Fungicide Spray Programs for Defender, A New Potato Cultivar with Resistance to Late Blight and Early Blight

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ABSTRACT

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Defender (A90586-11) is a new late blight-resistant potato cultivar which was released from the Tri-State Potato Variety Development Program in 2004. Conventional and reduced fungicide spray programs were compared on Defender and Russet Burbank (3 years) and Ranger Russet (1 year) in Wisconsin experimental field trials. Useful levels of field resistance to both late blight and early blight were observed in Defender in the absence of fungicide sprays and reduced fungicide input programs. Disease progressed slowest on Defender regardless of fungicide program, relative to Russet Burbank and Ranger Russet. Organic, conventional, and reduced fungicide spray programs also were compared on Defender and Russet Burbank in experimental greenhouse and field tests in Washington. Fungicide spray programs performed similarly on both Defender and Russet Burbank; however, area under the disease progress curve values for no-fungicide treatments were either three times (greenhouse) or six times (field) lower on Defender compared with Russet Burbank. Regardless of the fungicide program, total yield was higher for Defender than Russet Burbank. Mean economic returns associated with Defender also were higher than for Russet Burbank ($6,196 versus $4,388/ha). Fungicide and nonfungicide treatment programs generated similar returns on Defender whereas conventional and reduced fungicide programs generated comparable but higher returns than the nonfungicide program on Russet Burbank.

Additional keywords: *Alternaria solani, Phytophthora infestans*

Most of the commercial potato cultivars currently grown in the United States are susceptible to late blight (5,17,19,25) caused by *Phytophthora infestans* (Mont.) de Bary, and field tolerance to early blight (*Alternaria solani* Sorauer) rarely enters into the decision of cultivar selection (27). Careful management of both diseases is essential; otherwise, losses can be severe

In the Columbia Basin of the Pacific Northwest, the costs of managing late blight along with resulting decreased crop productivity totaled over $30 million in 1995 (20). Although losses and control costs associated with late blight can vary from area to area, Marshall-Farrar et al. (22) reported that, due to the costs of additional sprays, unharvested fields, and reduced yields and storage losses, late blight cost the potato industry in Wisconsin an estimated $26 million in 1994. Negative economic impacts have been compounded by new and aggressive strains of *P. infestans* (7) that are resistant to mefenoxam (metalaxyl) (3), the primary fungicide used for control in the mid-1980s and early 1990s, as well as a lack of available foliage and tuber resistances. These difficulties have highlighted the need to develop new potato cultivars with improved resistance to late blight.

Losses from early blight rarely exceed 20%, and intensive fungicide treatment helps contain losses to less than 5% (31). Management costs for early blight in North America during 1990 were estimated to be $21.4 to $44.8 million for fungicide plus the costs associated with application. Since then, fungicide costs for early blight management have continued to increase as newer chemistries have entered the marketplace. In years when late blight is also present, the cost for management of both diseases increases further and can exceed $618 per hectare.

The Tri-State Potato Variety Development Program (TSPVDP) of Idaho, Oregon, and Washington has focused on identifying potato breeding materials and advanced selections with resistance to late blight. TSPVDP clones have been tested against late blight at multiple locations over multiple years (1,9–11,13–15,25,28), and against isolates of *P. infestans* with complex virulences (4). One newly named cultivar, called Defender, was described

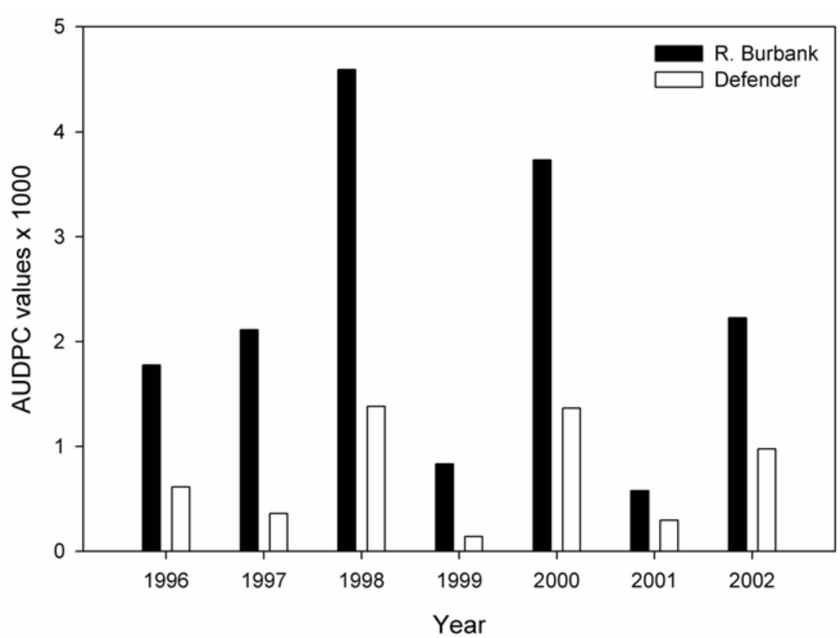

Fig. 1. Annual area under disease progress curve (AUDPC) values for late blight on Defender and Russet Burbank in potato germplasm evaluations at Washington State University-Mount Vernon, 1996 to 2002.

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recently (24); it has better foliage and tuber resistances to late blight than commercial potato cultivars now planted in the United States, and has moderate levels of resistance to foliar and tuber early blight as well as several other diseases. It also has flowers that are highly resistant to both US-8 and US-11 genotypes of *P. infestans* (25). Because Defender has yield comparable to or better than Russet Burbank, along with acceptable processing attributes, it is a good candidate for both reduced input and organic disease management programs.

Improved host resistance integrated with fewer fungicide applications previously has been investigated to improve the management of late blight on potato. Grunwald et al. (8) reduced the number of fungicide applications in Mexico by using cultivars with moderate to high levels of resistance. Kirk et al. (21) demonstrated that advanced potato breeding lines with reduced susceptibility can be managed with lower fungicide rates and longer intervals between fungicide applications, offering disease control options that are more economical. Shtienberg et al. (26) showed that potato cultivars with improved foliar resistance reduced the number of fungicide applications in New York. In their study, disease-induced defoliation of cultivars moderately resistant to both early and late blight, sprayed with a fungicide every 14 days, was not significantly different from defoliation in a susceptible cultivar sprayed on a 7-day schedule.

This report on fungicide programs for the recently-available Defender includes (i) responses in western Washington over 7 years of low, medium, and high late blight pressure; (ii) effects of extending fungicide application intervals on early and late blight development in Wisconsin; and (iii) results of organic, conventional, and reduced fungicide spray programs in greenhouse and field studies in Washington, including an analysis of the economic returns.

