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L’effet des fongicides de la strobilurine sur la lutte contre l’alternariose (*Alternaria solani*) et le rendement de la pomme de terre cultivée sous deux régimes de fertilité azotée

William MacDonald, Rick D. Peters, Robert H. Coffin et Christian Lacroix

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Résumé de l'article

L’alternariose, causée par *Alternaria solani*, est une maladie omniprésente qui peut réduire le rendement de la pomme de terre. Une fertilisation adéquate de la culture et l’application de fongicides appropriés suppriment généralement le développement de cette maladie. Des essais en champs ont été effectués à l’Île-du-Prince-Édouard pour déterminer si des analogues de la strobilurine, notamment l’azoxystrobine et la pyraclostrobine, pouvaient supprimer l’alternariose de la pomme de terre (cv. Shepody et Russet Burbank) cultivée sous deux régimes de fertilité azotée (forte et faible doses de N). L’azoxystrobine et la pyraclostrobine ont été associées au rendement total en tubercules significativement supérieur pour Russet Burbank en 2003 et pour Shepody en 2004, comparativement à des parcelles n’ayant reçu aucun fongicide apparenté à la strobilurine. La fertilité azotée n’a entraîné aucune différence significative du rendement, bien que la dose élevée d’azote ait significativement réduit la maladie dans les parcelles témoins de Russet Burbank en 2004. En raison de l’absence de l’alternariose en 2003, l’augmentation du rendement du cv. Russet Burbank peut être attribuée aux modifications causées par les produits de la strobilurine dans la physiologie et le développement des plantes traitées. En 2004, l’alternariose a été importante dans les parcelles témoins inoculées, mais la suppression a été significative dans les parcelles ayant reçu de l’azoxystrobine ou de la pyraclostrobine, quels que soient le cultivar ou le régime de fertilité. Ainsi, les producteurs devraient appliquer uniquement les quantités d’azote nécessaires pour optimiser les rendements en tubercules et contrôler l’alternariose avec des fongicides.

Effect of strobilurin fungicides on control of early blight (*Alternaria solani*) and yield of potatoes grown under two N fertility regimes

William MacDonald[1], Rick D. Peters[2], Robert H. Coffin[3], and Christian Lacroix[1]

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Early blight, caused by *Alternaria solani*, is a ubiquitous disease that can reduce potato yield. Adequate crop fertility and appropriate fungicide applications usually suppress the development of this disease. Field trials were established in Prince Edward Island to determine whether strobilurin analogs, namely azoxystrobin and pyraclostrobin, could suppress early blight of potatoes (cvs. Shepody and Russet Burbank) grown under two nitrogen (N) fertility regimes (high or low N). Azoxystrobin and pyraclostrobin were linked to significantly higher total tuber yield for Russet Burbank in 2003 and Shepody in 2004 when compared to plots receiving no strobilurin fungicides. No significant differences in total tuber yield based on N fertility were observed, although the high N rate decreased disease in Russet Burbank control plots in 2004. Due to an absence of early blight in 2003, the increase in Russet Burbank yield may be attributed to the physiological and developmental alterations brought about by strobilurin products in treated plants. In 2004, early blight was severe in inoculated control plots, but it was significantly suppressed in plots having received azoxystrobin or pyraclostrobin, regardless of the cultivar type or fertility regime. Therefore, to prevent unnecessary N inputs, growers need to supply only the necessary N amount to optimize tuber yields and manage early blight with fungicides.

Keywords: *Alternaria solani*, azoxystrobin, early blight, potato, pyraclostrobin, *Solanum tuberosum*.

