com diferentes severidades, desde D1 até D4, em ordem decrescente, o que permitiu comparar o efeito das epidemias no crescimento da planta e na produção de tubérculos, bem como determinar o momento de se iniciar o controle da doença. Tendo como base o tempo desde o plantio até o aparecimento dos primeiros sintomas da epidemia, foram avaliados os seguintes métodos para previsão da doença: dias acumulados (DA); graus-dia acumulados (GD), tendo como temperatura-base 7ºC; e dias fisiológicos acumulados (DF), tendo como temperatura mínima 7°C, máxima de 30°C e ótima de 21ºC. O estabelecimento do gradiente da doença mostrou diferenças significativas na produção em cada experimento. As maiores reduções na produção dos tubérculos ocorreram na parcela não tratada com fungicida D1, com 49,6% em 2000; 52,7% em 2001; e 58,2% em 2002. A previsão da epidemia utilizando-se os métodos DA e GD não indicou o momento certo para iniciar o controle da epidemia. O método DF foi o mais adequado, estabelecendo-se o primeiro sintoma entre 240 e 333 DF. Conclui-se que a pinta-preta, dependendo da severidade, afeta a área foliar e a produção de tubérculos. Dos métodos para determinar o estabelecimento da pinta-preta, o DF apresentou o maior potencial, recomendando-se seu uso para iniciar o manejo da doença aos 250 DF após o plantio, sempre e quando as condições ambientais favorecem o estabelecimento do patógeno.*

Palabras chaves: grau dia, dia fisiologico, epidemiologia, previsão.

Early blight caused by (*Alternaria solani* Sorauer) is the major disease of potato crops (*Solanum tuberosum* L.) grown in warm to hot climates, above 20°C in Israel epidemic intensity and frequency decrease gradually with distance from the desert to the Mediterranean climatic zone (Rotem, 1981). This disease can reduce tuber yield by more than 20% (Johnson and Teng, 1990; Shtienberg *et al*., 1996), but losses of about 50% have been reported from Brazil (Campo *et al*. 2001).

Early blight is one the major causes of defoliation of potatoes in the North-eastern United States the increased disease severity is favored by alternating wet and dry conditions in the plant canopy (Franc, Harrison, and Lahman, 1988); however, inoculum buildup is slow because young and middle-aged plants have low susceptibility to infection being disease influenced by the crop age. Young plants are relatively resistant, but the susceptibility increases gradually and continuously from the initiation of tuber formation so that mature plants are most susceptible to the disease (Campo *et al.,* 2001; Johnson and Teng, 1990; Rotem, 1981; Shtienberg *et al*., 1996).

The disease initially appears on the older leaves causing premature senescence and leaf area reduction (Johnson and Teng, 1990; Pelletier and Fry, 1989). The pathogen is highly favored by tempera-tures between 20 and 28°C and relative humidity over 90% (Nunes 1983, Pelletier and Fry 1989). The epidemic severity increases by alternating dry and moist periods, common in hot climates especially, when the crop is sprinkle irrigated (Franc, Harrison, and Lahman, 1988; Rotem, 1981 and Shtienberg *et al.*, 1996).

Most approaches to control of foliar early blight have depended on the use of protectant fungicides during the warm-hot weather, but the criteria used to determine proper time of initial fungicide have varied widely caused unnecessary sprays (Christ and Maczuga, 1989; Christ, 1991; Easton and Nagle, 1985; Reis *et al.*, 1999).

Wisconsin growers normally begin spraying potatoes for early blight when plants are 20 to 25 cm high and continue to be applied until maturity, as suggested by Pscheidt and Stevenson 1986. However, this practice requires a high number of sprays, reaching 12 in a crop season, which increase the production cost and contaminates tubers and the environment. Since the temperature and plant phenological stage are two of the most important components for epidemic development, the prediction models considering these two components are being successfully used to reduce fungicide sprays from 12 to 8 with efficient disease control (Gent and Schwartz, 2003).

