Incorporation of Cultivar Resistance in a Reduced-Sprays Strategy to Suppress Early and Late Blights on Potato

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ABSTRACT

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Predictions from simulation analysis concerning the relative contributions of host resistance and protectant fungicide in a reduced-sprays strategy to suppress potato early and late blights were examined in field trials. As predicted, disease-induced defoliation in cultivars moderately resistant to both diseases, sprayed on a 14-day schedule, was not significantly different ($P = 0.05$) from defoliation in a susceptible cultivar sprayed on a 7-day schedule. Evaluation of the reduced-sprays strategy using cultivars of different resistance indicated that disease in plots treated according to the reduced-sprays strategy did not differ significantly ($P = 0.05$) from disease in plots treated according to the common management practice, although three fewer sprays were applied in the reduced-sprays treatment. Thus, incorporation of host resistance into a reduced-sprays strategy should enable large reductions in the amount of fungicide required for adequate disease suppression.

Because of the uncertainties resulting from meteorological and biological variance in agriculture, production of some crops involves heavy reliance on periodic application of fungicides for disease suppression. Fungicides are sometimes used as insurance and are applied irrespective of the prevalence of diseases and weather (20). Potato (*Solanum tuberosum* L.) and diseases such as early blight, caused by *Alternaria solani* Sorauer, and late blight, caused by *Phytophthora infestans* (Mont.) de Bary, exemplify this situation. In the northeastern United States, seven to 10 sprays are typically applied to potato foliage for suppression of early and late blights.

Concerns about the environment, farm worker safety, public health, economics, and fungicide resistance have stimulated efforts to reduce the amount of fungicide used in agricultural production. One method is to substitute host resistance for fungicides (7,8). It is recommended that New York State potato growers adjust the frequency of late blight fungicide applications according to resistance of the cultivar: susceptible cultivars are sprayed weekly, moderately susceptible cultivars on a 10-day schedule, and moderately resistant cultivars on a 14-day schedule (9). However, in many potato growing regions, including New York State, control of both early and late blights must be integrated into one management scheme, because considering only one disease might result in a severe epidemic of the other (10,12,18).

Based on analyses done with complex simulation models describing potato early blight development (13,19), potato late blight development (1), and chlorothalonil dynamics (2,3), we developed a strategy (known as the "reduced-sprays strategy"). The aim of this strategy was to increase the efficiency of fungicides applied for management of both early and late blights and to reduce fungicide use (16). According to the reduced-sprays strategy, sprays should be initiated when late blight is predicted by a forecast system (e.g., Blitecast [11]), or when the severity of early blight is predicted to

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become important (6–7 wk after planting), whichever comes first. Subsequent spray intervals during the first 6–7 wk are determined according to the resistance of cultivars to late blight, and after 7 wk, on a weekly schedule. The last spray would be applied approximately 3 wk before vine kill. The reduced-sprays strategy was evaluated in the field and via computer simulation experiments (18). Use of this strategy could save two to four sprays per growing season without substantially increasing foliar disease relative to the common grower management practice (18).

The early blight simulator was then used to estimate the relative contribution to disease suppression of genotype resistance and protectant fungicides (19). Spraying a cultivar moderately resistant to *A. solani* on a 17-day schedule results in defoliation levels similar to those achieved by spraying a susceptible cultivar on a 7-day schedule. However, these suggestions had not been evaluated in the field. The purpose of this work was to field test the predictions concerning the contribution of host resistance and fungicide in the reduced-sprays strategy. A preliminary report has been previously published (14).

