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Control of Early Blight in the San Luis Valley, Colorado

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Abstract Early blight of potatoes caused by *Alternaria solani* is a disease that growers in Colorado often do not consider a major problem. However, past and this current research suggest that judicious use of a well-managed fungicide program can significantly reduce disease and increase yields. Additionally, wide spread use of fungicides in various rotations (azoxystrobin, pyraclostrobin, chlorothalonil, dithiocarbamate, mancozeb and boscalid) was shown to substantially decrease the disease levels of plants in treated versus untreated plots. Field trials evaluating fungicide rotations and application scheduling were conducted using the cultivar Russet Norkotah Selection 8. Treatments were first applied to either coincide with the dates as indicated by the early blight degree day model currently used in the San Luis Valley (~60 days after planting - DAP), or starting later in the season (~80 DAP). While significant differences ($P < 0.05$) in disease reduction were noted each year using fungicides, there was no corresponding yield advantage of fungicide treated versus the control (un-treated) plots. However, when data were analyzed over three years, a significant higher ($P < 0.05$) foliar disease control and subsequent yield increase among treatments was observed when a strobilurin product was used first in the fungicide rotation at 78 DAP. Results indicate that for a cost of $100–125/ha, growers can use fungicides with an appropriate rotation of active ingredients to control early blight and potentially increase yields.

Resumen El tizón temprano de la papa, causado por *Alternaria solani*, es una enfermedad que a menudo los productores en Colorado no la consideran como un problema mayor. No obstante, investigaciones anteriores y esta sugieren que el uso razonado de un programa de fungicidas bien manejado puede reducir significativamente la enfermedad y aumentar los rendimientos. Además, la gran amplitud del uso de fungicidas en varias rotaciones (azoxistrobina, piraclostrobina, clorotalonil, ditiocarbamato, mancozeb y boscalid) mostró una disminución substancial de los niveles de la enfermedad de las plantas en lotes tratados contra las de los no tratados. Se condujeron ensayos de campo evaluando rotaciones de fungicidas y programaciones de aplicación en la variedad Russet Norkotah Selección 8. Los tratamientos primero se aplicaron ya fuera para coincidir con las fechas como estaba indicado por el modelo de grados día de tizón temprano usado comúnmente en el Valle de San Luis (~60 días después de la siembra, DAP), o empezando más tarde en el ciclo (~80 DAP). Mientras que se notaron diferencias significativas ($P < 0.05$) en la reducción de la enfermedad cada año usando fungicidas, no había la ventaja correspondiente en rendimiento en los lotes de tratamiento con fungicidas contra el testigo (no tratado). No obstante, cuando se analizaron los datos en tres años, se observó un control significativamente más alto ($P < 0.05$) de la enfermedad foliar y un aumento subsecuente en el rendimiento entre tratamientos cuando se usó primero un producto de strobilurina en la rotación de fungicidas a 78 DAP. Los resultados indican que por un costo de $ 100–125/ha, los productores pueden usar fungicidas con una rotación apropiada de ingredientes activos para controlar el tizón temprano y aumentar los rendimientos potencialmente.

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Introduction

Early blight of potatoes caused by *Alternaria solani* is a pathogen that infects potato foliage and, in some years, can be quite serious. Foliar symptoms become evident and more prevalent as the plants mature. Symptoms typically start on the lower, more mature leaves of the plant and show as a small, dark brown necrotic lesion. As the plants grow and mature, these initial lesions sporulate, spores are dispersed and infect the leaves giving rise to typical leaf spot symptoms. Lesions are angular or round and are dark brown, with concentric rings giving each lesion a target board or 'bulls eye' appearance. The lesions are usually confined to the leaf vein margins and begin in the lower leaf canopy and spread into the upper foliage (Stevenson et al. 2008). Depending upon moisture, temperature and the nutritional state of the plant, lesions can multiply dramatically as individual leaf spots coalesce which can cause partial to complete defoliation prior to normal maturation and vine death. This polycyclic disease can be of major importance because of its ability to reduce yields after foliage is destroyed (Olanya et al. 2009).