MATERIALS AND METHODS

Field comparisons of late blight resistance in western Washington. Area under disease progress curve (AUDPC) values for Defender and Russet Burbank were obtained over a 7-year period from previous published (10,11,13–15) and unpublished reports of potato germplasm evaluated against late blight in the field at the Washington State University (WSU) NWREC near Mount Vernon. Early blight was not detected on the plants, and is rarely of concern in western Washington. In these studies, multiple germplasm entries generally were planted in late May in three replications arranged as randomized

Table 1. Interaction of fungicide sprays and cultivar response to early blight and late blight in Wisconsin, 2002

Cultivar, treatment (application no.)[w]	Disease severity (%)[u]: Early blight		Late blight		Combined				Relative AUDPC[v]			Yield (t/ha)		
	12 Aug	26 Aug	12 Aug	26 Aug	2 Aug	12 Aug	26 Aug	3 Sep	Early	Late	Comb.	Total	US 1	SG[x]
Russet Burbank														
Untreated	18.5	48.8	5.9	44.5	4.7	31.4	91.7	99.9	0.108	0.075	0.163	47.4	30.2	1.073
Chlorothalonil (1,4,7)	6.7	68.8	0.4	4.1	3.5	6.7	82.0	99.4	0.093	0.005	0.093	53.2	33.9	1.081
Chlorothalonil (1,3,5,7,9)	7.6	73.6	0.0	0.1	3.1	7.6	81.8	98.1	0.094	0.000	0.087	52.0	32.2	1.080
Chlorothalonil (1-9)	8.8	74.2	0.0	0.0	4.4	8.8	82.1	98.5	0.117	0.000	0.108	51.8	32.5	1.078
Defender														
Untreated	5.0	37.9	0.0	0.0	3.8	5.0	50.6	88.3	0.060	0.000	0.060	40.8	31.7	1.085
Chlorothalonil (1,4,7)	4.2	45.3	0.0	0.0	4.1	4.2	62.7	89.7	0.075	0.000	0.075	45.0	35.6	1.081
Chlorothalonil (1,3,5,7,9)	3.4	37.9	0.0	0.0	3.4	3.4	48.2	83.9	0.062	0.000	0.062	42.3	33.1	1.086
Chlorothalonil (1-9)	4.1	32.6	0.0	0.0	3.1	4.1	44.9	77.4	0.053	0.000	0.053	49.0	38.3	1.079
P > F	<0.01	<0.01	<0.01	<0.01	0.06	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.26	0.01
LSD	6.1	20.1	1.4	12.7	NS	11.4	22.0	9.9	0.034	0.020	0.029	6.6	NS	0.006
Analysis[y]														
Effect of cultivar														
Russet Burbank	10.4	66.4	1.6	12.2	3.9	13.6	84.4	99.0	0.103	0.020	0.112	51.1	32.2	1.078
Defender	4.2	38.4	0.0	0.0	3.6	4.2	51.6	84.8	0.063	0.000	0.062	44.3	34.7	1.082
P > F	<0.01	<0.01	<0.01	<0.01	0.25	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.12	<0.01
LSD	3.1	10.0	0.7	6.4	NS	5.7	11.0	4.9	0.017	0.010	0.014	3.3	NS	0.003
Effect of fungicide														
Untreated	11.7	43.4	2.9	22.3	4.2	18.2	71.1	94.1	0.084	0.037	0.111	44.1	30.9	1.079
Chlorothalonil (1,4,7)	5.5	57.0	0.2	2.1	3.8	5.5	72.3	94.6	0.084	0.002	0.084	49.1	34.8	1.081
Chlorothalonil (1,3,5,7,9	5.5	55.8	0.0	0.1	3.2	5.5	65.0	91.0	0.078	0.000	0.074	47.1	32.6	1.083
Chlorothalonil (1-9)	6.4	53.4	0.0	0.0	3.7	6.4	63.5	88.0	0.085	0.000	0.080	50.4	35.4	1.078
P > F	0.02	0.21	<0.01	<0.01	0.11	<0.01	0.57	0.21	0.92	<0.01	<0.01	0.06	0.18	0.14
LSD	4.3	NS	1.0	9.0	NS	8.1	NS	NS	NS	0.014	0.020	NS	NS	NS
Interaction[z]														
P > F	0.06	0.15	<0.01	<0.01	0.07	0.02	0.50	0.37	0.24	< 0.01	< 0.01	0.48	0.66	0.05

[u] Severity rated on a Horsfall-Barratt scale of 0 (no infection) to 11 (all foliage and stems dead). Ratings were converted to percent. Combined disease severity (early blight and late blight, attempting to exclude damage from early dying) was assessed first. Then, amounts of early and late blight were estimated separately (the separate estimates do not necessarily add up to the combined defoliation figure because they were done independently). Prior to 2 August, only early blight was observed in this trial.

[v] Relative area under the disease progress curve (AUDPC). Data for each observation date were plotted on a graph and the area under the line was calculated for each treatment, providing a measure of the relative severity of disease throughout the season. A disease rating of 100% severity for the entire season would produce a value of 1.0. All relative AUDPC values are expressed as a proportion of this value. Either decreased disease severity or later disease development will contribute to lower relative AUDPC. Early and late blight AUDPC values were calculated from 24 June to 26 August (disease had progressed to the point that early and late blight could not be rated separately for many of the plots on 3 September). The combined (Comb.) AUDPC was calculated from "combined" blight rating data (total defoliation of the plot, combining both early and late blight) from 24 June to 3 September (if only early blight was seen in a plot, the combined severity was equal to the early blight rating).

[w] All fungicide applications were chlorothalonil (Bravo Zn 4.17F), 2.49 liter/ha. Application dates were: 1 = 26 June, 2 = 3 July, 3 = 10 July, 4 = 17 July, 5 = 24 July, 6 = 31 July, 7 = 7 August, 8 = 14 August, and 9 = 21 August. *P* > F: analysis of variance was performed on data, and Fisher's protected least significant difference (LSD) was calculated. NS = not significant at *P* = 0.05.

[x] Specific gravity.

[y] Analysis of the effect of cultivar and fungicide treatment. For effect of cultivar, data were pooled for fungicide treatments and, for effect of fungicide treatment, data were pooled for cultivars.

[z] Interaction: cultivar–fungicide treatment.

complete blocks (except in 1999, when plots of Defender and Russet Burbank were not replicated). Plots consisted of single rows planted to five to seven seed pieces at 23-cm within-row spacing; each plot was separated by 1-m between-row spacing and 1.5-m end-to-end spacing. In addition, rows were staggered, offsetting the plots and alleys, in order to facilitate plant growth and disease assessment. Plants generally received 2.5 cm per week of supplemental water by drip irrigation beginning in July, and the cultural practices typical of the region (except for fungicide applications) were employed. None of the plots was artificially inoculated; rather, disease resulted each year from naturally occurring isolates of *P. infestans* with complex virulences (4). All entries were rated weekly for percent blighted foliage to generate AUDPCs. Disease pressure classes were assigned to years based on the AUDPC values for Russet Burbank, where low = <1,000, intermediate = 1,000 to 3,000, and severe = > 3,000.