Research in Colorado and San Luis has shown a model to determine fungicide spray initiation, based on plant growth determined by degree days (DD) accumulated since planting and first symptom appearance has been developed, required for appearance of first lesions is 361 in San Luis and 625 DD in northeastern Colorado; the model based upon accumulated degree days above 7,2°C (Franc, Harrison and Lahman, 1988). The weekly fungicidal sprays were initiated after the appearance of the first symptoms and continued until crop maturity.

Pscheidt and Stevenson (1986), used a model based on accumulated physiological days (PD_s), which were calculated considering the minimum, optimum and maximum temperatures of 7, 21, and 30°C, respectively, and initiating the sprays when the crop has accumulated 300 PDs after emergence. The use the physiological days was effectively initiate weekly protectant sprays fungicides prove useful for the control the early blight for Wisconsin potatoes growers.

In Brazil, depending upon the region, potatoes are grown throughout the year, therefore it is difficult to establish an adequate disease management plan for each region using the conventional methods or models. The objective of this study was to evaluate the effect of early-blight epidemic on tuber yield and compare the methods that allow predicting initial early blight disease in a potato field.

MATERIALS AND METHODS

The study was done in the fields of Universidade Federal de Viçosa, in Minas Gerais State, during three consecutive years (September 2000, August 2001 and March 2002). Four epidemic levels of the early blight were obtained in each trial from natural inoculum from a potato crop planted at one end of the treatments.

The experimental area of 400 m^2 was planted using seed potatoes (cultivar Bintje) of 40 to 60 g, with spacing of 25 cm between plants and 80 cm between rows, except in the year 2000 when the row space was 75 cm. The experimental area was divided into four consecutive 6 x 5 m plots of 10 rows each of six-meter length. All plots were treated according to the cultural practices of commercial fields as fertilization, insecticide sprays, weed control and supplemental irrigation. Minimum, maximum and mean daily temperatures were obtained from a nearby meteorological station.

To obtain different disease levels, was established a disease gradients method. The change in disease intensity along a straight line from one point to another is termed a disease gradient (Zadoks and Schein, 1979). The method used for obtain different severity between plots was the use of fungicides at different rates and times (Sah and MacKenzie, 1987).

Four epidemic levels of the early blight were obtained in each trial from natural inoculum from a potato crop planted at one end of the treatments three weeks earlier on the north side of the main experimental area (Nutter, 1989). The plants in this plot were naturally infected with the pathogen from field and served as the main inoculum source for the experimental plots. The experimental plots denominated as D1, D2, D3 and D4, served as inoculum source for the next plot thus creating a disease severity gradient of D1 (maximum severity) to D4 (lowest severity). As the first symptoms appeared, plots were sprayed, at 14 day intervals, with chlorothalonil, in the following fractions of the commercial product recommendation (1,7 kg · ha^{-1} a.i. 750 g · kg^{-1}): D1= without fungicide (0x), D2 = 25% the dosage of fungicide D3 = 75% the dosage of fungicide, and D4= fully dosage recommend.

A diagrammatic scale (Granovsky and Peterson, 1954) was used to evaluate the disease severity, at 10 to 15 day intervals. Five plants were selected 30 days after planting in 2000 and 20 in the 2001 and 2002 years. The selection criteria were the homogeneity in height, canopy and number of stems, in order to decrease the variation owing to differences in growth (Causton, 1991). The disease severity was quantified in the upper, middle and lower part of each plant and the means data were used to plot the epidemic curve, estimate apparent infection rate (r) by linear regression, the maximum severity (Ymax.), and the area under the disease progress curve (AUDPC).

The disease progress curves were transformed to determine the most appropriate model (exponential, monomolecular, logistic, Gompertz), using the statistical program SAS. The model adjustment to explain the "r" (apparent infection rate) was selected on the basis of the curve shape, coefficient of determination "R^2", standard deviation of apparent infection rate (r), the mean square of error and the standard residue. The disease progress curve was adjusted to the logistic model using the following equation (Campbell and Madden, 1990):

$$Wt = \frac{W\max}{1 + Ae^{-Bt}}$$

where *Wt* = total severity, *Wmax* = asymptotic estimate of maximum severity, A = antilog of intercept obtained in the linear regression multiplied by (-1), B = apparent infection rate and t = time in days.