A. solani is also the cause of potato tuber blight, a grade defect that can be devastating on certain cultivars of potatoes. Tuber infection takes place during harvest when spores enter into wounds on the tuber surface. Infected tubers show sunken, dark brown surface lesions which are fairly shallow. These lesions develop into dry rot type symptoms in storage and are considered grade defects when marketing the tubers. Storage temperatures above 10 °C tend to favor development of the symptoms (Venette and Harrison 1973). Cultivars differ dramatically in their susceptibility to tuber blight incited by *A. solani*, but often the thin skinned red, whites and specialty cultivars are most prone to infection (Davidson and Houser 2008).

Use of well-timed fungicide programs utilizing a rotation of fungicides with different modes of action (protectant like chlorothalonil, contact like mancozeb, strobilurin products and boscalid) is critical for resistance management (Horsfield et al. 2010) and in maintaining healthy plants with the potential for increased yields (Pscheidt and Stevenson 1986, Teng and Bissonnette 1985). Resistance to certain fungicides such as chlorothalonil (Holm et al. 2003), the strobilurin products (Pasche et al. 2004; Rosenzweig et al. 2008) and boscalid (Wharton et al. 2012) have been well documented. Thus, it is in the producer's best interest to utilize application schedules and combinations where fungicides with different modes of action are rotated as part of a solid resistance management program (Horsfield et al. 2010).

In Colorado, producers have utilized a simple degree day model to decide when it is best to start fungicide applications on a field. This model, developed by Franc et al. (1988), predicts the appearance of the first early blight lesions on potato foliage and is based upon the accumulated day-degrees above 7.2 °C. In the San Luis Valley, when 650 DD have been reached in any given year, growers are informed and most fungicide spray programs begin. Then, based upon individual fungicide combinations, four to six applications are made to the crop prior to haulm killing. This model typically predicts first early blight lesions developing on the foliage near the time of first tuber initiation to very early bulking.

A portion of this study was to examine fungicide schemes that began later in the season, during mid tuber bulking and prior to the onset of plant maturation, and compare disease control against the standard degree day model currently utilized. Fungicides with different modes of action were utilized within each scheme and broad spectrum protectant fungicides were intermixed or used exclusively. Utilizing late applications of fungicides to control the foliar phase of early blight was attempted for two reasons. First, controlling early blight during the time that most of the inocula are present or recorded, (Harrison et al., 1965 a; b; c) may help in reducing the dramatic increase in the foliar phase of the disease on exposed plants. This is also the time when nitrogen levels in the plant are high, therefore the plant is less susceptible to disease. Additionally, plant maturation is beginning (Miller and Rosen 2005). Secondly, later fungicide applications could help reduce the number of spores available on the infected plants and, thus, the soil surface, for eventual infection of the tubers during and after harvest (Venette and Harrison 1973).

The remainder of the study was focused on the impact of comprehensive, valley-wide fungicide applications after late blight was reported during the latter part of the season in 2007. The additional fungicide applications in 2008 of products that control both early and late blight were made by the majority of The Valley growers in response to protection of the foliage against late blight. This allowed an evaluation for their impact on foliar early blight in the established plots, both the amount as determined by AUDPC and the timing until the observation of the first foliar symptoms.

The objectives of this study were to assess the effects of fungicide applications on early blight disease in relation to the degree day model and the benefits derived from such applications, to assess the timing of fungicide applications within the seasons and the impact of differing fungicide application dates on disease, and to assess the impact of increased fungicide use by the entire potato industry in the San Luis Valley.