Fungicide comparison of host resistance and fungicide spray regimes in Wisconsin. Field trials were planted to Defender and Russet Burbank from 2002 to 2004 at the Hancock Agricultural Research Station, Hancock, WI. Cv. Ranger Russet was included in the 2004 trial. Preliminary results of these trials were reported previously (28–30). Field plots consisted of four 7.3-m-long rows spaced 0.9 m apart with tubers 38 cm apart in the row, arranged in a randomized complete block design with four replications. Each field trial was irrigated three times weekly using a center-pivot system, fertilized according to soil test results, and treated with insecticide and herbicide according to normal grower use recommendations. Fungicide treatments using chlorothalonil (Bravo Zn [38.5% chlorothalonil]; Syngenta Crop Protection, Inc., Greensboro, NC) at 2.48 liter/ha were applied every 7, 14, or 21 days to all four rows of each plot beginning in late June and continuing until mid- to late August for a total of 9, 5, and 3 sprays, respectively. A plot sprayer consisting of a tractor-mounted boom pressurized with an air compressor using Tee Jet Hollow Disc Cone D3-23 nozzles at a rate equivalent to 327 liter water/ha at 276 kPa/cm^2 (15 nozzles at 20.3-cm spacing) was used to apply all treatments. Plots were not inoculated but relied on natural dispersal of both *P. infestans* (US-8 genotype) and *A. solani* for disease establishment. Disease severity was rated weekly from late June to early September of each year using the Horsfall-Barratt rating scale. Vines were desiccated with diquat dibromide (Reglone Desiccant [37.3% diquat dibromide]; Syngenta Crop Protection, Inc.) (1.17 liter/ha) plus paraffinic petroleum oil (Peptoil [83% paraffinic petroleum oil]; Drexel Chemical Company, Memphis, TN) (2.34 liter/ha) in preparation for harvest. The two center rows of each plot (a total of 14.6 m of row) were machine harvested and graded in late September. Tubers were graded into US no. 1, undersize, and cull categories, with all tubers in the US no. 1 category from each treatment plot sorted, using an optical size grader, into six categories: <113 g, 113 to 170 g, 171 to 283 g, 284 to 369 g, 370 to 454 g, and >454 g. Specific gravity was determined for a representative tuber sample (113-to-283-g categories) from each plot.

Fungicide spray program evaluations in Washington. *Greenhouse studies*. All greenhouse studies were carried out at WSU-Pullman in 2001. Growing buds of

Table 2. Interaction of fungicide sprays and cultivar response to early blight in Wisconsin, 2003

Cultivar, treatment (application no.)[v]	Disease severity, early blight (%)[u]					Relative AUDPC[w]	Yield (t/ha)		SG[x]
	7 Jul	21 Jul	4 Aug	18 Aug	2 Sep		Total	US no. 1	
Russet Burbank									
Untreated	1.9	3.5	15.5	84.6	98.5	0.292	53.9	45.7	1.080
Chlorothalonil (1,4,7)	2.0	3.4	7.3	77.3	97.2	0.253	54.4	46.7	1.082
Chlorothalonil (1,3,5,7,9)	2.0	2.5	3.8	55.1	94.9	0.200	61.8	55.0	1.083
Chlorothalonil (1-9)	2.0	3.8	4.7	56.6	93.1	0.208	61.3	54.6	1.082
Defender									
Untreated	1.3	2.9	4.4	44.1	85.6	0.181	50.5	38.3	1.081
Chlorothalonil (1,4,7)	1.9	3.5	4.7	24.0	83.3	0.151	49.9	40.6	1.082
Chlorothalonil (1,3,5,7,9)	2.2	3.1	2.8	12.4	81.8	0.125	56.0	46.0	1.085
Chlorothalonil (1-9)	2.2	2.5	3.7	15.5	78.9	0.122	55.5	44.8	1.085
P > F	0.29	0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.23
LSD	NS	0.8	5.2	13.0	6.7	0.044	6.4	7.3	NS
Analysis[y]									
Effect of cultivar									
Russet Burbank	2.0	3.3	7.8	68.4	95.9	0.238	57.8	50.5	1.082
Defender	1.9	3.0	3.9	24.0	82.4	0.145	53.0	42.4	1.083
P > F	0.53	0.14	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.22
LSD	NS	NS	2.6	6.5	3.4	0.022	3.2	3.7	NS
Effect of fungicide									
Untreated	1.6	3.2	10.0	64.4	92.1	0.237	52.2	42.0	1.081
Chlorothalonil (1,4,7)	2.0	3.4	6.0	50.7	90.3	0.202	52.1	43.7	1.082
Chlorothalonil (1,3,5,7,9)	2.1	2.8	3.3	33.8	88.4	0.163	58.9	50.5	1.084
Chlorothalonil (1-9)	2.1	3.1	4.2	36.1	86.0	0.165	58.4	49.7	1.083
P > F	0.15	0.13	<0.01	<0.01	0.08	<0.01	<0.01	<0.01	0.09
LSD	NS	NS	3.7	9.2	NS	0.031	4.5	5.2	NS
Interaction[z]									
P > F	0.41	<0.01	0.03	0.45	0.99	0.66	0.93	0.88	0.68

[u] Severity rated on a Horsfall-Barratt scale of 0 (no infection) to 11 (all foliage and stems dead). Ratings were converted to percent.

[v] All fungicide applications were chlorothalonil (Bravo Zn 4.17F), 2.49 liter/ha. Application dates were: 1= 25 June, 2 = 2 July, 3 = 9 July, 4 = 16 July, 5 = 23 July, 6 = 30 July, 7 = 6 August, 8 = 13 August, and 9 = 20 August. *P* > F: analysis of variance was performed on data, and Fisher's protected least significant difference (LSD) was calculated (α = 0.05). NS = not significant at *P* = 0.05.

[w] Relative area under the disease progress curve (AUDPC). Data for each observation date were plotted on a graph and the area under the line was calculated for each treatment providing a measure of the relative severity of disease throughout the season. A disease rating of 100% severity for the entire season would produce a value of 1.0. All relative AUDPC values are expressed as a proportion of this value. Either decreased disease severity or later disease development will contribute to lower relative AUDPC.

[x] Specific gravity.

[y] Analysis of the effect of cultivar and fungicide treatment. For effect of cultivar, data was pooled for fungicide treatments and, for effect of fungicide treatment, data was pooled for cultivars.

[z] Interaction: cultivar–fungicide treatment.