The disease effect on the green leaf area (GLA) was evaluated between 54 and 60 days after planting (DAP), maximum tuber fill stage. Five plants from each plot were harvested and the leaf area was measured with the help of a leaf area meter (Model Li – 3100, Li-Cor) and GLA was obtained by subtracting the diseased areas. The tuber yield in each plot was estimated by harvesting the 20 plants, and compared at the confidence interval of $P<0,05$. The reduction in the leaf growth and the tuber yield were transformed to percentage of relative yield obtained in D4, plot with fully fungicide protection, where leaf growth and tuber yield reduction were minimum.

Comparison of methods to predict the beginning of the potato early blight. The planting date was used as the starting points for determining accumulated days (AD), degree days (DD) and physiological days (PD) accumulated till the appearance of the first symptoms. Since these parameters showed a relationship with the plant phenological stage at the tuber formation phase, AD, DD and PD, were used not only to determine appearance of the first symptoms, but also for different plant phenological stages through sampling five plants from each plot at 10-day intervals, from emergence to maturation.

The following formula was used to determine the DD:

$$DD = \sum_{i=1}^{n-1} [(T_{maximum} + T_{minimum})/2] - 7;$$

where T is the temperature.

The PDs were determined through the following equation (Gent and Schwartz, 2003):

$$PD = \sum_{i=1}^{n-1} \{1/24[5P(T_{min.}) + 8P(2T_{min.}/3 + T_{max.}/3) + 8P(2T_{max.}/3 + T_{min.}/3) + 3P(T_{max.})]\}$$

where:

$P(T) = 0$, if $T < 7$ °C
$P(T) = 10 [1 - (T - 21)^2 / (21 - 7)^2]$, if 7 °C $\leq T \leq$ 21 °C
$P(T) = 10(1 - (T - 21)^2 / (30 - 21)^2]$, if 21 °C $\leq T \leq$ 30°C
$P(T) = 0$, if $T \geq 30$ °C

This model is based on the fact that the daily minimum temperature for potato growth is 7°C, the optimum is 21° and the maximum is 30°C. The equation also considers that the plants are exposed for three hours to maximum temperature, for five hours to minimum temperature and for 16 hours between the two extremes.

These data were confirmed in this study by verifying the daily temperatures during the growing period (Gro Weatherlink - Davis instruments).

RESULTS

In all the three trials the potato plant emergence started 15 after planting DAP and the tuberization occurred between 30 and 35 DAP. The first early blight symptoms on the lower leaves appeared in D1, plots without fungicide treatment, at the turberization stage and thereafter the disease disseminated in varying intensities to the entire experimental area.

The disease progress curves, adjusted to the logistic model, of the three trials (Figure 1), showed differences among the plots, in the apparent infection rate. The greater epidemic rate occurred in the plot without fungicide treatment (D1), while the least epidemic rate occurred in the plot fully fungicide-protected treatment D4 (Table 1).

Table 1. Summary of linear regressions used to describe the early blight in a potato field, adjusted to the logistic model during the years 2000 through 2002.

Year-plot	Bo	Bx	R^2
2000-D1	- 8,91	0,13	0,87
2000-D2	- 8,32	0,10	0,93
2000-D3	- 8,06	0,08	0,76
2000-D4	- 8,29	0,01	0,70
2001-D1	- 14,99	0,23	0,82
2001-D2	- 13,27	0,18	0,72
2001-D3	- 14,65	0,19	0,80
2001-D4	- 13,94	0,17	0,73
2002-D1	- 25,18	0,53	0,80
2002-D2	- 26,09	0,52	0,81
2002-D3	- 22,04	0,32	0,83
2002-D4	- 18,00	0,26	0,76

Bo= intercept; Bx= angular coefficient or apparent infection rate; R^2= coefficient of determination.

