Effect of Adjuvants on the Performance of Pyraclostrobin for Controlling Cercospora Leaf Spot on Sugarbeet

Mohamed F. R. Khan[1*], Greg Richards[2], Jahangir Khan[3], R. Harikrishnan[3], R. Nelson[3], and Carl A. Bradley[3]

[1]Department of Plant Pathology, North Dakota State University, Fargo, ND 58105-5758 and University of Minnesota; [2]American Crystal Sugar Company, Moorhead, MN; and [3]Department of Plant Pathology, North Dakota State University, Fargo, ND 58105-5758.
[*]Corresponding author: Mohamed Khan (Mohamed.khan@ndsu.edu)

ABSTRACT

Cercospora leaf spot (CLS), caused by the fungus *Cercospora beticola*, is the most damaging foliar disease of sugarbeet (*Beta vulgaris* L.) in Minnesota and North Dakota. Most fields require fungicide applications to control CLS and to improve sugar yield and quality. Trials were conducted near Breckenridge, Minnesota, in 2001 and 2002, to determine the effect of adjuvants added to pyraclostrobin on control of CLS and on sugarbeet yield and quality. Cercospora leaf spot severity was low in both years of the trial. Pyraclostrobin applied alone always provided effective control of Cercospora leaf spot. Adjuvants in combination with pyraclostrobin did not result in a significant improvement in disease control, yield, and quality compared to pyraclostrobin applied alone. Addition of adjuvants to pyraclostrobin in most cases increased phytotoxicity, and in some instances reduced yield, compared to pyraclostrobin applied alone. Based on these results, there was no consistent benefit of adding adjuvants to pyraclostrobin for CLS control or for increased sugar yield and quality.

Additional key words: *Beta vulgaris*, fungicide, phytotoxicity, strobilurin, Headline.

Cercospora leaf spot (CLS), caused by *Cercospora beticola* Sacc., is the most damaging foliar disease of sugarbeet (*Beta vulgaris* L.) in North Dakota and Minnesota. Severely infected plants are defoliated as leaves become necrotic. CLS reduces sucrose yield and increases impurities that result in higher processing costs (Lamey et al., 1996; Shane and Teng, 1992; Smith and Ruppel, 1973). In uncontrolled high disease pressure situations, losses as high as 50% in recoverable sucrose have been reported (Lamey et al., 1996; Shane and Teng, 1992; Khan et al., 2000). In North Dakota and Minnesota, sugarbeet roots are stored in piles following harvest and are processed during a 7-9 month period. Roots of diseased plants do not store well compared to healthy roots in storage piles, resulting in additional economic loss (Smith and Ruppel, 1973).

Currently available commercial sugarbeet varieties have moderate levels of resistance to CLS and require regular fungicide applications to prevent economic losses, especially under high disease pressure (Miller et al., 1994). The fungicides registered for CLS control on sugarbeet in the late 1990s included triphenyltin hydroxide, thiophanate methyl, copper and mancozeb. The US Environmental Protection Agency (EPA) approved a special section 18 label for azoxystrobin use on sugarbeet in 1998 (Dexter and Luecke, 1999). Triphenyltin hydroxide, thiophanate methyl, mancozeb, and azoxystrobin were applied alone or in different combinations for CLS control on sugarbeet in North Dakota and Minnesota in 1998 (Dexter and Luecke, 1999). These fungicides provided inconsistent and inadequate disease control during the CLS epidemic of 1998 which resulted in economic losses of over $45 M for American Crystal Sugar Company growers (Cattanach, 1999). This necessitated an urgent need to find different chemistries that would provide effective CLS control.

In 1998, field trials were initiated to evaluate pyraclostrobin, a new strobilurin fungicide from BASF, Raleigh, NC, to manage CLS. Pyraclostrobin, like other strobilurin compounds, inhibits mitochondrial respiration of fungal pathogens by binding to the outer quinone oxidizing pocket of cytochrome b, thus blocking electron transfer in the respiration pathway leading to energy deficiency (Sauter et al., 1995; Ammermann et al., 2000; Bartlett et al., 2002). In 1999, under high CLS disease pressure, it was observed that pyraclostrobin when applied with adjuvants, sometimes resulted in better disease control and higher sucrose yields than when applied alone (Khan et al., 2000).