Defender and Russet Burbank were cut with a disk-shaped cutter from certified seed tubers to produce a potato seed piece weighing approximately 130 g. Seed pieces were planted in a standard potting mix of peat moss, pumice, and sand (3:1:1 vol/vol/vol) in 15-cm-diameter pots. For each pot, 10 g of 16-16-16 N-P-K fertilizer was incorporated into the potting mix before planting. Inoculum of an isolate of the US-8 clonal lineage of *P. infestans* collected from a Russet Burbank plant in the Columbia Basin of Washington in 2000 was increased on excised leaves of Russet Norkotah in humidity chambers at 18°C. Sporangia were washed from infected sporulating leaflets, and the resultant suspension was chilled for 2 h at 4°C before inoculation. Plants, each approximately 55 cm tall, were inoculated on day 0, 7, 14, and 21 beginning at the preflowering stage. Multiple inoculations simulated a natural epidemic in which spores came into contact with exposed tissues at regular intervals as the plants grew and developed over the course of the season. Inoculations were done on plants by placing a 1-cm filter paper square, exposed to 0.05 ml of a sporangial suspension containing 10,000 sporangia/ml, onto the center of a leaflet. The side of the filter paper surface receiving the inoculum was placed against the plant surface and surface tension held the square in place. One leaflet was inoculated in the upper third, middle third, and lower third of the plant canopy on each inoculation date. Stems were inoculated at mid-stem height and within 15 cm of the top of the plant. If a lesion was present on a stem from a previous inoculation, inoculation was done below the existing lesions at mid-stem height, or either below or above existing lesions, depending on available tissue, at upper-stem heights. Inoculated plants were placed in a mist chamber for 18 h at 17 to 21°C. Following the mist chamber holding time, plants were moved to a greenhouse at 23 to 27°C during the day and 18 to 21°C at night. Inoculations were done during May through July when the natural photoperiod was at least 14 h; supplemental lighting was not used.

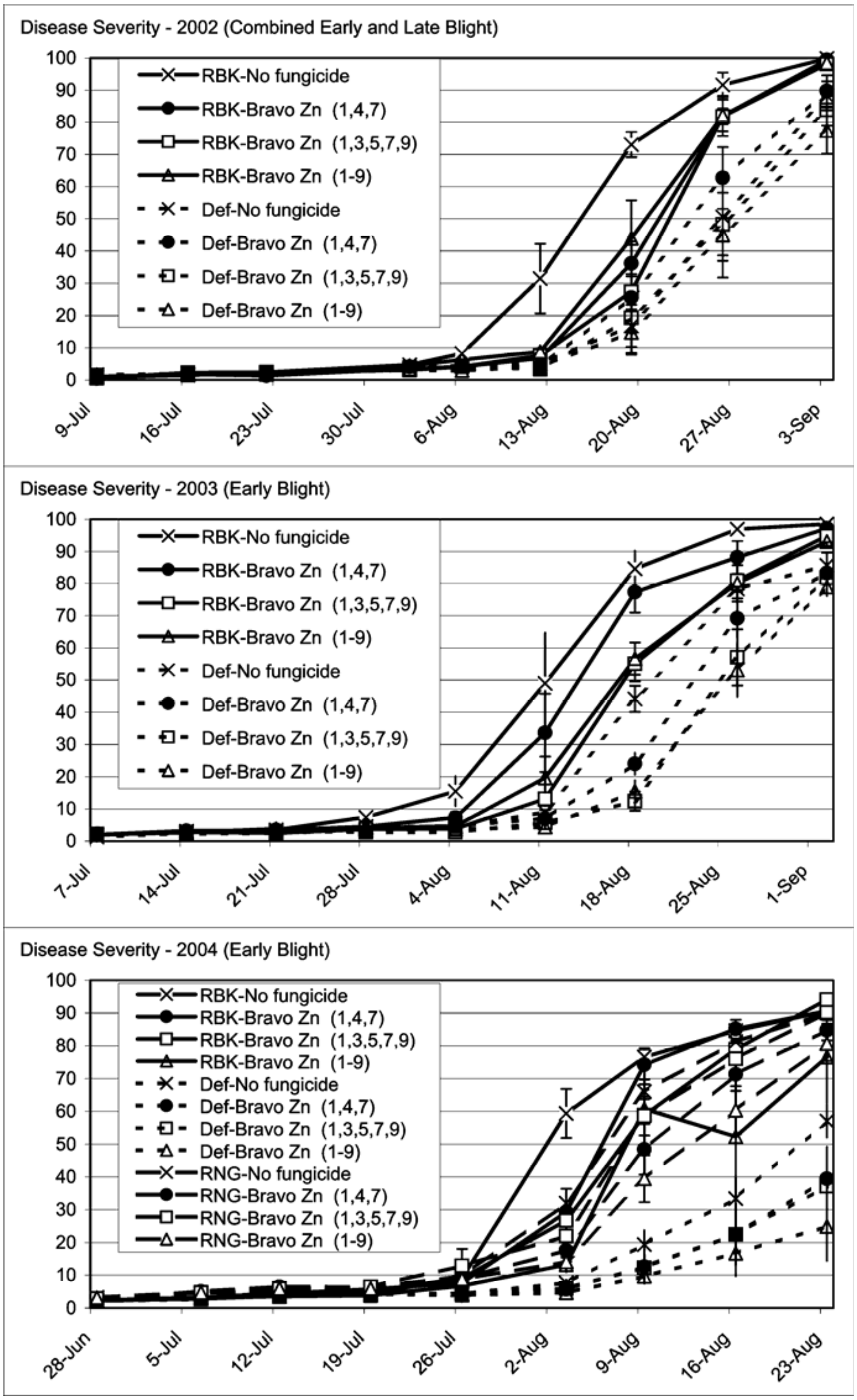

Fig. 2. Disease progression in fungicide treatment programs on Defender and Russet Burbank in field plots at the Hancock Agricultural Research Station, 2002 to 2004. Error bars represent standard error of the mean.

Fungicides and rates used in the tests were copper hydroxide (Kocide 2000 [53.8% copper hydroxide]; Griffin Corporation, Valdosta, GA) at 4.6 g a.i./liter, and mancozeb (Dithane Rainshield [75% zinc ion and manganese ethylene bisdithiocarbamate]; Rohm & Haas, Philadelphia) at 4.2 g a.i./liter (product and company names at the time the study was conducted). Fungicides were applied with a handheld sprayer at approximately 370 liter/ha. Fungicide rates were equivalent to those used in the field studies. Experimental treatments used on both cultivars included a nontreated control and fungicide treatments applied on day 0 at 3.5 h prior to inoculation (copper hydroxide and mancozeb), every 10 days (copper hydroxide and mancozeb), and every 20 days (mancozeb) to simulate the conventional and reduced application times used in the field study. The four treatment × cultivar combinations were arranged as randomized complete blocks of four replicates. The experiment was carried out twice.

Number of leaflets with lesions, area of lesions on leaves, length of lesions on stems, and total stem length were measured 7, 14, 21, and 33 days following inoculation. Percentage of surface area of leaflets with late blight symptoms was estimated following James (18). Late blight severity on stems was calculated by dividing the total length of lesions on stems by the length of the stems and multiplying by 100. AUDPC values for late blight lesion progression on stems were calculated using the proportion of disease on infected stems on each assessment date (2). Data for final late blight severity on infected leaflets and stem tissue and AUDPC values for disease on stems were analyzed by analysis of variance using the GLM procedure in SAS (version 6.12; SAS Institute, Cary, NC). Data from two tests were pooled because there were no significant test interactions (α = 0.05). Fisher's protected least significant difference (LSD) at $P = 0.05$ was used to compare treatment means.