Year 2000 trial. The first symptoms of early blight appeared at the beginning of tuberization, i.e., 28 DAP; the epidemic has established at 37 DAP, and lasted for 40 days. Plant mortality in plots D1 and D2 occurred 70 DAP. The maximum severity of 49,3% in most diseased D1 plots decreased to 2,5% in the relatively healthy D4 plots and the AUDPC increased with increasing disease severity (Table 2). The epidemic rate in the four epidemics adjusted to logistic model, was higher in D1 (r_L= 0,13) and D2 (r_L=0,10) plots and lowest in D3 (r_L= 0,08) and D4 (r_L=0,01) plots.

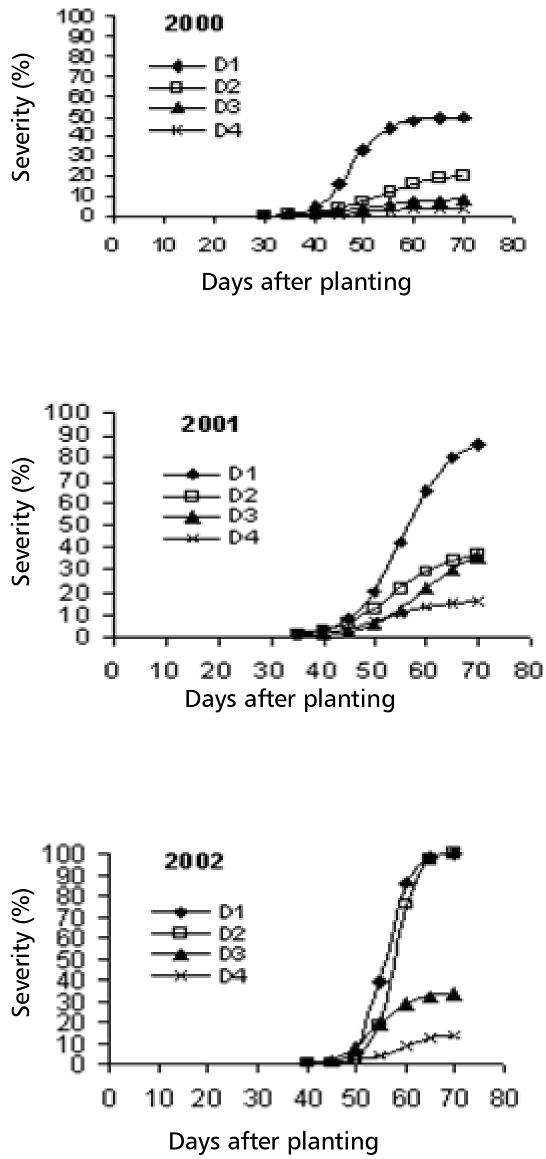

Figure 1. The patterns of potato early blight epidemics caused by (*Alternaria solani*) during 2000 to 2002. The highest disease severity occurred in plot D1 with a gradient to the lowest in plot D4.

In all plots, the different severities of early blight epidemic variously affected the GLA and tuber yield. The GLA in the plot D1 at 60 DAP was reduced by 82,2% and the tuber yield by 49,6%. There was a relationship between GLA and tuber yield in all plots but the reduction in GLA of 82,2% did not proportionately reduce the tuber yield (Table 2).

Table 2. Potato early-blight epidemics and its effects on the green leaf area index (GLA) and tuber yield during 2000.

Plot[d]	Severity[a]				Green leaf area[b]		Yield[c]		
	Y max, (%)	AUDPC (% - days)	r_L	Duration (days)	GLA	Loss (%)	Yield (gm^{-2})	CI (gm^{-2})	loss (%)
D_1	49,3	711,2 ± 210,1	0,13	40	0,43	82,2	1805	1457 – 2152	49,6
D_2	20,0	502,6 ± 33,9	0,10	40	1,78	26,4	2785	2453 – 3116	22,6
D_3	8,0	82,7 ± 49,0	0,08	40	1,88	22,3	3325	2879 – 3770	7,3
D_4	2,5	15,4 ± 48,0	0,01	40	2,42	0,0	3581	2896 – 4265	0,0

[a]Maximum severity at 68 DAP (Ymax.); area under the disease progress curve (AUDPC); standard deviation from mean of five plants (±); epidemic rate (r_L). [b]Green leaf area index (GLA). [c]Confidence interval for the mean yield of 20 plants (P = 5%). [d]Plots arranged in the descending order of highest (D1) to the least severity (D4).