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Mots clés : *Alternaria solani*, alternariose, azoxystrobine, pomme de terre, pyraclostrobine, *Solanum tuberosum.*

1. Department of Biology, University of Prince Edward Island, 550 University Ave., Charlottetown, PE, Canada C1A 4P3
2. Agriculture and Agri-Food Canada, Crops and Livestock Research Centre, 440 University Ave., Charlottetown, PE, Canada C1A 4N6; corresponding author e-mail: petersr@agr.gc.ca
3. Cavendish Farms, P.O. Box 3500, Summerside, PE, Canada C1N 5J5

INTRODUCTION

Early blight, caused by *Alternaria solani* Sorauer, is a common potato (*Solanum tuberosum* L.) disease found in production areas throughout North America (Franc and Christ 2001). The disease often occurs initially on older, less productive foliage, followed by a gradual upward progression within the canopy, resulting in premature leaf senescence (Franc and Christ 2001; Rotem 1994). If the inoculum load is high during favourable environmental conditions, early blight may become severe enough to cause significant reductions in yield (Kapsa and Osowski 2003; Patel *et al.* 2004; Shtienberg *et al.* 1996; Teng and Bissonnette 1985; van der Waals *et al.* 2001). Under such conditions, frequent applications of protectant fungicides are often required to reduce foliar disease severity and subsequent yield loss.

In addition to fungicidal control, optimal soil fertility and plant nutrition may decrease the severity of early blight (Lambert *et al.* 2005). For example, high rates of nitrogen (N) fertilizer have been shown to suppress early blight by postponing natural senescence (Barclay *et al.* 1973; Soltanpour and Harrison 1974). However, the excess N required for early blight control may suppress potato yield by delaying tuber formation and bulking (Westermann 1993), and decrease crop quality by lowering the dry matter content of immature tubers. In addition, fertility management has become a concern in recent years, especially with regard to nitrate contamination of groundwater sources in close proximity to potato systems (Davenport *et al.* 2005). For this reason, it has been suggested that growers manage early blight with fungicides while applying N at rates which optimize yield and not necessarily disease control (Lambert *et al.* 2005; MacKenzie 1981).

A novel group of fungicides, the strobilurins, have demonstrated fungicidal activity against numerous foliar pathogens (Sauter *et al.* 1999). Their cytostatic effects stem from the inhibition of cellular respiration by blocking electron transfer at the cytochrome-bc_1 complex in mitochondria (Bartlett *et al.* 2002). One active ingredient in particular, azoxystrobin, is currently used by many potato growers because of its high activity against *A. solani*. Because strobilurin fungicides are active against a wide range of fungal species (Bartlett *et al.* 2002), azoxystrobin may also be suppressing other pathogens, such as *Verticillium dahliae* Kleb., believed to predispose potato foliage to early blight.

In addition to their direct fungicidal effects, strobilurin chemicals may induce physiological and developmental alterations in the foliar tissues of treated plants. These alterations are often observed as an enhanced and prolonged greening of foliage. Spinach leaves treated with kresoxim-methyl, a strobilurin derivative, exhibit enhanced nitrate reduction, which translates into an increase in the plant's utilization of nitrogen (Glaab and Kaiser 1999). This enhanced nitrate reduction may be responsible, at least partially, for the "greening effect" observed in crops treated with kresoxim-methyl and other strobilurin fungicides. When treated with kresoxim-methyl, wheat leaves have been observed to have a decreased production of ethylene, a hormone known to accelerate leaf senescence (Grossman and Retzlaff 1997). When treated with azoxystrobin, wheat leaves demonstrated a delay in senescence due to enhanced antioxidative activity via superoxide dismutase, which protects foliar tissues from the harmful effects of active oxygen species (Wu and von Tiedemann 2001). These non-fungicidal, secondary effects delay foliar senescence, which may contribute to improving yield.

Assuming that the activity of azoxystrobin in potato plants is similar to the aforementioned strobilurin-plant interactions, azoxystrobin applications to potato crops may delay foliar senescence and enhance tuber yield. Furthermore, since strobilurin fungicides enhance nitrate reduction and maintain the green leaf area of a crop, application of these chemicals may also allow potato growers to reduce the rate and frequency of N fertilizer applications. This is especially important in Prince Edward Island (PEI), Canada, where groundwater contamination, as a result of elevated levels of nitrate, has occurred more frequently in recent years (Prince Edward Island Environmental Advisory Council 2007).