Materials and Methods

Field plots were established on the San Luis Valley Research Center in Center, Colorado during the 2005–2009 growing seasons. The cultivar utilized was Russet Norkotah Selection

8, a commonly grown cultivar in the San Luis Valley. Planting dates were similar each year, between May 10-14th. Plots were established in the same location of the field in opposite corners by year. Plots were on a two year rotation of potatoes and barley. Each plot consisted of 12.2 m of row with potatoes spaced between rows at 0.91 m and within rows at 0.3 m. The basic design was four rows 6.1 m in length making up each plot with the interior two rows utilized for readings and harvest. Only the interior 2 rows were treated with the various fungicides or left un-treated. Border rows were placed on the outside edges of each of the plots to be used as an untreated source of natural early blight inoculum. Generation 2 certified seed was cut prior to planting and treated with Fir Bark at a rate of 600 g ai/MT to aid in healing. No seed treatment other than the fir bark was applied to the cut seed. The cut seed was sized to about 71 g/seed piece and allowed to suberize in burlap sacks at 9 °C and 95 % relative humidity for a period of one week prior to planting. Plots were placed in the field utilizing a randomized complete block design with four replications per treatment.

All production practices were handled in a manner consistent with good potato production practices for the San Luis Valley, Colorado. These practices included using a herbicide after hilling (S-ethyl dipropylthiocarbamate (Eptam) at 1.753 l/ha + Rimsulfuron (Matrix) at 109.7 ml/ha). Total N for the season included 35 kg from the soil as residual, 11 kg from the irrigation water, and 90 kg from the pre-plant, with 66.0 kg applied during the season at increments of roughly 22 kg per application at 65, 72, and 80 days after planting (DAP), respectively. This resulted in a total N residual plus application of 202 kg/ha. Total irrigation water plus precipitation for the growing season was calculated using a standard ET model for the San Luis Valley, but averaged 1.32 m/ha over the five seasons. No other pesticides were applied during the season with only the fungicide treatments applied based upon individual treatment regimes. In each year of the study the plots (including planting dates, harvest, etc.) were treated in a manner as close as possible to other years to keep uniformity within the study time frame. The only differences were related to fungicide applications based upon the degree day model time frame for each year.

Treatments (Table 1) consisted of using various fungicide combinations either early or late in the season. A degree day model (Fig. 1) developed by Franc et al. (1988) was utilized as the starting point for fungicide applications to the plots. Fungicides were applied based on label recommendations and applied either early to coincide with tuber initiation and early tuber bulking, at or just prior to 60 DAP (weeks 1–3 post 650 DD), or later, at approximately 80 DAP (weeks 4–6 post 650 DD), to coincide with mid tuber bulking.

The Area Under Disease Progress curves (AUDPC) were calculated by using the cumulative totals of weekly assessmetns of three whole plants/rep or twelve per treatment.

Table 1 Treatments utilized in each fungicide regime, 2005–2007

Treatments	Application timing[b]		Rates
Untreated control			
S + C + B[a]	Late	4 + 5 + 6	0.44 l/ha; 1.74 l/ha; 0.17 kg/ha
D + C	Late	4,6 + 5	2.25 kg/ha; 1.74 l/ha
D + A	Early	1,5 + 3	2.25 kg/ha; 0.44 l/ha
D + A	Late	4,6 + 5	2.25 kg/ha; 0.44 l/ha

[a] S = Strobilurin product – azoxystrobin (Quadris) or pyraclostrobin (Headline); A = azoxystrobin (Quadris); C = chlorothalonil (Bravo Weatherstick); D = dithiocarbamate & mancozeb (Diathane Rainshield); B = boscalid (Endura)

[b] Treatments began either as early based on reaching 650 DD for each year (weeks 1–3 post 650 DD for fungicide application), or as late (weeks 4–6 post 650 DD for fungicide application)

Disease severity was calculated by assigning an overall disease rating to each plant with a disease severity rating of 1–100 (a rating of 100 indicated that 100 % of the plant was expressing early blight symptoms. Disease severity readings were used to calculate AUDPC with the following formula:

$$A_k = \sum_{i=1}^{N_\varepsilon - 1} \frac{(y_i + y_{i+1})}{2} (t_{i+1} - t_i)$$

AUDPC was calculated based on the method used by Shaner and Finney (1977) and similar to the method utilized by Stevenson et al. (2007). Each year, foliar readings for early blight disease incidence and severity were taken during similar time frames post emergence to keep between year variations to a minimum. AUDPC were additionally calculated for each year for comparison purposes for the amount of early blight disease observed during the late blight outbreak.