Year 2001 trial. The epidemic started at 47 DAP, which coincided with the beginning of tuberizations and lasted for 14 days. Plant mortality in D1 and D2 plots started at 65 DAP, and reduced the vegetative cycle by 25 days. The Ymax. of 87,5% in the most diseased plot (D1) decreased to 16,8% in the healthiest D4 plot. The fastest epidemic rate of r_L= 0,23 occurred in the D1 plot and the slowest r_L= 0,17 occurred in the D4 plot (Table 3).

Table 3. Potato early-blight epidemic and its effects on the green leaf area index (GLA) and tuber yield during 2001

Plot[d]	Severity[a]					Green leaf area[b]		Yield [c]		
	Y max. (%)	AUDPC (% - days)	Duration (days)	r_L	R^2	GLA	Loss (%)	Yield (gm^{-2})	CI (gm^{-2})	Loss (%)
D_1	87,6	639,6 ± 286,1	14	0,23	0,82	0,50	50,0	1067	866 – 1268	52,7
D_2	38,6	244,3 ± 222,3	14	0,18	0,72	0,75	25,0	1604	1372 – 1837	28,7
D_3	36,8	179,3 ± 120,4	14	0,19	0,80	0,85	15,0	2001	1750 – 2252	11,3
D_4	16,8	86,8 ± 93,8	14	0,17	0,75	1,00	0,00	2248	1951 – 2561	00,0

[a]Maximum severity at 70 DAP (Ymax.); area under the disease progress curve (AUDPC); standard deviation from the mean of 20 plants (±); epidemic rate adjusted to logistic model (r), and coefficient of determination (R^2). [b]Green leaf area index (GLA). [c]Confidence interval (CI)for the mean yield of 20 plants (P = 5%).

The effect of the epidemic differed on GLA (reduction of 50%) and on tuber yield (reduction of 52,7%) in the D1 plot that had the highest disease severity. In all three trials the maximum tuber yield loss, ranging from 50 to 58%, occurred in D1 plots, where the defoliation reached 50 % at 55 DAP and 100% at 55 at 60 DAP. The minimum yield loss of 7,3% occurred in the year 2000, when the plants had 22% defoliation (Table 3).

Year 2002 trial. The epidemic developed eight days after the initiation of tuberization (47 DAP) and lasted for 30 days in plots D1 and D2 and for 20 days in D3 and D4. Premature plant mortality occurred in plots D1 and D2 by 60 DAP. The vegetative cycle for D1 plots was reduced by 30 days and by 35 days for the D2 plots. The Ymax of 100% in D1 plots can be compared to the Ymax of 13,8% in the D4 plots. The fastest epidemic rate (r_L= 0,53) occurred in D1 plots compared to the rate (r_L= 0,26) in the D4 plots (Table 4).

The effect of epidemics of early blight on GLA and tuber yield varied in a descending gradient from most diseased D1 plot to the healthier D4 plot. The GLA at 54 DAP was reduced by 99% in D1 plot and the tuber yield by 58,2%. There was a relationship between reduction in GLA and yield loss in all plots (Table 4).

Table 4. Epidemic of potato early blight and its effects on the green leaf area index (GLA) and tuber yield in 2002.

Plot[d]	Severity[a]					Green leaf area[b]		Yield[c]		
	Y max. (%)	AUDPC (% - days)	Duration (days)	r_L	R^2	GLA	Loss (%)	Yield (gm^{-2})	CI (gm^{-2})	Loss (%)
D_1	100,0	818,6 ± 233,0	30	0,53	0,80	0,01	99,1	1500	1190 – 1809	58,2
D_2	100,0	757,7 ± 241,5	30	0,52	0,81	0,15	86,9	1976	1693 – 2259	54,9
D_3	27,0	183,6 ± 121,3	22	0,32	0,83	0,75	34,7	2628	2203 – 3053	26,8
D_4	13,8	82,5 ± 127,0	20	0,21	0,76	1,10	00,0	3593	2947 – 4239	00,0

[a]Maximum severity at 70 DAP (Ymax.); area under the disease progress curve (AUDPC); standard deviation from the mean of 20 plants (±); epidemic rate adjusted to logistic model (r) and coefficient of determination (R^2). [b]Green leaf area index (GLA) and leaf area loss (%). [c]Confidence interval (CI) for the mean yield of 20 plants (P = 5%).