Several studies have confirmed the effectiveness of strobilurin fungicides for control of early blight caused by sensitive populations of the pathogen (Miller and Rosen 2005; Pasche *et al.* 2004). However, despite the information available about their general performance, no published data is available concerning their efficacy for early blight control in the Maritime regions of Canada. The objective of this study was to evaluate, under field conditions, the influence of two strobilurin analogs (azoxystrobin and pyraclostrobin), under different N fertility regimes, on potato yield and early blight control in PEI.

MATERIALS AND METHODS

Plot design

Plots were established in 2003 and 2004 at the Cavendish Farms Experimental Research Station in New Annan, Prince Edward Island, Canada. The soil at this site is a fine sandy loam (Orthic Podsol in FAO classification; Carter and Sanderson 2001). Plots were planted in areas not planted with potatoes during the two previous years. Two years prior to potato planting, a barley crop was underseeded with a mixed grass/legume crop consisting of Timothy grass and clover.

Certified seed tubers of cvs. Shepody and Russet Burbank were planted in plot islands on 20 May 2003 and 24 May 2004. Potato seed pieces were planted with a 25 cm and 46 cm within-row spacing for Shepody and Russet Burbank, respectively. Each plot consisted of four rows (two rows of Shepody and two rows of Russet Burbank) measuring 6.1 m in length with 91 cm spacing between rows; the two outer rows were used as guard rows. Plot islands were separated by fallow areas approximately 4 m wide to permit the application of chemicals with a tractor-mounted sprayer (Hardi three-point hitch model). This separation of treated blocks reduces drift concerns and prevents mechanical damage to foliage caused by tractor wheels during spraying.

Chemical treatments

At planting (for both years), 15-15-15 (N-P-K) fertilizer was applied at a rate of 1121 kg ha^{-1} using the banding technique, giving approximately 165 kg ha^{-1} usable N. All plots received standard commercial pesticides to control weeds and insects. The herbicides linuron (3-(3,4-dichlorophenyl)-1-methoxy-1-methylurea) at 1.25 kg a.i. ha^{-1} and paraquat (1,1'-dimethyl-4,4'-bipyridinium) at 750 g a.i. ha^{-1} were applied for pre-emergence weed control. Throughout the growing season, the plots were sprayed one time each with foliar insecticides spinosad (2-{(6-Deoxy-2,3,4-tri-O-methyl-alpha-L-mannopyranosyl)oxy}-13-{{5-(dimethylamino)tetrahydro-6-methyl-2H-pyran-2-yl}oxy}-9-ethyl-) at 72 g a.i. ha^{-1} and imidacloprid ((EZ)-1-(6-chloro-3-pyridylmethyl)-N-nitroimidazolidin-2-ylideneamine) at 48 g a.i. ha^{-1} for control of the Colorado potato beetle, *Leptinotarsa decemlineata* Say [Coleoptera: Chrysomelidae], and aphids [Homoptera: Aphididae]. Plots were also sprayed post-emergence with clethodim herbicide ((5RS)-2-{(E)-1-[(2E)-3-chloroallyloxyimino]propyl}-5-[(2RS)-2-(ethylthio)propyl]-3-hydroxycyclohex-2-en-1-one) (15 g a.i. ha^{-1}) to suppress couch grass.

The experimental design was a randomized block (factorial) with fungicide treatments (control, azoxystrobin or pyraclostrobin) and nitrogen fertility rates (high or low) as factors, with each treatment combination occurring once in each of the four replications. To facilitate mechanical planting, seed of a particular cultivar was planted continuously across successive plot islands. Therefore, cultivars were not randomly assigned to plot locations and could not be considered as a factor in subsequent analyses of variance.