Field studies. An experimental field trial was planted to Defender and Russet Burbank in 2001 at WSU-NWREC near Mount Vernon, WA, and the results reported (12). A subsequent trial was planted in 2002. Field plots consisted of six rows, 6.1 m long, with 23-cm in-row spacing and 1-m between-row spacing. There were two outside border or spreader rows of White Rose, two paired rows of Defender, and two paired rows of Russet Burbank per plot. Plots were arranged in randomized complete blocks, separated on all sides by 4.6-m alleys, and replicated four times. All plots were fertilized with a preplant broadcast application of 112 kg of N, 224 kg of KCl, 28 kg of $MnSO_4$, 5.6 kg of $ZnSO_4$, and 16.8 kg of B per hectare. An additional banded application of 10-34-0 (608 liter/ha) was made at planting. The herbicide metribuzin (Sencor 4F [41% metribuzin]; Bayer CropScience LP, Research Triangle Park, NC) was applied on 4 June for preemergence weed control at 0.56 kg a.i./ha. Plots were rated weekly for percent blighted foliage from 11 July to 6 September. Disease resulted from naturally occurring inoculum of the US-8 genotype of *P. infestans* as determined by allozyme analysis (6). Vines were flailed and desiccated with diquat dibromide herbicide (1.17 liter/ha) and harvested 17 days later on 23 September. Tubers were stored at 48°C until 21 October, when they were washed and sorted into U.S. no. 1 and U.S. no. 2 grades and individually weighed on an electronic sorter.

Six applications of copper hydroxide and mancozeb were made on 23 and 31 July, and 7, 15, 21, and 28 August, for the organic and conventional fungicide spray programs, respectively. Three applications of mancozeb were made on 23 July and 7 and 28 August for the reduced fungicide spray program. The 23 July application date was selected to coincide with the first report of late blight in the surrounding area. All fungicides were applied in 468 liter/ha at 262 kPa/cm^2 using a spray boom with flat fan nozzles (8002 tips; Spraying Systems Co., Wheaton, IL). Total rainfall from 23 May to 6 September was 10.7 cm, with 90% occurring before 28 July; rainfall was 0.89 cm during August and 0.2 cm from 1 to 6 September. Supplemental irrigation with drip tape delivered an additional 11.43 cm from 15 July to 23 August. The average maximum and minimum temperatures from 23 May to 6 September were 22.1 and 10.8°C, respectively.

Data for AUDPC values, tuber size distribution, and total yield were analyzed using the analysis of variance procedure in SAS (version 6.12; SAS Institute). Fisher's

Table 3. Interaction of fungicide sprays and cultivar response to early blight in Wisconsin, 2004

Cultivar, treatment (application no.)[v]	Disease severity, early blight (%)[u]					Relative AUDPC[w]	Yield (t/ha)			
	28 Jun	12 Jul	26 Jul	9 Aug	23 Aug		Total	US no. 1	171–369 g (%)	SG[x]
Russet Burbank										
Untreated	2.2	3.7	9.1	76.6	90.6	0.232	39.3	33.2	37.0	1.079
Chlorothalonil (1,4,7)	2.3	4.4	7.6	74.2	90.6	0.195	36.5	30.4	37.0	1.079
Chlorothalonil (1,3,5,7,9)	2.2	4.1	9.1	58.9	94.1	0.172	36.8	30.0	34.7	1.079
Chlorothalonil (1-9)	2.3	3.5	6.7	60.7	76.6	0.146	39.4	32.6	35.3	1.072
Ranger Russet										
Untreated	3.2	5.0	9.7	66.0	90.0	0.194	34.7	30.5	53.5	1.084
Chlorothalonil (1,4,7)	2.6	6.4	8.9	48.4	84.8	0.152	38.1	34.1	53.6	1.087
Chlorothalonil (1,3,5,7,9)	2.8	5.9	12.9	58.6	90.2	0.176	33.2	26.6	51.4	1.085
Chlorothalonil (1-9)	3.1	5.9	8.8	39.5	80.7	0.131	36.7	31.8	60.2	1.088
Defender										
Untreated	2.2	4.5	4.2	19.3	57.0	0.074	48.3	38.0	56.0	1.090
Chlorothalonil (1,4,7)	2.2	4.1	3.8	12.6	39.5	0.056	50.7	36.5	51.4	1.088
Chlorothalonil (1,3,5,7,9)	2.2	4.2	4.4	12.3	37.1	0.057	51.0	36.5	55.2	1.090
Chlorothalonil (1-9)	2.3	4.4	3.9	9.7	24.9	0.049	53.5	35.8	54.9	1.095
P > F	<0.01	<0.01	0.08	<0.01	<0.01	<0.01	<0.01	0.26	<0.01	<0.01
LSD	0.6	1.1	NS	17.1	26.4	0.038	6.4	NS	9.7	0.009
Analysis[y]										
Effect of cultivar										
Russet Burbank	2.3	3.9	8.1	67.6	86.5	0.186	38.0	31.6	36.0	1.077
Ranger Russet	2.9	5.8	10.1	53.1	86.4	0.163	35.7	30.8	54.7	1.086
Defender	2.2	4.3	4.1	13.5	39.6	0.059	50.9	36.7	54.4	1.091
P > F	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.01	<0.01	<0.01
LSD	0.3	0.6	3.0	8.5	12.7	0.019	3.2	4.2	4.9	0.004
Effect of fungicide										
Untreated	2.5	4.4	7.7	51.9	77.0	0.166	40.8	33.9	48.8	1.084
Chlorothalonil (1,4,7)	2.4	5.0	6.8	45.1	65.3	0.134	41.8	33.7	47.3	1.084
Chlorothalonil (1,3,5,7,9)	2.4	4.7	8.8	41.8	67.1	0.135	40.4	31.1	47.1	1.085
Chlorothalonil (1-9)	2.6	4.6	6.5	36.6	57.5	0.109	43.2	33.4	50.2	1.085
P > F	0.50	0.32	0.54	0.01	0.04	<0.01	0.42	0.61	0.66	0.99
LSD	NS	NS	NS	9.8	13.3	0.022	NS	NS	NS	NS
Interaction[z]										
P > F	0.64	0.30	0.97	0.36	0.69	0.23	0.67	0.83	0.72	0.24

[u] Severity rated on a Horsfall-Barratt scale of 0 (no infection) to 11 (all foliage and stems dead). Ratings were converted to percent.

[v] All fungicide applications were Bravo Zn 4.17F, 2.49 liter/ha. Application dates: 1= 23 June; 2 = 30 June; 3 = 7 July; 4 = 14 July; 5 = 21 July; 6 = 28 July; 7 = 4 August; 8 = 11 August; 9 = 18 August. Analysis of variance was performed on data, and Fisher's protected least significant difference (LSD) was calculated (α = 0.05). NS = not significant at $P = 0.05$.

[w] Relative area under the disease progress curve (AUDPC). Data for each observation date were plotted on a graph and the area under the line was calculated for each treatment providing a measure of the relative severity of disease throughout the season. A disease rating of 100% severity for the entire season would produce a value of 1.0. All relative AUDPC values are expressed as a proportion of this value. Either decreased disease severity or later disease development will contribute to lower relative AUDPC.

[x] Specific gravity.