Comparison of methods to predict the beginning of the potato early blight. The first symptoms of early blight were observed 28, 40, and 37 DAP in 2000, 2001, and 2002, respectively. In each case, however, the epidemics were well established eight days after the first symptoms. This coincided with the beginning of tuberization. The tuberization time differed among trials, being at 38, 45, and 41 DAP in 2000, 2001, and 2002, respectively. This difference in the DAP for tuberization did not allow for determination of AD for epidemic occurrence (Table 5).

Table 5. Determination of plant phenology and of establishment of potato early blight epidemics in accumulated days (AD), degree days (DD) and physiological days (PD) accumulated since planting, during the years 2000 through 2002.

	2000			2001			2002		
	AD	DD	PD	AD	DD	PD	AD	DD	PD
Seeding	1	9.65	8.98	1	11.55	8.04	1	15.5	7.5
Emergence	18	235	156	14	179	117	11	188	73
Beginning of tuberization	28-30	364-399	239–251	35-37	451-474	289–307	30-32	506-539	204-218
Tuber growth	38-40	326–561	311-23	45-47	581-608	379–398	41-43	698-730	275-289
Plant maturity	71	1052	558	70	942	587	71	1171	499
Harvest	95	1425	754	82	1110	688	80	1291	579
First symptoms of early-blight	28	364	239	40	313	333	37	622	254
Beginning of early-blight epidemic	37	510	305	47	608	398	48	815	321

The number of DDs accumulated since the planting date, required for disease initiation was 364, 313, 622 in 2000, 2001, and 2002, respectively, and the epidemic established, respectively, at 510, 608, and 815 DDs. The range of DDs among the trials conducted at the same locality, though at different times, does not allow its use to predict early blight.

The required number of PDs accumulated after planting was of 239, 333, 254 in 2000, 2001, and 2002, respectively, and the epidemic established at 305, 398, and 321 PDs, respectively. This narrow range of accumulated PDs among different trials shows that this method has a good potential to predict early blight epidemic initiation from 250 PDs.

DISCUSSION

The different plot distances from the inoculum source and the chlorothalonil sprays at different doses, permitted the establishment of disease gradients, through which different epidemic patterns were obtained in each of the three trials. A similar strategy was used by Zwankhuizen, Govers and Zadoks (1998), to create disease gradients for potato late blight.

Despite high disease severity and high reduction in yield, the early blight epidemic could be controlled by protecting the plants at the right time with an appropriate dose of chlorothalonil. The protection increased gradually as the fungicide dose increased from 25% to 100% of the commercially recommended dose, thus confirming the efficacy of this fungicide (Franc, Harrison and Lahman, 1988; Pscheidt and Stevenson, 1986).

The high disease intensity in 2001 and 2002 cannot be attributed only to the favorable climatic conditions, but also to higher external inoculum build-up due to the four successive potato plantings in the same area, compared to the first year. Early blight is a polycyclic disease and the pathogen has a high capacity to produce secondary inoculum. In this case, the disease most likely was favored by the successive potato plantings and the presence of other host crops, such as tomato, close to the experimental area.

The GLA index was reduced significantly due to early blight-induced necrosis and premature defoliation. This disease reduced the vegetative cycle by 20 days (D1 plots) and 15 days (D2 plots). However, the disease did not damage the stems and the tubers, as observed by Johnson and Teng (1990), and yield reduction was caused by reduced tuber size and number of tubers/plant (Shtienberg *et al.*, 1996).