In 2003, the fungicide chlorothalonil (tetrachloroisophthalonitrile) was applied five times at 1 kg a.i. ha^{-1} during the early part of the growing season to prevent the development of late blight. However, because chlorothalonil, even though applied early in the season, could still potentially have had a suppressing effect on the development of early blight, an initial application of chlorothalonil was followed by five applications of fluazinam (3-chloro-N-(3-chloro-5-trifluoromethyl-2-pyridyl)-α,α,α-trifluoro-2,6-dinitro-p-toluidine) at 200 g a.i. ha^{-1} in 2004. Experimental fungicide treatments, in addition to the aforementioned applications, included controls treated with either chlorothalonil (2003) or fluazinam (2004), azoxystrobin treatments (methyl (E)-2-{2-[6-(2-cyanophenoxy)pyrimidin-4-yloxy]phenyl}-3-methoxyacrylate), and pyraclostrobin treatments (methyl {2-[1-(4-chlorophenyl)pyrazol-3-yloxymethyl]-phenyl}(methoxy)carbamate). Each of the azoxystrobin and pyraclostrobin plots were sprayed twice (once in late July/early August and once in early September) at a rate of 162.5 g a.i. ha^{-1} and 140 g a.i. ha^{-1}, respectively. Fungicides were applied with a tractor-mounted Hardi three-point hitch sprayer calibrated to apply 40 L ha^{-1}.

Fertility treatments included two rates of N fertilizer. Initial N application for all treatments was 165 kg ha^{-1} as starter fertilizer banded at planting as described above (standard N application rate). Plots receiving the high rate of N fertilizer were top-dressed with an additional 165 kg ha^{-1} of ammonium nitrate (34% N) in mid-July for a total of 55 kg ha^{-1} available N.

Plot inoculation

Due to the lack of natural disease development, attempts were made to initiate fungal infections in the research plots by inoculating plants with a conidial suspension of *A. solani*. Conidia were produced by plating several virulent *A. solani* isolates obtained locally onto clarified V-8 agar and incubating them in a growth cabinet set at 21°C with alternating exposure to UV light and darkness (12 h UV exposure followed by 12 h darkness). After 12-14 d, the cultures were profusely covered with spores, and inoculum was prepared by flooding the plates with 40-50 mL sterile distilled water and gently rubbing the surface of the plates with a rubber policeman to dislodge the conidia. The resulting suspensions were combined and then mixed with 10 L of sterile distilled water. The concentration of conidia was determined with a hemacytometer and the final concentration was adjusted, with additional sterile distilled water, to 5 x 10^3 conidia mL^{-1}. The isolates were determined to be sensitive to azoxystrobin using an *in vitro* agar assay which measured inhibition of spore germination in the presence of the chemical (MacDonald *et al.*, unpublished data).

Plots were artificially inoculated on 3 September 2003 and 21 August 2004 with the conidial suspensions using a hand-held sprayer. A total of 200 mL of inoculum was applied per row. Inoculations were performed at dusk so that leaves would remain wet for several hours following inoculation.

Crop assessments

At the end of the season, while the foliage was still green, early blight disease severity was assessed visually in each plot. The assessments were made first by estimating the percentage of foliage showing early blight lesions and assigning a disease rating based on the Horsfall-Barratt disease assessment scale (Horsfall and Barratt 1945).

Prior to harvest, plots were vine-killed with diquat (9,10-dihydro-8a,10a-diazoniaphenanthrene) at 300 g a.i. ha^{-1}. Tubers from plots were machine-harvested from the two inner rows, one each of Russet Burbank and Shepody, on 8 October 2003 and 7 October 2004. All tubers harvested from each plot (6.1 m row) were graded for size distribution and weight based on three categories: <2 in. (5.08 cm) diameter; >2 in. (5.08 cm) diam but less than 10 oz. (283.5 g); and >10 oz. (283.5 g). These data were used to calculate total tuber yield in each plot. A sub-sample of 25 tubers was taken from each plot to determine specific gravity, fry colour, and internal defects (hollow heart, etc.). The prime tuber yield, often referred to as the pay weight, was determined by subtracting small (<2 in. (5.08 cm) diam) and defective tubers from the total yield. Furthermore, economic return values, measured in Canadian dollars ha^{-1}, of harvested tubers were generated based on Cavendish Farms contract criteria. Based on these criteria, increased payments are made for potato samples with increased weight of tubers >10 oz. (283.5 g), increased specific gravity, and uniform light fry colour, while potato samples with internal defects (hollow heart, etc.) are subject to dockage.