At harvest, yields and grade were determined by hand harvesting each plot and grading and weighing the tubers in each category. Categories used for grade were <113 g, 113–283 g, >283 g, U.S. No 2 grade, and culls. Total yield of the US No 1 grade category were calculated for each treatment (Colorado Dept. of Ag. 2013). Statistical analysis of the AUDPC and yields was conducted on treatments within each year and between years using a least significant difference (LSD) mean separation ($P < 0.05$) with the Proc GLM model of analysis of variance (SAS® 9.2).

Results and Discussion

The early blight control program had a significant impact ($P < 0.5$) on both disease incidence and severity and overall yield of US No 1 grade potatoes. As seen in Table 2, when a strobilurin product was utilized first in the late treatment scheme (80 DAP) and coupled with the broad spectrum

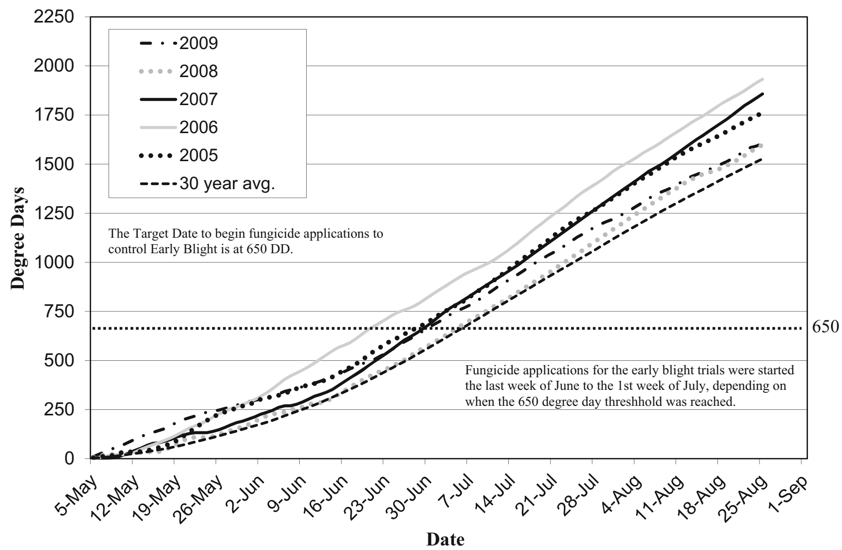

Fig. 1 Cumulative degree days for early blight disease levels on Russet Norkotah at the San Luis Valley Research Center during the 2005 to 2009 years. Data were collected during the potato cropping season from May to mid-September of each year. For comparison, the 30 year average of degree days were also included

fungicide chlorothalonil, and then boscalid, there was significantly lower disease ($P < 0.5$) recorded when data of three year means were averaged than in any of the other treatments. Late fungicide applications impacted early blight disease incidence and severity, and yielded more than the treatments in which typical early fungicide applications (60 DAP) were used. It should be noted that no comparative treatment using a strobilurin product first in the series of fungicides under the early application time frame was done. Early fungicide applications with azoxystrobin applied in the middle of the series had significantly more disease ($P < 0.5$) than the similar late fungicide application series. With the late applications, the broad spectrum fungicide dithiocarbamate plus mancozeb coupled with azoxystrobin in the middle had significantly more disease ($P < 0.5$) than when a strobilurin product was used first in the series. However, this treatment had less disease than the other two treatments utilizing either the broad spectrum fungicides chlorothalonil and dithiocarbamate plus mancozeb applied later in the season, or the broad spectrum fungicides plus azoxystrobin within the series, when applications started earlier in the season.