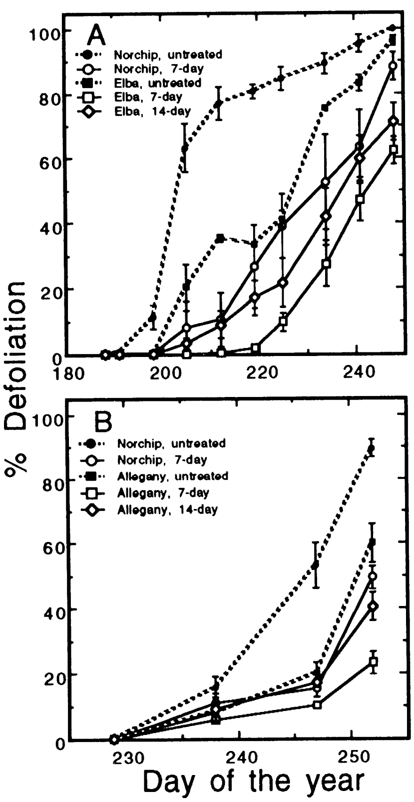

Fig. 1. Effects of genotype resistance and fungicide treatment on defoliation induced by potato early and late blights in **(A)** 1989 and **(B)** 1992. Norchip is susceptible to early and late blights; Elba and Allegany are moderately resistant to both diseases. Bars indicate the standard error. Results are the means of four replications.

MATERIALS AND METHODS

Cultural practices. Field experiments were conducted at the Homer C. Thompson Research Farm of Cornell University at Freeville, New York. Certified potato seed (whole tubers or pieces, each weighing about 50 g) was machine planted on 23 May 1989 (cvs. Norchip and Elba), on 5 June 1990 (cvs. Norchip, Atlantic, and Katahdin), and on 27 May 1992 (cvs. Norchip and Allegany). In 1989 and 1992, plots consisted of four 4-m-long rows; and in 1990, plots were eight 7.4-m-long rows. Spacing between rows was 0.9 m, and plants were spaced 23 cm apart within a row. Plots were separated from each other by fallow areas about 4 m wide in 1989 and 1992, and 7 m wide in 1990. Fertilizer (175 kg each of N, P, and K per hectare) was applied at planting. The herbicide linuron (50WP, 1.7 kg a.i./ha, in 1989 and Linex 50DF, 3.7 kg a.i./ha, in 1990 and 1992) was applied after planting but before plant emergence. Insecticides were applied in each experiment every 10–20 days, starting in late June according to the prevalence of Colorado potato beetles. The broad-spectrum protectant fungicide chlorothalonil (Bravo 720) was applied at the rate of 0.85 kg a.i./ha, in water at 470 L/ha and 860 kPa with a tractor-mounted boom sprayer. Vines were killed mechanically (by mowing) in early mid-September each year, and the two middle rows of each experimental plot were machine harvested 2 wk later. Tubers were rated visually for late blight infections 3–10 days after harvest, and infected tubers were weighed.

Experimental treatments. In the 1989 and 1992 trials, the relative contributions of host resistance and protectant fungicide were evaluated. Sprays were initiated on 29 June 1989 and 15 July 1992. (In 1992, the initiation of sprays according to Blitecast and according to standard grower practice was coincidental). Subsequent sprays were applied on a 7-day schedule for cv. Norchip, and on 7- and 14-day schedules for cvs. Elba and Allegany. For each cultivar, control plots were not treated with fungicides. Norchip is susceptible, and Elba and Allegany are moderately resistant to *A. solani* and *P. infestans*.

In 1990, the conventional management practice was compared with the reduced-sprays strategy on three cultivars (Norchip, Atlantic, and Katahdin). Controls consisted of untreated plots. For the conventional management practice treatment, sprays were initiated on 13 July, when plants were approximately 20 cm high. Subsequent sprays were applied on a 7-day schedule until vine kill, with nine fungicide applications in total. For the reduced-sprays strategy treatment, sprays were initiated on 19 July, when late blight was predicted by Blitecast (11), and applied weekly until 3 wk before vine kill, with 6 fungicide applications in total. The spray on the second week of August was a mixture of chlorothalonil (standard rate) with metalaxyl at a rate of 0.15 kg a.i./ha. Atlantic and Katahdin are moderately susceptible to both pathogens. Treatments in all trials were arranged in randomized complete blocks with four replicates.