Data analysis

Following tests for homogeneity of variance and due to the presence of significant interactions of the repeated experiments with main effects or with interaction terms, data for each field season was analyzed separately. Since Shepody and Russet Burbank plot locations were not randomly assigned, data for each cultivar within a field season was analyzed separately to examine differences among fungicide and N fertility treatments within a cultivar. Testing for statistical significance of fungicide treatment, N rate and interactions between these two factors was achieved by using a two-way analysis of variance (ANOVA). The analyses were conducted with SPSS statistical software (SPSS® for Windows®, Chicago, IL, USA).

RESULTS

Total tuber yield

The total yield of tubers, measured in tonnes ha^{-1}, was influenced by the fungicide treatment. In 2003, there was a significant fungicide effect on the total tuber yield of Russet Burbank, while in 2004, a significant fungicide treatment effect was observed for the total yield of Shepody (Table 1). In both instances, azoxystrobin and pyraclostrobin treatments were linked to significantly higher yields compared with the untreated control plots (Figs. 1A and 1B).

There were no significant differences in total tuber yield based on the N fertility regimes in either 2003 or 2004 (Table 1). Similarly, there were no significant interactions between fungicide treatment and N rate in both years of the study (Table 1), indicating that the effect of fungicide treatment was independent of N fertility regime.

Pay weight

A significant fungicide treatment effect was observed for the pay weights, measured in tonnes ha^{-1}, of Russet Burbank in 2003 and Shepody in 2004 (Table 1). Plots of Russet Burbank treated with azoxystrobin or pyraclostrobin yielded significantly higher pay weights compared with the untreated control plots (Fig. 1C). However, a *post hoc* analysis of the 2004 Shepody pay weights revealed that only the azoxystrobin treatment gave a significantly higher pay weight compared with the untreated control plots (Fig. 1D). Although the average pay weight for the pyraclostrobin treated plots was higher than that in the control plots, this difference was not significant.

Similar to the results obtained for total tuber yield, pay weights were not influenced by the level of N fertility and no significant interactions between fungicide and N fertility programs were observed in either year of study (Table 1).

Economic return

As stated previously, economic return is based on a series of criteria including tuber size/weight categories, specific gravity, fry colour, and internal defects. It is the economic return that determines what the grower will receive, in terms of dollars, for a particular yield of tubers. Although azoxystrobin and pyraclostrobin always gave higher monetary returns compared with the controls (Table 2), the only significant increases in return were observed in the 2003 Russet Burbank crop and the 2004 Shepody crop (Tables 1 and 2). Again, there was no effect of N fertility on financial returns, and no interactions between fungicide and N fertility regimes were observed (Table 1).

Table 1. Significance of fungicide treatment (F), nitrogen rate (N), and their interaction (F X N) on total yield, pay weight and economic return for Russet Burbank and Shepody potatoes in 2003 and 2004

Experimental Treatment	Total yield			Pay weight			Economic return		
	df	*F*	*P > F*	df	*F*	*P > F*	df	*F*	*P > F*
Russet Burbank									
2003									
F	2	5.602	0.013	2	5.702	0.012	2	6.551	0.007
N	1	0.055	0.818	1	0.211	0.651	1	0.076	0.786
F X N	2	0.044	0.957	2	0.587	0.586	2	0.493	0.619
2004									
F	2	0.592	0.564	2	0.088	0.916	2	0.074	0.929
N	1	0.647	0.432	1	0.142	0.711	1	0.132	0.720
F X N	2	1.302	0.296	2	0.340	0.716	2	0.483	0.625
Shepody									
2003									
F	2	0.011	0.989	2	1.008	0.385	2	1.488	0.252
N	1	0.721	0.407	1	2.670	0.120	1	3.361	0.183
F X N	2	1.314	0.293	2	1.915	0.176	2	1.138	0.342
2004									
F	2	10.043	0.001	2	4.372	0.028	2	2.836	0.085
N	1	0.018	0.894	1	0.523	0.479	1	1.210	0.286
F X N	2	1.132	0.344	2	1.413	0.289	2	1.703	0.210