Adjuvants are additives applied with pesticides to aid operation and/or to increase efficacy. Adjuvants are widely used to improve the efficacy of herbicides. Research also shows that adjuvants may significantly increase the efficacy of fungicides in controlling powdery mildew of wheat, celery leaf spot (Amer et al., 1993), late blight of potato (Grayson et al., 1996a), and downy mildew of grape (Grayson et al., 1996b).

The objective of this study was to determine the effect of adjuvants on the performance of pyraclostrobin for controlling CLS on sugarbeet.

MATERIALS AND METHODS

Field trials were conducted near Breckenridge, MN, on a silty clay loam soil in 2001 and 2002. The experimental design was a randomized complete block with four replicates. 'Hilleshog Agate', a sugarbeet cultivar susceptible to CLS (Steen 2001), was planted with a commercial 'John Deere MaxEmerge 2' (Deere & Company, Moline, IL) planter. Plot size was six 56 cm wide rows, 11 m long. Planting dates were 11 May and 7 May in 2001 and 2002, respectively. Terbufos (Counter 15G; BASF, Raleigh, NC) was applied at 3.7 kg a.i. ha^{-1} modified in-furrow so that it was not in direct contact with seeds (Boetel et al., 2006) at planting time to control sugarbeet root maggot (*Tetanops myopaeformis* von Rőder; Diptera: Ulidiidae). Plots were thinned manually at the six-leaf stage to 86,450 plants ha^{-1}. Recommended agronomic practices were used for fertilization and weed management (Khan, 2001).

The 33 treatments evaluated are listed in Table 1. Treatments were applied with a four-nozzle (D4 orifice disk and DC23 disc core – TeeJet Technologies, Wheaton, IL) boom sprayer operating at 690 kPa and delivering 187 L ha^{-1} of spray solution to the middle four-rows in each plot. Pyraclostrobin (Headline 2.09 EC, BASF, Raleigh, NC) was tested at either 0.17 (low rate - equivalent to the recommendation of 9 fl oz per acre (Khan, 2003) or 0.34 kg a.i ha^{-1}(high rate) with adjuvants at different rates or without adjuvants (Table 1). The adjuvants tested were Agri-Dex (paraffin base petroleum oil, Helena Chemical Co. Memphis, TN), MSO Concentrate (methylated seed oil and emulsifiers, Loveland Industries, Greeley, CO), Activator-90 (alkyl polyoxyethylene ether and free fatty acids, Loveland Industries), Hyper-Active (dialkyl dimethyl ammonium, Helena Chemical Co.), and Silwet L-77 (silicone-polyether copolymer, Loveland Industries). Adjuvants were also applied alone, and an untreated check was included. Treatments started when initial leaf spot symptoms were observed and were repeated at close to 14 days intervals. In 2001, treatments were applied on 25 July, 8 and 22 August, and 5 September. In 2002, treatments were applied on 23 July, 9 and 26 August, and 9 September.

CLS severity was rated using the 1 to 9 Kleinwanzlebener Saatzucht (KWS) scale (Anonymous, 1970), where 1 = no disease and a rating of 9 = all plants had only new leaf growth, all earlier leaves were dead. CLS severity was evaluated weekly starting at first symptoms, but the rating done one day prior to harvest is reported since recoverable sucrose is

Table 1. Effect of treatments on phytotoxicity, recoverable sugar, net tonnage, sugar concentration, sugar loss to molasses, and Cercospora leaf spot severity of sugarbeet in trials at Breckenridge, MN in 2001 and 2002.