[y] Analysis of the effect of cultivar and fungicide treatment. For effect of cultivar, data was pooled for fungicide treatments and, for effect of fungicide treatment, data was pooled for cultivars.

[z] Interaction: cultivar–fungicide treatment.

protected LSD at $P = 0.05$ was used to compare treatment means.

Economic analysis. Data were analyzed for economic returns based on contract assumptions developed by Dr. Tom Schotzko at WSU-Pullman. The assumptions included $73.55 per metric ton (t) of usables; a size incentive for 171-g and larger tubers of $0.549/t per percentage point above 50% to a maximum of 70% ($10.98) and a deduction of $0.549 per percentage point below 50% to a maximum of $2.74 at 45%; and a grade incentive that paid $0.549 per percentage point per metric ton for each percentage point above 50% U.S. no. 1s to a maximum of $6.04/t, and no deduction below 50%. Usables usually are defined as all tubers grading U.S. no. 1 or U.S. no. 2. A complete breakdown by grade was not determined during the grading process. Thus, for this analysis, usables are defined as total yield less all tubers under 113 g. Processing culls were valued at $21.96/t up to a maximum of 10% of the delivered volume. Processing culls were defined as those tubers that grade as U.S. no. 1 or U.S. no. 2 processing grade but are less than 113 g in size. The gross value of each replication was adjusted for the cost of treatment (materials and application) based on cost data typical to northwestern Washington. Kocide 2000 was priced at $6.38/kg and Dithane Rainshield at $6.60/kg. Costs per application were assumed to be $22.23/ha. A value differential often associated with organic potato was not factored into this economic analysis.

Fig. 3. Late blight lesions on leaflets of Defender **(A)** and Russet Burbank **(B)** on plants grown in the greenhouse with a 20-day interval between applications of mancozeb.

RESULTS

Field comparisons of late blight resistance in western Washington. The level of late blight on the foliage of Defender was 17 to 50%, 17 to 44%, and 30 to 36% of that obtained on Russet Burbank, the susceptible control, during years regarded as having low disease pressure (1999 and 2001), intermediate disease pressure (1996, 1997, and 2002), and high disease pressure (1998 and 2000), respectively (Fig. 1).

Fungicide comparison of host resistance and fungicide spray regimes in Wisconsin. Early blight first appeared in mid- to late June each year of the field trials and steadily progressed throughout each growing season, leading to high levels of foliar infection. Although symptoms of early blight were common on all cultivars, disease progressed slowest on Defender. In comparisons between Russet Burbank and Defender (2002 to 2003; Tables 1 and 2; Fig. 2) and Russet Burbank, Ranger Russet, and Defender (2004; Table 3; Fig. 2) with data pooled for fungicide treatments, the Defender AUDPC values were significantly lower than Russet Burbank and Ranger Russet values. Fungicides helped to slow early blight progress on all cultivars in 2003 and 2004, as indicated by lower AUDPC values, but not in 2002, when weather conditions were less favorable for early blight development. When data were pooled for both cultivars, fungicide treatment slowed early blight progress, but there was no obvious advantage of one treatment schedule over another.

Late blight appeared in only one year, 2002, of the Wisconsin study, primarily on

Table 4. Severity of late blight on foliage of Defender and Russet Burbank treated with copper hydroxide at 10-day intervals and mancozeb at 10- and 20-day intervals[w]

	Stems		Leaves
Fungicide treatment, spray interval	**Final severity rating** [x]	**AUDPC**[y]	**Final severity rating**[z]
Defender			
No-fungicide control	12	220 b	29 b
Copper hydroxide, 10-day	1	11 a	0 a
Mancozeb, 10-day	5	82 ab	1 a
Mancozeb, 20-day	8	90 ab	3 a
LSD ($P = 0.05$)	NSD	140	19
Russet Burbank			
No-fungicide control	54 b	741 b	100 b
Copper hydroxide, 10-day	20 a	200 a	15 a
Mancozeb, 10-day	15 a	191 a	38 a
Mancozeb, 20-day	18 a	166 a	41 a
LSD ($P = 0.05$)	19	282	44

[w] Data are the pooled results of two greenhouse tests. Numbers within a column followed by the same letter are not significantly different as determined by Fisher's least significant difference (LSD) test; NSD = no significant difference.
[x] Percentage of surface area of leaflets with late blight symptoms.
[y] Area under disease progress curve.
[z] Length of lesions divided by length of stems multiplied by 100.

Russet Burbank, where the disease contributed to significant leaflet and petiole infection on plots not treated with fungicide. Approximately 1% of the Defender foliage exhibited symptoms of late blight on individual leaflets on the 3 September 2002 rating (*data not shown*), just prior to vine desiccation in preparation for harvest, regardless of fungicide treatment. Symptoms of late blight were not observed on harvested tubers. All fungicide treatment schedules provided significant control of late blight on Russet Burbank, and fungicide application was not necessary to control late blight on Defender. Yields of Russet Burbank were significantly higher than Defender in both 2002 and 2003; however, in 2004, Defender yields were higher than both Russet Burbank and Ranger Russet. When data were pooled for cultivars, fungicide treatment provided significant yield improvement in 2003 but not in 2002 and 2004.

Fungicide spray program evaluations in Washington. *Greenhouse studies*. Lesions on leaflets of Defender did not expand onto petioles, whereas lesions on leaflets of Russet Burbank expanded onto petioles and led to development of late blight symptoms on the entire plant (Fig. 3). Abundant sporulation was observed on Russet Burbank, but not Defender, when plants were removed from mist chambers for disease assessments at days 7, 14, and 21. Lesions and sporulation developed only on the tissues of the inoculated Russet Burbank plants not protected with fungicide.

The interaction between cultivar and spray program for the pooled data sets was significant (P = 0.05) for final stem severity ratings and AUDPC values on stems, and final leaf severity ratings. Mean values for fungicide spray treatments did not differ significantly among the two cultivars, but were approximately three times lower for the no-fungicide control on Defender compared with Russet Burbank (Table 4). Stem AUDPC values on Defender were significantly lower than the no-fungicide control when copper hydroxide rather than mancozeb was used. Stem AUDPC values were approximately equivalent for both fungicides on Russet Burbank. Final leaf severity ratings were similar to the stem ratings in that the 10- and 20-day fungicide application intervals were statistically the same for all three spray programs on Defender and Russet Burbank, even though the no-fungicide controls of the Defender plants had about three times less disease than Russet Burbank.