Inoculation. In 1989, four seed tubers infected with *P. infestans* were hand planted in each experimental plot. Seed tubers were inoculated by injecting a 0.01-ml drop of inoculum (containing approximately 500 sporgania of *P. infestans*) to a depth of 7 mm at the base of two eyes with a side-port 16-gauge needle attached to a Hamilton repeating dispenser syringe (Hamilton Co., Reno, NV). Inoculated tubers were stored at room temperature for 2 wk prior to planting. Before planting, all tubers were checked for infection, and those with noticeable soft rot were discarded.

In 1990 and 1992, inoculum of *P. infestans* came from other experiments which were located downwind and which were inoculated with *P. infestans* on 3 August 1990 and 30 July 1992. Experimental plots were not artificially inoculated with *A. solani,* because soil at the test sites was already heavily infested with debris from previous potato crops.

Disease assessments. Disease was assessed visually. Defoliation of the two middle rows of each plot (in 1989), of the entire plot (1992), or of eight main stems per plot (in 1990) was estimated every 3–7 days using a modification of a blight assessment key published by the British Mycological Society (7). No attempt was made to distinguish between lesions induced by *A. solani* and *P. infestans*. Assessments started in each trial after symptoms first became apparent (early June 1989, mid-August 1990 and 1992) and continued until vines were killed (early mid-September). For some analyses, the relative area under the defoliation progress curve (RAUDPC), as calculated by Shaner and Finney (15), was used. The period used for calculating RAUDPC was from the date of first appearance of noticeable disease symptoms in any plot until the last disease assessment. Results were subjected to statistical analysis; and where F values showed significant differences, Fisher's protected LSD Test was applied at $P = 0.05$.

RESULTS

In the experiments illustrating the contribution of host resistance (1989 and 1992), disease developed more slowly on the more resistant cultivar. As expected in the 1989 trial, defoliation induced by early and late blights developed very rapidly in untreated plots of the susceptible cultivar Norchip. The proportion of defoliated foliage progressed from 0.02 to 62.5% within 17 days. However, for the moderately resistant cultivar

Elba, this level of disease increase required 32 days. In the 1992 trial, disease-induced defoliation developed late and progressed relatively slowly, but defoliation in cultivar Allegany was again significantly lower than that of Norchip (Fig. 1, Table 1).

In both trials (1989 and 1992), defoliation in fungicide-treated plots was significantly lower than defoliation in untreated plots (of the same cultivar) throughout the entire growing season. Spraying Elba or Allegany on a 14-day schedule was slightly less effective than the 7-day schedule, but defoliation in the 14-day treatment resembled that of Norchip sprayed on a 7-day schedule (Fig. 1). Differences with respect to defoliation among fungicide-treated plots were insignificant ($P = 0.05$) in most assessment dates (Fig. 1).

Although fungicide suppressed foliar disease, the effect of fungicide on yield was generally not significant, except for the susceptible cultivar Norchip in 1989. Tuber blight intensity was low and was not affected significantly by any treatment (Table 1).

In the reduced-sprays experiment in 1990, early and very late sprays had no detectable effects on disease development; however, host resistance had a significant ($P < 0.001$) effect. Although plots protected by the reduced-sprays strategy had three fewer sprays than those protected according to the common management practice, there were no significant differences in terms of defoliation, RAUDPC, yield, or percent tubers blighted among treatments (Fig. 2, Table 2). Norchip was most affected (in terms of foliar disease and yield) by the pathogens, followed by Atlantic; and Katahdin was affected the least (Fig. 2, Table 2). In general, defoliation within each cultivar was significantly lower ($P < 0.05$) in fungicide-treated than in untreated plots.