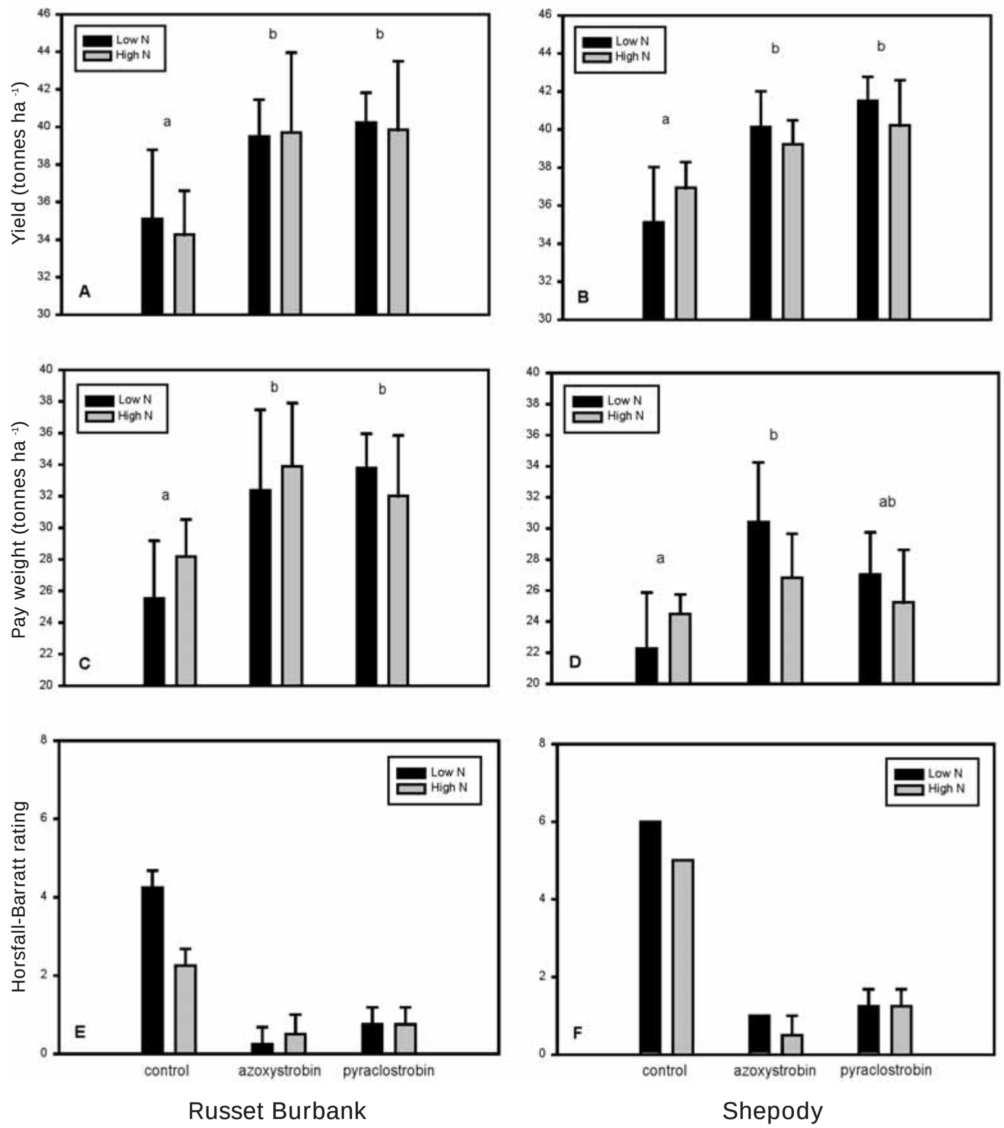

Figure 1. Differences (mean ± SD) in total yield (A, B), pay weight (C, D), and early blight severity (E, F) among data sets grouped by fungicide and nitrogen fertility for both Russet Burbank (A, C, E) and Shepody (B, D, F) cultivars in 2003 (A, C) and 2004 (B, D, E, F). Bars within a graph annotated with the same letter are not significantly different at $P < 0.05$. Values on the y-axis for early blight severity (E, F) are estimates of leaf area necrosis using the Horsfall-Barratt disease assessment scale (Horsfall and Barratt 1945). Bars with no deviation indicate that all replications were given the same foliar rating.