Table 2 AUDPC for early blight foliar symptoms in fungicide trials over three years

Treatment	AUDPC[a]			
	2005	2006	2007	Mean
Untreated control	782.5 a	998.1 a	1281.1 a	1020.6 a
S[b] (4)[c] + C (5) + B (6)	261.6 d	736.5 d	994.5 b	644.2 d
D (4,6) + C (5)	389.9 c	877.0 b	1028.9 b	765.3 b
D (1,4) + A (3)	484.2 b	821.6 bc	1030.7 b	778.8 b
D (4,6) + A (5)	328.7 cd	783.1 cd	1015.6 b	709.2 c
LSD ($P < 0.05$)	69.0	60.0	36.3	30.7

Means followed by the same letters are not significantly different at $P < 0.05$ for yield

Yields were analyzed using a least significant difference (LSD) mean separation with the Proc GLM model of analysis of variance (SAS® 9.2) with years as a block

[a] AUDPC is the Area Under Disease Progress Curve, accumulated through the month of August.

[b] S = Strobilurin product – azoxystrobin (Quadris) or pyraclostrobin (Headline); A = azoxystrobin (Quadris); C = chlorothalonil (Bravo Weatherstick); D = dithiocarbamate & mancozeb (Diathane Rainshield); B = boscalid (Endura)

[c] Fungicide applications began once the Early blight degree day model reached a value of 650DD which typically occurs around the first week of July. The number in parentheses represents the week number after the threshold of 650DD was reached. For example: (1) = fungicide was applied the first week after 650DD was reached, (2) = the second week, etc.

The early season treatment beginning with a broad spectrum fungicide application after the degree day model threshold was reached is the most common practice for San Luis Valley potato producers. Now, growers have modified their practices and normally begin with a strobilurin product first in the cycle followed by a broad spectrum fungicide as the second application. All of the treatments were significantly better ($P < 0.5$) in terms of disease control than the untreated control in all years and the means of the three years.

Overall, the potato tuber yield for US No 1 grade indicated a different trend in yield in response to fungicide treatments. Within years, only 2007 demonstrated a significant yield increase ($P < 0.5$) in the late application series of the broad spectrum fungicide over the untreated control (Table 3). When yield data were analyzed across years, with years as blocks, only the treatment utilizing a late application with a strobilurin product applied first in the series was significantly higher ($P < 0.5$) than the control. Yields were comparable among the other treatments and the untreated control. This is of note, since the whole reason for applying fungicides in the first place is to help increase yield and quality of the potatoes

Table 3 Plot yields in fungicide trials for three years plus cost analysis of fungicide treatments

Treatment	Yield (MT/ha)[a]				
	2005	2006	2007	Mean	Cost/ha[b]
Untreated control	43.8	39.6	36.8 bc	40.1 b	–
S[c] (4)[d] + C (5) + B (6)	50.1	41.2	39.2ab	43.6 a	$115
D (4,6) + C (5)	40.3	37.5	41.5 a	41.4 ab	$ 87[e]
D (1,4) + A (3)	46.5	40.6	35.7 c	41.0 b	$ 99[e]
D (4,6) + A (5)	45.3	42.2	37.2 bc	41.5 ab	$ 99[e]
LSD (P < 0.05)	NS	NS	2.8	2.2	–

Means followed by the same letters are not significantly different at $P < 0.05$ for yield

Yields were analyzed using a least significant difference (LSD) mean separation with theProc GLM model of analysis of variance (SAS® 9.2) with years as a block

[a] Total yield expressed as metric tons/ha, 2–6.1 m rows per treatment per replication, mean of four replications

[b] These prices are for fungicide only and do not include application costs. Total cost/ha for fungicides was based on 2009 prices and were obtained from Schall Chemical Supply LLC

[c] S = Strobilurin product – azoxystrobin (Quadris) or pyraclostrobin (Headline); A = azoxystrobin (Quadris); C = chlorothalonil (Bravo Weatherstick); D = dithiocarbamate & mancozeb (Diathane Rainshield); B = boscalid (Endura)

[d] Fungicide applications began once the Early blight degree day model reached a value of 650DD, which typically occurs around the first week of July. The number in parentheses represents the week number after the threshold of 650DD was reached. For example: (1) = fungicide was applied the first week after 650DD was reached, (2) = the second week, etc.