Treatment †	**2001**						**2002**					
	Phytotoxicity rating ‡ 1 - 10	Recoverable sucrose kg ha^{-1}	Root yield Mg ha^{-1}	Sugar concentration %	Loss to molasses %	CLS severity§ 1 - 9	Phytotoxicity rating 1 - 10	Recoverable sucrose kg ha^{-1}	Root yield Mg ha^{-1}	Sugar concentration %	Loss to molasses %	CLS severity 1 - 9
Low rate	1.3mn¶	6518a-i	41.8a-d	17.0abc	1.4b-g	1.2fgh	2.4lmn	7822a-i	61.5b-h	14.9abc	2.0c-g	1.1e
Low rate + Agri-Dex 2%	2.7ij	7045a-e	43.3abc	16.6a-d	1.5abc	1.2fgh	4.8de	8074a-e	64.7a-d	14.6a-d	2.0c-g	1.1e
Low rate + Agri-Dex 1%	1.8kl	7450ab	46.5ab	16.5a-d	1.3efg	1.2fgh	3.5fgh	7649a-j	64.0a-e	14.3bcd	2.2a-d	1.1e
Low rate + Agri-Dex 0.5%	1.5lm	7546a	44.2abc	17.3ab	1.4b-g	1.2fgh	3.3f-i	8148a-d	65.0a-d	14.7abc	2.0c-g	1.2e
Low rate + Agri-Dex 0.25%	1.3mn	6990a-f	46.0ab	16.6a-d	1.3efg	1.2fgh	3.1g-k	8241abc	65.6abc	14.7abc	2.0c-g	1.1e
Low rate + MSO 2%	3.3h	5431g-k	33.6bcd	16.9a-d	1.5abc	1.3e-h	5.7bc	7877a-g	59.8e-j	15.2ab	1.9efg	1.1e
Low rate + MSO 1%	2.7ij	7110a-d	43.9abc	16.6a-d	1.4b-g	1.3e-h	4.6e	8023a-f	61.7b-h	15.2ab	2.0c-g	1.2e
Low rate + MSO 0.5%	1.3mn	7451ab	46.4ab	16.6a-d	1.4b-g	1.3e-h	3.6fg	7396b-j	61.5b-h	14.2bcd	2.0c-g	1.2e
Low rate + MSO 0.25%	1.1mn	6094a-j	34.6bcd	17.0abc	1.3efg	1.5c	3.0h-k	8546a	65.5a	15.0abc	2.0c-g	1.1e
Low rate + Activator-90 2%	8.3b	5061ijk	33.6bcd	16.8a-d	1.5abc	1.2fgh	5.4cd	7502b-j	60.6d-h	14.6a-d	2.1b-g	1.1e
Low rate + Activator-90 1%	5.5d	6331a-j	44.8ab	16.4bcd	1.4b-g	1.3e-h	4.6e	7756a-j	59.9e-j	15.0abc	1.9efg	1.1e
Low rate + Activator-90 0.5%	4.5f	6061a-j	40.3a-d	16.7a-d	1.5abc	1.5c	3.6fg	7108f-j	57.2hij	14.6a-d	2.0c-g	1.1e
Low rate + Activator-90 0.25%	4.0g	6343a-j	40.6a-d	17.1abc	1.3efg	1.5c	2.6j-m	8278ab	61.3b-h	15.6a	1.9efg	1.1e
Low rate + Hyper-Active 0.25%	2.0k	6392a-j	36.0bcd	17.2ab	1.5abc	1.2fgh	2.6j-m	8010a-g	63.5a-f	14.8abc	2.0c-g	1.2e
Low rate + Hyper-Active 0.125%	1.8kl	6116a-j	41.0a-d	16.0d	1.4b-g	1.2fgh	2.7i-l	7237d-j	59.8e-j	14.2bcd	1.9efg	1.1e
Low rate + Hyper-Active 0.06%	1.5lm	7206abc	41.1a-d	16.6a-d	1.4b-g	1.2fgh	2.6j-m	7573b-j	62.7a-g	14.3bcd	2.1b-g	1.2e
Low rate + Hyper-Active 0.03%	1.4lmn	6881a-g	39.0a-d	17.4a	1.4b-g	1.2fgh	2.4lmn	8118a-e	65.9ab	14.5a-d	2.1b-g	1.1e
Low rate + Silwet L-77 0.25%	8.5b	6755d-k	37.6bcd	16.9abc	1.4b-g	1.4cde	6.0b	7327c-j	60.4d-h	14.3bcd	1.9efg	1.1e