Table 2. Economic return values, measured in Canadian dollars ha^{-1}, of tubers harvested from plots treated with or without strobilurin fungicides[1]

		Fungicide treatment		
Year	Cultivar	Control	Azoxystrobin	Pyraclostrobin
2003	R. Burbank[2]	5395[a]	6574[b]	6707[b]
	Shepody	5480	5936	6257
2004	R. Burbank	6157	6337	6269
	Shepody[3]	4652[A]	5487[B]	5183[AB]

[1] Values shown are averages of high and low nitrogen fertility treatments. Economic return values are generated based on Cavendish Farms contract criteria. Increased payments are made for potato samples with increased weight of tubers >10 oz. (283.5 g), increased specific gravity, and uniform light fry colour, while potato samples with internal defects (hollow heart, etc.) are subject to dockage.
[2] Within the row, values followed by the same lowercase letter are not significantly different at $P < 0.05$.
[3] Within the row, values followed by the same uppercase letter are not significantly different at $P < 0.10$.

Disease incidence

Natural early blight disease pressure was negligible in both years of the study. For this reason, plots were artificially inoculated in an attempt to induce the disease. In 2003, no early blight symptoms developed despite artificial inoculation. In 2004, leaf lesions induced by inoculation were visually apparent in the untreated controls about three weeks after artificial inoculation. Lesion areas, based on Horsfall-Barratt ratings, ranged from 1-5 (3-50%) in Russet Burbank controls (Fig. 1E) and from 4-6 (25-75%) in Shepody controls (Fig. 1F). In plots treated with azoxystrobin and pyraclostrobin, leaf area with lesions of early blight was consistently 0 or 1 (less than 3%) (Figs. 1E and 1F). Disease severity was consistently similar in replications of the same treatment.

The effect of N rate was less marked than the effect of fungicide treatment. However, Russet Burbank check plots treated with the low N rate had an average Horsfall-Barratt rating of 4.2, where 4 corresponds to 12–25% of lesion area, compared with the high N rate which had an average rating of 2.2, where 2 corresponds to 3–6% of lesion area (Fig. 1E). The severity of early blight was low at both rates of N fertility when azoxystrobin or pyraclostrobin were used as a component of the fungicide program (Fig. 1E). As expected, Russet Burbank control plots generally had lower severity of early blight compared with Shepody control plots (Figs. 1E and 1F).

DISCUSSION

Both strobilurin products were linked to significantly ($P < 0.05$) higher total tuber yields, and corresponding increases in pay weight, for Russet Burbank in 2003, when compared with plots receiving no strobilurin fungicides. This corresponded with a significant ($P < 0.05$) increase in economic return. Similar results were observed in 2004 for Shepody.

The reasons for these inconsistent tuber yield and pay weight increases are difficult to ascertain from the data collected. However, it is important to note that early blight infection was negligible in 2003. Therefore, the increases in yield and pay weight for Russet Burbank plots during the 2003 growing season may be attributed to the physiological and developmental alterations that strobilurin products brought about in treated plants. Strobilurin derivatives, such as kresoxim-methyl and azoxystrobin, have demonstrated enhanced greening of treated foliage, which has often translated into increases in yield potential (Grossamn and Retzlaff 1997; Wu and von Tiedemann 2001). It is possible that these beneficial effects may have contributed to the enhanced yield and quality of tubers in the absence of disease pressure. However, the aforementioned yield increases due to fungicide application were not observed for Shepody in 2003 or for Russet Burbank in 2004, which underscores the complex interactions of fungicide, plant physiology (cultivar) and environmental perturbations (including stress factors) that ultimately impact on crop yield.