[e] Due to the limited availability of Dithane Rainshield in 2009, the price of Penncozeb 75DF was used to calculate the overall cost/ha

while controlling potential disease threats (Harrison and Venette 1970, Holm et al. 2003, Horsfield et al. 2010). However, the use of fungicides to control foliar diseases is not just for the blights. By controlling blights, better plant health is achieved, especially in the latter part of the season. Healthier foliage may help in plant regrowth when environmental problems like hail or early frost occur.

Overall tuber quality was examined during storage. There were no tubers infected with early blight during the trials. Unfortunately, Russet Norkotah Selection 8 is rarely impacted by early blight tuber decay, so no comparisons of treatments for control of this phase of the disease could be analyzed.

In 2006, producers in the San Luis Valley applied fungicides starting most applications at the time that 650 DD was reached. However, as in most years, this did not include all producers or all of their fields with complete season wide fungicide applications. 2007 was also a normal year until late July when late blight was reported in the San Luis Valley. However, many of the potato fields were already killed by this time. Growers that had not killed their vines began a diligent spray program on their potatoes using broad spectrum fungicides like chlorothalonil. When 2008 began, the majority of producers had plans to commit to a fungicide program using a typical early season application prior to row closure (plants 0.3 m tall) and a second application right at row closure. The fungicides utilized were the same as those used to control early blight in previous years. Every two to three weeks throughout the season, additional fungicides were applied. This was a Valley-wide application of fungicides which typically control early blight disease, an unusual occurrence in most years. There was good chemistry rotation utilizing different modes of action to avoid resistance. Since no late blight

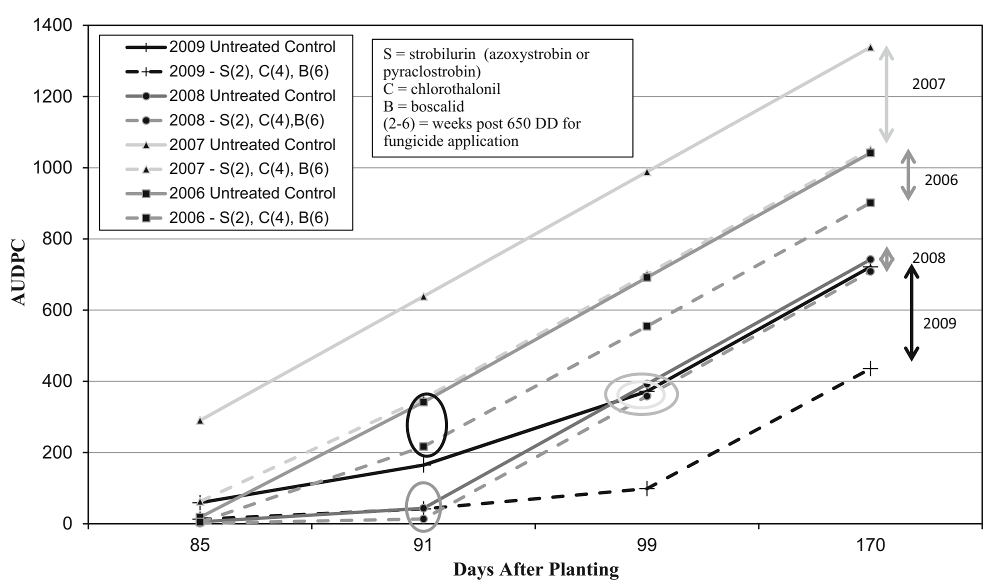

Fig. 2 A comparison of Area Under Disease Progress Curve (AUDPC) for early blight disease in fungicide treated versus untreated (control) plots . The curves represent the total units accumulated each year in the 2006 to 2009 seasons

was found in the crop in 2008, many growers moved back into their normal routine for fungicide applications in 2009. This consisted of fewer growers utilizing timely fungicide applications or appropriate fungicide combinations during the season.