Treatment †	**2001**						**2002**					
Low rate + Silwet L-77 0.125%	5.0e	4967jk	31.2cd	16.9abc	1.4b-g	1.4cde	3.8f	7720a-j	61.4b-h	14.7abc	2.0c-g	1.1e
Low rate + Silwet L-77 0.06%	1.5lm	5857c-k	39.1a-d	16.6a-d	1.4b-g	1.2fgh	3.0h-k	7829a-i	60.7d-h	14.8abc	1.8g	1.1e
Low rate + Silwet L-77 0.03%	3.0hi	5563e-k	36.4bcd	16.8a-d	1.4b-g	1.2fgh	2.4lmn	7740a-j	63.4a-f	14.5a-d	2.1b-g	1.1e
High rate	1.5lm	6688a-h	37.4bcd	17.0abc	1.4a-e	1.2fgh	3.2g-j	7865a-h	61.5b-h	14.9abc	2.0c-g	1.1e
High rate + Agri-Dex 2%	3.3h	5866c-k	36.7bcd	16.7a-d	1.3efg	1.2fgh	4.4e	7336c-j	61.5b-h	14.3bcd	2.1b-g	1.1e
High rate + MSO 2%	4.0g	6767a-h	42.0a-d	16.8a-d	1.4b-g	1.4cde	5.6bc	7781a-j	61.1c-h	14.9abc	2.0c-g	1.1e
High rate + Activator-90 2%	9.0a	5303h-k	35.7bcd	16.5a-d	1.6a	1.4cde	5.6bc	7220e-j	57.8hij	14.7abc	2.0c-g	1.1e
High rate + Hyper-Active 0.25%	1.5lm	7475ab	51.0a	16.3cd	1.4b-g	1.2fgh	2.8i-l	7663a-j	61.6b-h	14.5a-d	1.9efg	1.1e
High rate + Silwet L-77 0.25%	9.0a	5887c-k	36.8bcd	17.4a	1.3efg	1.2fgh	6.6a	6870jk	55.3j	14.6a-d	2.0c-g	1.1e
Agri-Dex 1%	2.5j	5805c-k	37.8bcd	16.5a-d	1.5abc	2.3ab	2.4lmn	6925ijk	58.4g-j	14.3bcd	2.3ab	2.9c
MSO 1%	1.5lm	6124a-j	39.8a-d	16.9abc	1.5abc	2.4ab	2.6j-m	6949h-k	59.7e-j	14.1cd	2.2abc	2.9c
Activator-90 1%	7.5c	4445k	29.7d	17.0abc	1.4b-g	2.3ab	2.5k-n	7099g-j	58.9f-j	14.4bcd	2.1b-g	2.6d
Hyper-Active 0.125%	1.5lm	5602d-k	38.6a-d	16.2cd	1.5abc	2.4ab	2.6j-m	7602b-j	60.3d-i	14.6a-d	1.9efg	3.3b
Silwet L-77 0.125%	1.8kl	5496f-k	36.5bcd	17.1abc	1.5abc	2.3ab	2.1mn	7293d-j	59.5e-j	14.5a-d	2.1b-g	2.9c
Untreated check	1.0n	6011b-j	35.5bcd	16.9a	1.4b-g	2.4ab	2.0n	6076k	55.6ij	13.6d	2.5a	3.8a

† Treatments were pyraclostrobin at low (0.17 kg a.i ha^{-1}) or high (0.34 kg a.i ha^{-1}) rates.