During the 2004 growing season, early blight was established following artificial inoculation. Although the total tuber yield and pay weight increases observed in Shepody plots in 2004 may be attributed to the aforementioned beneficial effects of strobilurins, there were also minimal levels of foliar disease severity in strobilurin-treated plots, so that disease suppression may also have contributed to the increased yield.

Increased yields in strobilurin-treated plots observed in 2003 and 2004 may also have been the result of some other factor that was not measured. Since strobilurin fungicides are effective in controlling numerous species of fungal pathogens (Bartlett *et al.* 2002), they may have been controlling other, less visible pathogens that affected potato yield and quality in the control plots. However, no visual evidence of other diseases caused by foliar or soil-borne pathogens (including black dot, *Colletotrichum coccodes* (Wallr.) J.S. Hughes) was obtained.

Although some studies have reported enhanced yield in potato at higher rates of N, the two N fertility regimes utilized in this study did not significantly differ in terms of yield. However, the high N rate applied to Russet Burbank in 2004 caused a reduction in early blight severity (Fig. 1E). Several studies have confirmed the beneficial effect that N fertility has on the severity of early blight by minimizing a premature descent into senescence (MacKenzie 1981; Soltanpour and Harrison 1974).

Furthermore, Russet Burbank control plots had a lower disease severity rating than the Shepody controls. Early blight developed at a different rate in these two cultivars with Russet Burbank, a late-maturing variety, having a certain degree of natural resistance to early blight compared with Shepody. Since Shepody is an earlier-maturing variety, its foliage tends to senesce more quickly, thus making it more susceptible to early blight. This confirms observations of other researchers who have noted increased resistance to early blight in late-maturing cultivars compared with early-maturing cultivars (Christ 1991; Johanson and Thurston 1990). As well, host resistance may be utilized in an integrated pest management program to reduce the number of fungicides required for disease control (Fry and Shtienberg 1990; Shuman and Christ 2005; Stevenson 1994).

Unfortunately, in 2003, no disease pressure was established. In addition to environmental conditions that were not conducive to disease, it is likely that the early use of chlorothalonil for prevention of late blight had a suppressing effect on early blight. Several studies have confirmed the efficacy of chlorothalonil as part of a regular protectant fungicide program for early blight management (Blachinski *et al.* 1996; Chaudhari *et al.* 2002; Shuman and Christ 2005). For this reason, fluazinam was used in 2004 to suppress late blight, since it is regarded as providing negligible suppression of early blight. In 2004, both strobilurin products used in this study provided excellent control of early blight following artificial inoculation. This finding is similar to that of Miller and Rosen (2005), who determined that an azoxystrobin-chlorothalonil fungicide program was more effective in controlling early blight than chlorothalonil alone. The severity of early blight was low at both rates of N fertility in plots where azoxystrobin or pyraclostrobin had been applied. Similarly, Miller and Rosen (2005) found that when azoxystrobin was used in a fungicide program, the N rate was not as critical in managing foliar disease. In Prince Edward Island, growers routinely apply 165 kg ha^{-1} N at planting and then topdress with additional N during the season (similar to the high N application protocol in our trials) in an attempt to delay plant senescence and increase crop yields. The data presented in this study does not support this approach. It has been suggested that growers apply N to optimize tuber yield and use fungicides, not elevated N levels, to control early blight (MacKenzie 1981). Using strobilurin products as a component of a fungicide program could allow growers to lower N inputs without compromising cultural early blight control. This would help to reduce the cost of fertilizer inputs and the risk of nitrate contamination of water sources. However, the task of monitoring and maintaining N levels close to the limits imposed by yield and environmental considerations remains a difficult task. Nevertheless, nutrient management recommendations based on potato cultivar and growing region are being developed by individual provinces in Canada to prevent overfertilization while maintaining adequate plant nutrition. Under these conditions, and in situations where early blight is a concern, strobilurin fungicides may become an integral part of a disease control program.

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