The impact of the additional fungicide applications on the overall crop from 2006 to 2009 in regards to early blight disease development was quite interesting. Typical disease onset for early blight in the San Luis Valley is around 85 DAP. In Fig. 2, 2006 and 2007 show first disease at 85 DAP or earlier. However, in 2008, disease onset was recorded at 91 DAP and later period. By 2009, onset in the untreated control was similar to the first two years, but where fungicides were applied onset was about 10 days later than the control. This is 15 days later than in most years. If there is little or no disease in the untreated plots, this is an indication that the level of inoculum in field plots is very low or limited during that year or the duration of disease assessments. Because no fungicides are applied in the untreated plots (control plots) more disease is expected in the untreated plots compared to plots in which fungicides are applied.

Secondly, the time to reach early blight disease levels where the lower foliage begins showing multiple lesions just prior to the disease beginning its normal rapid progression on the plant was impacted. The range in most years based upon plot information is 85–90 DAP. In 2008 and 2009, the time to reach this level was 10 days later, indicating a definite movement of the normal disease increase to later in the season. Additionally, in 2008 and 2009, overall total disease levels were much reduced from 2006 and 2007, with the untreated control showing substantial less disease incidence and severity at the end of the season than the other two years. Although no data on inocula were quantified, the variation in disease incidence and severity over years may also be attributed to inocula levels.

Finally, the shape of AUDPC in the treated and untreated control plots was dramatically affected. In 2006, 2007, and 2009 disease levels in the fungicide treated plots and untreated control plots were consistently separated throughout the season. However, in 2008, when Valley-wide fungicide applications throughout the season were taking place on the crop, the separation between the untreated control plots and the fungicide treated plots was negligible. This again demonstrates the significant impact that use of a comprehensive fungicide program applied on the large majority of the hectares planted to potatoes in a given area can have on early blight incidence and severity. Many studies have shown this to be the case (Teng and Bissonnette 1985, Harrison and Venette 1970, Horsfield et al. 2010, Pavilista and Gall 2011).

Costs for the fungicides only with no application or labor figured in for a season long program were comparable for all treatment schemes ranging between \$87/ha to \$115/ha (Table 3). These are very minimal costs in the whole budget for a growing season representing about 2 % of the entire budget for a certified seed producer. A typical budget for production may be in the range of \$5000/ha for production (Tranel et al. 2013). This investment in good plant health and foliar disease control can pay large dividends over time.

This study again demonstrates that the use of fungicides can reduce overall disease levels of foliar early blight during the season, regardless of the fungicide treatments utilized. A good rotation of chemistries can be beneficial to the producers in minimizing the potential for resistance buildup in the *Alternaria* populations (Staub 1991, Horsfield et al. 2010). The degree day model currently utilized by the San Luis Valley potato industry was quite good at predicting when first lesions appear on the foliage based upon observations in the plots. There were no years in the study when early blight lesions were observed prior to reaching the 650 DD threshold. Utilizing late applications of fungicides can demonstrate increased disease control and yields over the early season applications, but would not be appropriate where late blight is found in the region. While significant yield increases are often not seen, even with significantly better foliar control of the disease than untreated, the maintenance of good plant growth can be very important when considering late season inspections for certified seed, late season environmental impacts such as hail or frost, and in allowing the plant to utilize all of its fertility inputs through the entire season (MacKenzie 1981, Miller and Rosen 2005). Finally, each producer will need to decide if the efficacious use of fungicides justifies the cost versus their return. This study has demonstrated that the use of well-timed fungicide applications to the potato crop can effectively control foliar early blight and create the potential for higher yields.

When the majority of the producers in a given region follow good foliar early blight control practices with the appropriate rotation of chemistries and timing of fungicide applications, excellent control of early blight can be achieved. Area wide disease can be reduced in the crop, even to the point where there is little difference between treated and untreated potatoes, a boon for producers utilizing organic production methods. Additionally, later disease onset can be realized. For a small investment in their overall budget, producers can see less disease pressure and potential for increased yields.

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