‡ Phytotoxicity rated on a 1 to 10 scale, where 1 = no leaf damage and 10 = severely burned outer leaves.

§ CLS = rated using 1 to 9 Kleinwanzlebener Saatzucht (KWS) scale, where 1 = no disease and a rating of 9 = plants assessed had only new leaf growth, all earlier leaves being dead.

¶ Means within a column followed by the same letter are not significantly different ($LSD_{0.05}$).

inversely proportional to CLS severity (Smith and Ruppel, 1973).

Phytotoxicity usually occurred within 24 h after applications. Phytotoxicity ratings were conducted within two to three days following application of treatments. The average ratings are reported in Table 1.

Plots were defoliated mechanically and harvested using a mechanical two-row harvester on 24 and 23 September in 2001and 2002, respectively. The middle two-rows of each plot were harvested and weighed for root yield. Ten to fifteen harvested roots were sub-sampled for quality analysis at the American Crystal Sugar Company Quality Tare Laboratory, East Grand Forks, MN. Root yield, sugar concentration, recoverable sugar yield, and sugar loss to molasses were calculated. Treatment means were considered fixed and replicates random effects for analysis of variance. The least significant difference (LSD) test was used to compare treatments when the F-test for treatments was significant (p=0.05). The data analysis was performed with the ANOVA procedure of the Agriculture Research Manager, version 6.0 software package (Gylling Data Management Inc., Brookings, South Dakota, 1999).

RESULTS AND DISCUSSION

In 2001, Cercospora leaf spot was first observed in late July and progressed very slowly during the season, resulting in a CLS rating of 2.4 on the untreated check at harvest (Table 1). All fungicide treatments resulted in better disease control compared to the untreated check. None of the adjuvants used in combination with pyraclostrobin resulted in better disease control than pyraclostrobin applied alone. All treatments, except the untreated check, had some leaf damage. Stand alone applications of MSO Concentrate, Hyper-Active, and Silwet L-77 had minor leaf burning similar to that caused by pyraclostrobin applied alone. However, stand alone applications of Agri-Dex, and particularly Activator-90, resulted in significantly more phytotoxicity than pyraclostrobin applied alone. There was a general trend of increasing phytotoxicity as the rates of the adjuvants were increased when applied with pyraclostrobin at the 0.17 kg a.i ha^{-1} rate. The higher rate of pyraclostrobin with the highest rate of all adjuvants, except Hyper-Active, resulted in more phyotoxicity compared to the combination of the same adjuvants with pyraclostrobin at the lower rate. There was no significant difference in yield of recoverable sucrose between the untreated check and fungicide treatments, except for pyraclostrobin applied with Agri-Dex at 0.5% rate v/v where recoverable sucrose was highest. The data suggest that the disease severity of the untreated check did not reach the threshold necessary to cause measurable economic damage (Shane and Teng, 1992). There was no significant difference in yield of recoverable sucrose between the untreated check and adjuvants applied as stand alone treatments, except for Activator-90 where the yield was significantly lower. There was a general trend for yield reduction for treatments that resulted in more severe phytotoxicity, although disease control was very effective based on low disease severity ratings.

In 2002, Cercospora leaf spot disease pressure was slightly higher than 2001, with a final CLS rating of 3.8 on the untreated check at harvest (Table 1). All fungicide treatments, and even adjuvants applied alone, resulted in lower KWS ratings compared to the untreated check. However, all fungicide treatments provided significantly lower KWS ratings compared to adjuvants applied alone. None of the adjuvants used in combination with pyraclostrobin resulted in significantly better disease control than pyraclostrobin applied alone. All treatments, including the untreated check, had some leaf damage. Winds of 48 to 64 km hr^{-1} caused some of the leaf damage. With the exception of Hyper-Active, all adjuvants caused less leaf damage when applied alone than when used at the same rate in combination with pyraclostrobin. Hyper-Active caused similar damage used alone, and when in combination with pyraclostrobin. As in 2001, there was a general trend of increasing phytotoxicity as the rates of the adjuvants were increased when applied with pyraclostrobin at 0.17 kg a.i ha^{-1}. The higher rate of pyraclostrobin with the highest rate of all adjuvants, except Silwet L-77, resulted in similar damage compared to the combination of the same adjuvants with pyraclostrobin at the 0.17 kg a.i ha^{-1} rate. All fungicide treatments, except pyraclostrobin at the higher rate applied with Silwet L-77 at the highest rate, resulted in significantly higher recoverable sucrose than the untreated check. The data suggest that disease severity was high enough in the untreated check to adversely impact the yield of recoverable sucrose. In the untreated check, Cercospora leaf spot resulted in a combination of low root and sugar yield, low sugar concentration, and the greatest loss of sugar to molasses.