The early-blight induced defoliation by early blight had a relationship to the yield loss in all the plots. James *et al.* (1972), presumed that the tuber-filling process paralyzes when defoliation reaches 75%, and considered this value as the critical point for yield loss based on good correlations found in some tests. In the present study, defoliation of 50% to 100% with yield loss of about 55% was observed.

Under the GLA index between 55 and 60 DAP was highly correlated to tuber production. According to Rotem, Bashi and Kranz (1983), potato yield loss can best be estimated by relating it the duration of GLA from the beginning of tuber formation till senescence. In this work with cultivar Bintje, maximum tuber filling (phenological stage IV, (Rowe, 1993) occurred between 55 and 60 DAP, which would permit selection of this date as the critical point to construct models to estimate yield loss. It is important to note that, in field conditions besides disease, other factors such as temperature and soil moisture can affect plant yield.

The appearance of the first symptoms of early blight on the lower leaves indicates the time when the disease-management plan should be initiated, because the epidemic establishes within seven days thereafter. This critical point for epidemic establishment is being used in other countries to develop models for early-blight management (Franc, Harrison and Lahman, 1988; Gent and Schwartz, 2003; Pscheidt and Stevenson, 1986).

Predicting the moment of establishing the early blight management plan for susceptible cultivars is important for integrated management, by applying fungicides at the right moment. In the United States, the use of a thermic unit model reduced the number of sprays from 12 to 8 (Gent and Schwartz, 2003).

The data from this work showed that the prediction based on ADs or DDs accumulated after planting was not satisfactory to determine the initiation of disease management (Table 5).

In relation to the plant phenological stage, early blight started eight days after the start of tuber formation. This stage, therefore, can be considered as the critical point to start the epidemic management plan. This would require plant sampling to determine beginning of tuberization, because of high variability if this is based on the accumulated days. The tuber formation is physiologically related to the seed-tuber age, and climatic conditions such as photoperiod, temperature, nitrogen fertilization, etc. (Evans, 1983).

The methods with the accumulated thermal units as in DD had high variability among the trials because it is based solely on restricted plant growth at basal minimal temperature. Thus, differences can appear depending upon the planting date. Similar results were obtained by Franc, Harrison and Lahman (1988), who recommended the first spray at 361 DDs in the Vally of São Luis and 625 DDs for the northeast region of Colorado State (USA).

The method using accumulated PDs was more precise, and appears to have greater potential to establish a disease-management plan for the control of early blight. Accumulated PD considers temperature (maximum, minimum, and optimum) required for plant growth, and therefore shows consistencies with determination of disease appearance in crops planted at different localities and at different dates. This method indicates, *a priori,* the first spray at 250 PDs, before the epidemic establishes on lower leaves at 300 PDs (Table 6).

Table 6. Potato early blight prediction model based on physiological days (PD) accumulated between planting and appearance of first symptoms (2000 to 2002).

Year	First symptoms[a]	250 PD[b]	300 PD[c]
2000	28	30 (+ 2)	35 (+ 7)
2001	40	31 (- 9)	36 (- 4)
2002	37	36 (0)	45(+ 8)

[a]Days accumulated since planting. [b]Days accumulated when the plants reached 250 accumulated PD, (+) days after appearance of first symptoms, (-) days prior to appearance of first symptoms. [c]Physiological Days accumulated after planting.

The first spray at 250 PDs, in the three trials, to protect plants with chlorothalonil should have been done in the year 2000 trial, e.g., two days after the first symptoms appeared and before the start of the epidemic. The 2001 and 2002 trials, the first symptoms appearead at the start of the epidemic (Table 6). In the 2001 trial, when the first spray was done at 300 PDs, the initial symptoms had not yet appeared, while in the other years the epidemic had already been established, although disease severity on the lower leaves was below 1%.

In general, early blight reduced GLA at the tuber formation stage, presumably through necrosis and defoliation together with reduction in tuber production. The PD-based method showed greater potential for establishing a management plan for early blight; thus this can be recommended to initiate a disease-management plan for cultivar Bintje, at 250 PDs, which corresponds to the most susceptible stage, and under favorable climatic conditions the epidemic manifests eight days after the appearance of first symptoms.

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