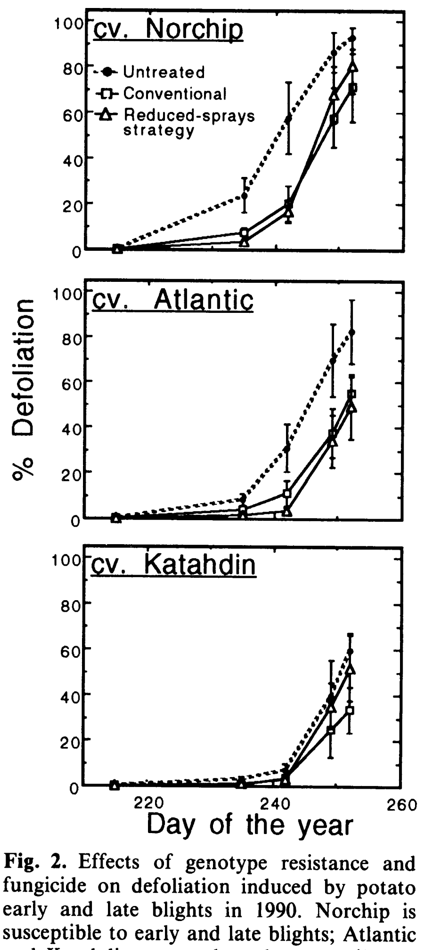

Fig. 2. Effects of genotype resistance and fungicide on defoliation induced by potato early and late blights in 1990. Norchip is susceptible to early and late blights; Atlantic and Katahdin are moderately susceptible to both diseases. Bars indicate the standard error. Results are the means of four replications.

DISCUSSION

Predictions concerning the relative contributions of genotype resistance and protectant fungicide in early (19) and late (7,8) blight suppression were corroborated in the field. As predicted, spraying a cultivar moderately resistant to early and late blights on a 14-day schedule resulted in defoliation not significantly different ($P = 0.05$) from that of a susceptible cultivar sprayed on a 7-day schedule (Fig. 1, Table 1). Previous guidelines for adjusting spraying intervals based on host susceptibility considered early blight or late blight separately. Consequently, in regions where both early and late blight threaten the crop, all potato cultivars (including those moderately resistant to late blight) are actually sprayed on a 7-day schedule. Our results show that cultivars moderately resistant to both diseases may be sprayed on a 14-day schedule without

Table 1. Effects of genotype resistance and fungicide on defoliation caused by potato early and late blights in 1989 and 1992

Year	Cultivar[w]	Spraying interval[x]	Percent defoliation[y]	RAUDPC[z]	Yield (t/ha)	Percent tubers blighted (by wt)
1989	Norchip	Untreated	100.0 a	0.648 a	14.7 c	1.77 a
		7-day	88.1 b	0.293 c	31.9 b	0.22 a
	Elba	Untreated	96.2 ab	0.401 b	36.9 ab	1.40 a
		7-day	62.2 c	0.144 d	44.1 a	0.55 a
		14-day	71.2 c	0.240 c	42.9 a	0.55 a
1992	Norchip	Untreated	89.5 a	0.320 a	29.9 a	0.00 a
		7-day	49.5 b	0.143 bc	30.3 a	0.40 a
	Allegany	Untreated	60.0 b	0.157 b	35.3 a	0.00 a
		7-day	23.2 c	0.080 c	37.7 a	0.80 a
		14-day	52.5 b	0.148 bc	33.5 a	0.50 a

[w] Norchip is susceptible to early and late blights; Elba and Allegany are moderately resistant to both diseases.
[x] Chlorothalonil (Bravo 720) was applied at the rate of 0.85 kg a.i./ha.
[y] Defoliation was recorded in early September both years. Numbers within a column (for each year) followed by the same letter are not significantly different ($P = 0.05$), as determined by Fisher's protected LSD test. Results are the means of four replications.
[z] Relative area under the defoliation progress curve.