Field studies. Late blight was not detected until 13 August on Defender, but occurred sometime between 3 and 9 August on Russet Burbank (Fig. 4A and B). Late blight disease pressure was assigned as intermediate based on AUDPC values of Defender obtained from field trials of five preceding years (Fig. 1). Like the greenhouse study, the interaction between cultivar and fungicide spray program for AUDPC values was significant (P = 0.0001). Although the organic, conventional, and reduced fungicide spray programs were statistically similar on both Defender and Russet Burbank, AUDPC values were nearly sixfold (263 versus 1,542) lower for no-fungicide on Defender compared with no-fungicide on Russet Burbank (Table 5; Fig. 5). Total yield was higher for Defender than for Russet Burbank regardless of fungicide spray program (Table 5). Yield for all tuber size

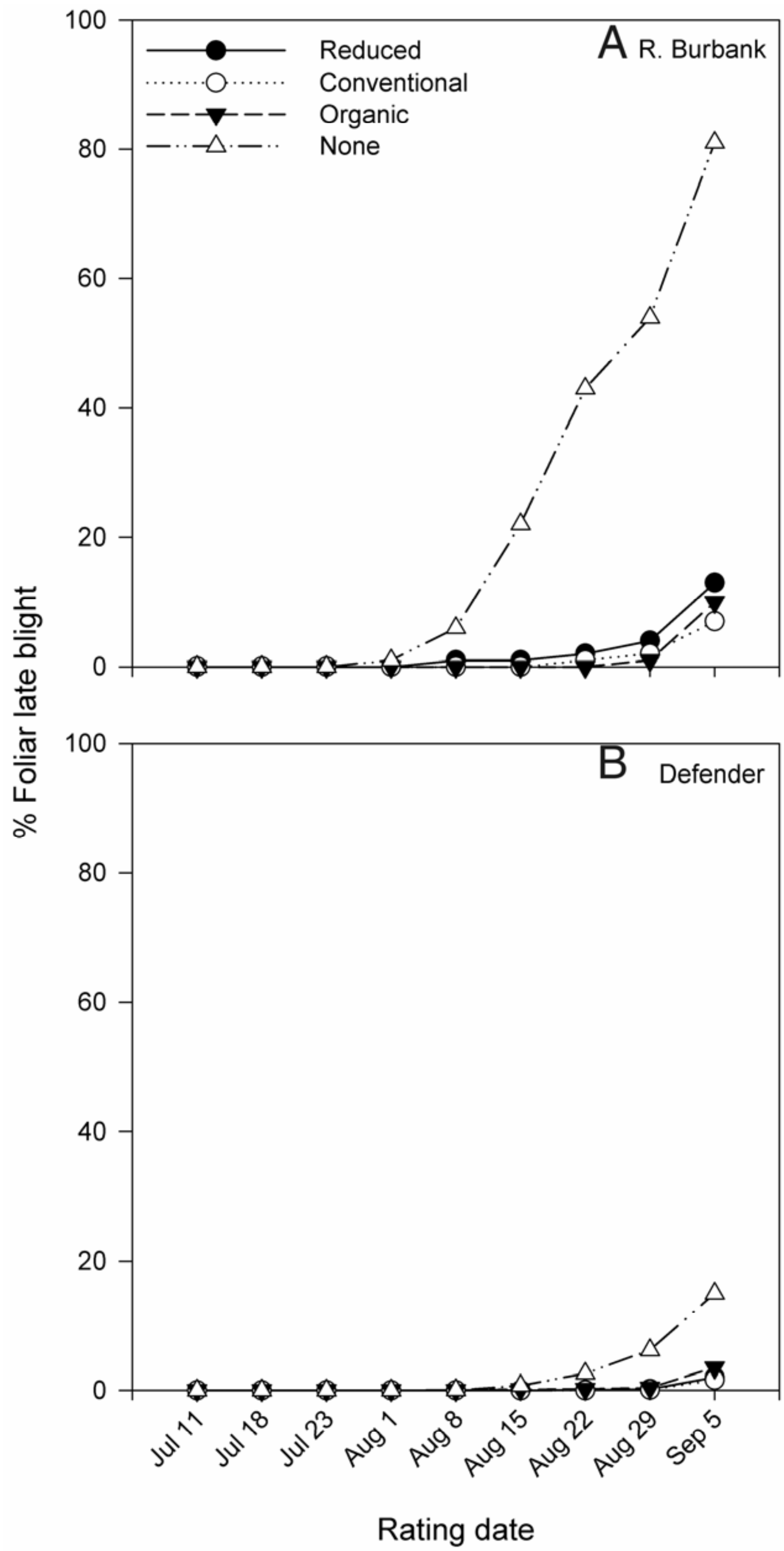

Fig. 4. Disease progress curves for fungicide spray programs on **A,** Russet Burbank and **B,** Defender obtained in the field at Washington State University-Mount Vernon NWREC in 2002.

Table 5. Area under disease progress curve values (AUDPC), total yield, and adjusted returns for spray programs on Defender and Russet Burbank used to control late blight in field studies at Washington State University-Mount Vernon NWREC in 2002

Cultivar, foliar fungicide spray program	AUDPC[y]	Total yield (t/ha)[y]	Returns ($/ha)
Defender			
No-fungicide control	263 b	77.9	6,102
Organic with copper hydroxide (3.36 kg/ha)	52 a	79.0	6,076
Conventional with mancozeb (2.24 kg/ha)	29 a	81.0	6,304
Reduced sprays with mancozeb (2.24 kg/ha)	32 a	79.0	6,305
LSD (*P* = 0.05)[z]	64	NSD	
Mean	…	…	6,196
Russet Burbank			
No-fungicide control	1,542 b	58.7 c	3,162
Organic with copper hydroxide (3.36 kg/ha)	183 a	74.1 a	5,179
Conventional with mancozeb (2.24 kg/ha)	147 a	72.4 ab	4,700
Reduced sprays with mancozeb (2.24 kg/ha)	257 a	67.7 b	4,511
LSD (*P* = 0.05)[z]	266	5.8	
Mean	…	…	4,388

[y] Numbers within a column followed by the same letter are not significantly different as determined by Fisher's least significant difference (LSD) test; NSD = no significant difference.
[z] *P* value is for analysis of variance.

Fig. 5. Photograph of Defender (left two rows) and Russet Burbank (right two rows) in experimental field plot at Washington State University-Mount Vernon NWREC where no fungicide was applied.

categories (Table 6) was statistically the same among treatments for Defender. However, yield among treatments in the total <113 g, U.S. no. 1s 171-to-283-g and 284-to-340-g, and total and percent U.S. no. 1s >113 g categories was significantly (*P* = 0.05) different for Russet Burbank. In the cases of total <113 g, U.S. no. 1s 284 to 340 g, and total U.S. no. 1s, the organic, conventional, and reduced spray programs had similar yields that were significantly better than the yields for the no-fungicide spray program. Also, the organic spray program on Russet Burbank had significantly more U.S. no. 1s in the 171-to-283-g size category than the other programs, and the conventional spray program on Russet Burbank had significantly more U.S. no. 2s + culls than the other treatments. Data were not pooled because of a significant cultivar–treatment interaction.

Economic analysis. Adjusted receipts by treatment for each cultivar are described in Table 5. The mean returns associated with Defender were higher than those associated with Russet Burbank. Adjusted returns on Defender ranged from $6,076/ha for the organic program to $6,305/ha for the reduced fungicide program. Adjusted returns on Russet Burbank ranged from $3,162/ha for the no-fungicide program to $5,179/ha for the organic fungicide program. Within cultivars, treatments (including no-fungicide) were similar on Defender. For Russet Burbank, all three fungicide spray treatments generated considerably higher returns than the no-fungicide treatment. The conventional and reduced fungicide programs were comparable ($4,700 and $4,511/ha) whereas the organic program generated slightly higher return ($5,179/ha).