In two years of field testing various adjuvants alone and in combinations with two rates of pyraclostrobin, our results indicate variable effects on phytotoxicity and CLS. In general, phytotoxicity increased with the addition of adjuvants and increasing rates of adjuvants compared to pyraclostrobin alone. The adjuvants that consistently caused the least amount of phytotoxicity when used at the recommended rate in combination with pyraclostrobin at the recommended rate were Hyper-Active and Agri-Dex; there was no significant decrease in phytotoxicity when lower rates of the adjuvants were used with pyraclostrobin. It was surprising that MSO Concentrate with pyraclostrobin caused leaf damage, since MSO Concentrate is widely used with similar emulsifiable concentrate formulations of herbicides for weed control in sugarbeet (Khan, 2001) with no report of phytotoxicity. However, it may be because MSO concentrate is recommended for use only with reduced rates of herbicides.

In some instances, particularly in 2002, CLS was reduced by stand alone applications of adjuvants compared to the untreated check, but when used in combination with pyraclostrobin, did not improve efficacy compared to pyraclostrobin used alone. The surfactants Naiad and sodium dodecyl sulfate were also shown to be effective and provided comparable control to the fungicide azoxystrobin in reducing white rust, *Albugo occidentalis* G. W. Wils., on spinach (Irish et al., 2002). The adjuvants used in this trial, however, even under low disease pressure, did not appear to have potential as fungicides for controlling CLS.

Earlier research has shown that selection of adjuvants is critical to reduce phytotoxicity because certain crops are more sensitive to phytotoxicity than others. In our study, all classes of adjuvants resulted in phytotoxicity. Similar results were observed by Grayson et al. (1996b) who found increased phytotoxicity due to the addition of alkylamine, nonylphenol, and silicone based adjuvants to dimethomorph for controlling downy mildew in grapes. Several studies have shown enhanced activity of fungicides in controlling various diseases with the addition of adjuvants. Grayson et al. (1996a) noticed enhanced therapeutic control of potato late blight with the addition of adjuvants to dimethomorph, while Stanghellini et al. (1996) showed improved control of *Pythium aphanidermatum* root rot in cucumbers with stand alone application of nonionic surfactants in a hydroponic system. In our two-year field study, benefits of adding adjuvants to pyraclostrobin for the management of CLS in sugarbeet was variable and did not significantly improve disease control compared to pyraclostrobin alone. In one of the two years, pyraclostrobin increased recoverable sugar yield compared to the untreated check. Similar results of enhanced yield due to pyraclostrobin have been reported on sugarbeet in the United Kingdom (Asher, 2005) and in the United States (Smith et al., 1999). There are several possible reasons for the inconsistent effect of the adjuvants observed in our studies. Transcuticular absorption and effectiveness of adjuvants depends upon the crop and/or host-pathogen system (Gent et al., 2003). Additionally, effects of adjuvant on leaf wettability and droplet spreading can differ with crops, cultivars, and with phenological stage of the crop (Steurbaut, 1993). Based on our two-year field trial, the adjuvants tested did not significantly improve the efficacy of pyraclostrobin; therefore, adjuvants are not recommended in combination with pyraclostrobin for controlling CLS under conditions of low disease severity.

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