Table 2. Effects of genotype resistance and fungicide treatment on defoliation caused by potato early and late blights in 1990

Cultivar[v]	Fungicide treatment[w]	Percent defoliation[x]	RAUDPC[y]	Yield (t/ha)	Percent tubers blighted (by wt)
Norchip	Untreated	92.7 a	0.322 a	35.6 a	0.07 a
	Conventional	71.1 a	0.156 b	38.9 a	1.02 a
	Reduced-sprays	80.4 a	0.150 b	38.1 a	0.05 a
Atlantic	Untreated	82.5 a	0.196 a	37.0 a	0.00 a
	Conventional	55.3 b	0.097 b	37.2 a	0.05 a
	Reduced-sprays	49.1 b	0.070 b	41.0 a	1.06 a
Katahdin	Untreated	59.5 a	0.107 a	40.0 a	0.68 a
	Conventional	33.5 b	0.058 a	37.9 a	0.00 a
	Reduced-sprays	52.0 ab	0.083 a	39.8 a	0.00 a
Block		0.0001[z]	0.0001	0.0001	NS
Cultivar		0.0001	0.0001	NS	NS
Fungicide treatment		0.001	0.0001	NS	NS
Cultivar × fungicide treatment		NS	0.02	NS	NS

[v] Norchip is susceptible to early and late blights; Atlantic and Katahdin are moderately susceptible to both diseases.
[w] Chlorothalonil (Bravo 720) was applied at the rate of 0.85 kg a.i./ha.
[x] Defoliation was recorded on 14 September 1990, 3 wk after the last spray was applied in the reduced-sprays strategy treatment. Numbers within a column (for each cultivar) followed by the same letter are not significantly different ($P = 0.05$), as determined by Fisher's protected LSD test. Results are the means of four replications.
[y] Relative area under the defoliation progress curve.
[z] P values for the analysis of variance. NS = not significant.

substantially increasing the risk of uncontrolled epidemics; and for the cultivars tested, this may save up to five sprays in a growing season.

Predictions (18) of the overall efficacy of sprays applied according to the reduced-sprays strategy relative to the common management practice were corroborated. Disease suppression in plots treated according to the reduced-sprays strategy was not significantly different ($P = 0.05$) from that of plots treated according to common management practice, although three fewer sprays were applied in the former treatment (Fig. 2, Table 2). Our results show that neither defoliation nor tuber blight infections were intensified when sprays were terminated 3 wk before vine kill (Table 2).

Conclusions from this and other experiments (4–6,17–19) suggest possible means of improvement of the reduced-sprays strategy. Sprays should be initiated when late blight is predicted by a forecast system (e.g., Blitecast [11]), or when early blight is predicted to become important, whichever comes first. If sprays are initiated due to late blight forecast, spray intervals during the first 6–8 wk should be determined by cultivar response to late blight. After 8 wk, spraying intervals should be determined by cultivar response to both early and late blights: cultivars moderately resistant to both diseases should be sprayed on a 14-day schedule, whereas cultivars susceptible or moderately susceptible to one or both diseases should be sprayed on a weekly schedule. Once, in midseason (for example, mid-June) or after the appearance of late blight (whichever comes first), a protectant with metalaxyl should be applied (5,6). Because of the high incidence of metalaxyl resistance in *P. infestans* in some regions, this treatment is recommended only where the pathogen is still susceptible to that fungicide. The last spray should be applied approximately 3 wk before vine kill.

If sprays are not initiated by Blitecast, then early blight consideration will be important. The history of potato and tomato production and the immediate preceding crop affect the earliness of early blight appearance (17) and determine when disease is expected to become important. If potatoes or tomatoes are grown only occasionally (for example, once every 3 or 4 yr) and if neither potato nor tomato preceded the current crop, early blight is expected to become important 7–8 wk after planting. In fields where potatoes or tomatoes are grown more frequently, or when potato or tomato precedes the current crop, early blight is expected to become important 6–7 wk after planting (16,17).

The use of host resistance in the reduced-sprays strategy (as indicated above) would further reduce the number of sprays applied for early and late blight suppression without substantially increasing foliage or tuber infections, and without increasing risks involved in the development of fungal populations resistant to metalaxyl.

Further refinements of the reduced-sprays strategy include additional consideration of age-related susceptibility and of new systemic fungicides (e.g., difenoconazole and tebuconazole) in the management of early blight, and quantification of the effects of one pathogen on the other while they develop in combination. Inclusion of these factors in the reduced-sprays strategy may enable a further reduction in the quantity of fungicides applied to potato foliage in the northeastern United States.

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