DISCUSSION

Since the mid 1990s, the TSPVD program has annually provided breeding materials to various locations throughout North America in order to have them evaluated for resistance to late blight. In spite of location or year, the resistance to late blight in Defender has appeared to be durable, making it an especially good candidate for reduced- and organic-fungicide spray programs (24). Data from Wisconsin over three consecutive years demonstrates the value of Defender resistance to both late blight and early blight. Although fungicide treatment helped to manage early blight on all cultivars, disease progress (AUDPC) in nonsprayed Defender plots was slower than disease progress in plots of Russet Burbank and Ranger Russet plots treated with any of the spray schedule regimes, including weekly treatment with the highest labeled rate of chlorothalonil.

Under high disease pressure in Washington greenhouse tests, and intermediate and low disease pressure in the field in Washington in 2002 and 2001, respectively, the organic, conventional, and reduced fungicide spray programs were approximately the same in controlling late blight on Defender. Although a similar statement also could be made for Russet Burbank, the severity of disease was three to six times less on Defender than Russet Burbank due to Defender's improved resistance. Lesions did not expand to petioles on Defender in greenhouse tests, and late blight was observed nearly 1 week later on Defender in the field in Washington. Further, the observed sporulation in lesions, stem and leaf severity ratings, and AUDPC values were consistently lower on Defender than Russet Burbank. These observations, along with those made on Defender in Wisconsin and by others (25), suggest that several components of late blight resistance may be operative in this cultivar and, under high disease pressure, growers will face less risk of a rapidly developing epidemic.

The first fungicide applications made in the field in Washington deliberately coincided with the first reports of late blight in the surrounding vicinity. The importance of applying regular protective foliar fungicides early in order to prevent infections and assure good distribution of fungicide within the canopy is commonly known. Application timing is especially critical for protecting a susceptible cultivar like Russet Burbank. With a cultivar like Defender that has improved resistance to late blight, there may be more flexibility in application timing. In the Washington field study, AUDPC values for the conventional and reduced fungicide spray programs were virtually identical on Defender, but were lower for the conventional program compared with the reduced program on Russet Burbank. In the Washington study, a reduced number of fungicide applications

Table 6. Size distribution of US no. 1 and US no. 2 tubers of Defender and Russet Burbank in experimental field trial at Washington State University-Mount Vernon NWREC in 2002[w]

		US no. 1[x]									
		t/ha								US no. 2 + culls[y]	
Cultivar, treatment[z]	Total (t/ha) <113 g	113–170 g	171–283 g	284–340 g	341–397 g	>397 g	Total >113 g	Percent >113 g	Total (t/ha)	Percent
Defender										
Control	11.9	9.8	17.5	6.5	6.0	10.1	49.9	64.0	16.1	20.7
Organic	10.4	9.4	17.7	7.7	6.1	12.6	53.4	67.6	15.1	19.1
Conventional	10.8	10.0	19.5	7.3	6.0	13.0	55.7	68.8	14.4	17.7
Reduced	10.2	10.1	19.0	8.1	5.5	13.1	55.8	70.7	13.0	16.4
LSD (P = 0.05)	NSD	NSD	NSD	NSD	NSD	NSD	NSD	NSD	NSD	NSD
Russet Burbank										
Control	17.7 b	14.3	13.0 c	1.9 b	1.1	1.9	32.3 b	55.0 c	8.8 a	15.0
Organic	12.2 a	15.2	2.0 a	5.3 a	2.6	3.2	50.3 a	67.7 a	11.5 a	15.7
Conventional	14.4 a	14.0	16.7 bc	5.8 a	3.1	3.4	4.0 a	59.2 bc	15.0 b	20.8
Reduced	13.8 a	14.8	18.3 b	4.5 a	2.4	3.6	43.6 a	64.5 ab	10.2 a	15.0
LSD (P = 0.05)	2.8	NSD	4.2	1.6	NSD	NSD	7.4	7.1	3.0	NSD

[w] Numbers within a column followed by the same letter are not significantly different as determined by Fisher's least significant difference (LSD) test; NSD = no significant difference.
[x] Tubers hand-sorted.
[y] Not marketable on the fresh market.
[z] Treatments: Control = no-fungicide control, Organic = organic with copper hydroxide (3.36 kg/ha), Conventional = conventional with mancozeb (2.24 kg/ha), and Reduced = reduced sprays with mancozeb (2.24 kg/ha). P value is for analysis of variance.

was chosen as the method of reducing the costs associated with fungicide applications rather than by reducing fungicide rates. Naerstad et al. (23) observed that fungicide application intervals could be extended when there was a high level of field resistance to both foliar and tuber late blight, as shown for Defender (24,25). For Defender, the organic program was comparable with the conventional program, and the reduced spray program slightly exceeded the conventional program for maximizing returns. For Russet Burbank, the organic program returns exceeded both the conventional and reduced fungicide program returns, which were comparable. However, returns for all three spray programs were considerably higher when compared with the no-fungicide spray program on Russet Burbank. Copper hydroxide was chosen for the organic program even though late blight foliar fungicide programs with other types of protectant fungicides generally have been shown to be more effective (16). However, at the time of the study, copper hydroxide was one of the few alternatives for use in producing organic potato.

The yield potential of Defender and Russet Burbank reported by Thornton and Knowles (32,33) was not observed in the Washington field trial because the crop was grown for only 123 days in western Washington under conditions favorable to late blight, rather than in the Columbia Basin under long-season conditions favorable to tuber bulking. Even so, both the conventional and reduced spray programs were comparable in managing late blight on Defender. In fact, the highest net returns of the study ($6,304 and $6,305/ha) were achieved for the two fungicide programs on Defender. In Wisconsin, the yield of US no. 1 tubers was similar for both Defender and Russet Burbank for two of the three evaluation years.

The availability of a potato cultivar with acceptable yield and processing characteristics as well as an improved level of resistance to late blight is highly desirable. For growers and processors wishing to reduce disease management inputs and reduce the risk of foliar diseases, Defender provides an inviting alternative to currently available cultivars that need to be treated regularly with fungicides for disease management and risk reduction. Although Defender has useful levels of resistance to both late and early blights, its higher-than-normal susceptibility to common scab may limit adoption unless effective common scab management can be employed by growers. Tubers also are prone to greening. Even if only 20% of Washington and Wisconsin potato growers adopted this new cultivar, savings of several million dollars due to lower fungicide costs and fewer losses in storage could result. Defender additionally presents a viable alternative for organic potato producers. All evidence to date suggests that its improved resistance to late blight and early blight is a long-lasting type of resistance that promises to reduce fungicide use.

ADDENDUM

The University of Idaho, acting on behalf of the Northwest (Tri-State) Potato Variety Development Program, has received Plant Variety Protection for Defender with licensing of this variety being conducted by the Potato Variety Management Institute (PVMI). Contact information for growers of Defender may be found at: http://www.pvmi.org/seed_growers/seed_growers.htm.

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