Final Report:
Evaluation of Fungicide Rotation Strategies to Manage *Sclerotinia homoeocarpa* Populations Resistant to DMI and Benzimidazole Fungicide Classes

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Introduction

Frequent fungicide applications to control dollar spot on golf courses have led to the selection of *Sclerotinia homoeocarpa* (F.T. Bennett) isolates resistant to benzimidazole and dicarboximide fungicide classes, and insensitive to the sterol demethylation inhibitor (DMI) fungicide class. Recent monitoring work (2011-2012, Database assay) of New England golf courses revealed 80% of the courses assayed between 2008-2012 were comprised of *S. homoeocarpa* populations resistant to the benzimidazole class and insensitive to the DMI class. The current recommendation for the DMI resistance management is to avoid using DMI fungicides on *S. homoeocarpa* populations with confirmed insensitivity.

This is the safest recommendation, however, anecdotal reports from golf course superintendents claim that reductions in DMI efficacy were not experienced despite confirmation of in vitro sensitivity levels capable of causing reduced DMI efficacy. In many of these instances golf course superintendents implemented sound fungicide rotations and applied DMI fungicides preventatively. This information refutes the previous reports of reduced field efficacy by Popko et al (2012). One key difference between the previous research conducted by Popko et al. and dollar spot control in the field might be the variation in spray strategies. Popko et al. repeated applications of the same active ingredients, whereas golf course superintendents utilize fungicide rotations and tank-mixes with different active ingredients. Previous work by Popko et al. sought to determine the sensitivity of *S. homoeocarpa* isolates causing reduced efficacy and classify the level of reduction in efficacy. This work has been extremely useful in detecting *S. homoeocarpa* populations capable of causing reduced DMI efficacy, however, many questions remain regarding the most effective rotational strategies to practically control dollar spot.

Recently, greater insight on the genetic mechanisms behind DMI resistance has been discovered (Hulvey et al 2012 and Sang et al., 2013). These findings suggest multiple genes are involved in the resistance response and lead to a qualitative resistance response. Greater understanding of the genetic mechanisms coupled with reports of DMI fungicides still providing adequate control led us to reexamine some of the questions regarding DMI resistance and practical dollar spot control. Based on dialog with superintendents and personal observation, we felt like DMI fungicides could still provide some level of dollar spot control if applied at the correct time of the year and rotated with the appropriate non-DMI fungicide classes. Furthermore, our experience in the database assay project brought up questions regarding effective rotation strategies for locations that have chlorothalonil restrictions

Objectives

1. Can DMI fungicides be used in a rotation strategy for control of *S. homoeocarpa* populations with confirmed DMI insensitivity?

2. What are the most effective rotation strategies without chlorothalonil?

Materials and Methods

Field Trial Locations

Field efficacy testing was conducted at Hickory Ridge Country Club (Hadley, MA) and The Ranch Golf Club (Southwick, MA). Both sites are resistant to the benzimidazole and insensitive to DMI fungicide class. The trial was conducted on a creeping bentgrass/annual bluegrass mixed stand mowed three times per week at fairway height (0.5 inches). Irrigation was provided as needed. A total of 1.5 lbs of N/1,000 ft^2 was applied in 2012 and 1.75 lbs of N/1,000 ft^2 was applied at the Ranch Golf Club. A total of 1.0 lb N/1,000 ft^2 was applied at Hickory Ridge Golf Club in both years. Individual plots measured 3x6 ft and were separated by a one foot buffer strip on all four sides. Plots were arranged in a randomized complete block design with four replications. Treatments are listed in Table 1 and were applied in the equivalent of 2 gallons of water per 1,000 ft^2. All treatments were applied on a 21-day application interval. Fungicide treatments were applied at a nozzle pressure of 40 psi using a CO_2 pressurized boom sprayer equipped with two XR Teejet 8004VS flat fan nozzles.

Field Efficacy Testing

This study was a two-year project and began at both locations on 25 May (2012) and 12 June (2013). Five fungicide applications were made for each fungicide rotation and the rotation schedules are listed in Table 1. The experimental rationale was to simulate different fungicide rotation strategies for the majority of a growing season. Ratings were taken each week that a detectable amount of dollar spot was observed. Brown patch ratings were also taken during select dates in 2013. Turf quality data was taken, but will not be presented. Phytotoxicity was not observed and as a result disease severity predominantly affected turf quality, therefore, presenting both ratings was avoided.

Dollar spot severity was visually rated by counting number of dollar spot infection centers once per week. Towards the end of the 2013 at the Ranch Golf Club Percent Dollar Spot was assessed due to high dollar spot counts and coalescence of infection centers. To summarize disease severity over time, the area under the disease progress curve (AUDPC) was calculated for the number of infection centers at each location using the following formula $\Sigma[(y_i + y_{i+1})/2](t_{i+1} - t_i)$, where $i = 1, 2, 3, \ldots, n\text{-}1$ and y_i is the amount of disease (number of infection centers) at the time t_i (days) of the i_{th} rating. All dollar spot assessments and AUDPC were subject to an analysis of variance and means were separated using Fisher's LSD test ($P < 0.05$).

Results

Ranch Golf Club

2012

Favorable environmental conditions for dollar spot coincided with the beginning of the trial and dollar spot was present in the untreated 7 days after treatment (DAT). Disease pressure remained steady with the exception of the latter portion of July (dry conditions). The highest dollar spot incidence was observed at the end of the trial. Overall, all rotations

provided significantly more control than the untreated, however, there were three treatments (Rot. # 15, 17, and 21) that were statistically similar to the repeated DMI treatment (Table 2). Among the different DMI placement rotations, all rotations were statistically similar to each other. The top three numerical (AUDPC) DMI placement rotations used a single DMI application for the second application (Table 2). In the analysis of non-chlorothalonil rotations, # 16 and 20 provided very good overall control and did not use chlorothalonil. Interestingly, significantly less dollar spot was observed on #16 than #15 and #17. Rotations #15 and #16 are the same with exception of the addition of chlorothalonil to #15. The addition of mancozeb (# 17) to same the rotation schedule as # 16, also did not improve control. Rotations #18 and #19 included the PGR Trimmit (paclobutrazol), which is similar to DMI fungicides in chemistry and shown to have some dollar spot control properties. Both rotations were similar to each other in the 2012 trial.

2013

Favorable environmental conditions for dollar spot coincided with beginning of the trial and were present in the untreated 7 DAT. Disease pressure was low to moderate during the first two application intervals and increased significantly during the last 3 applications. Overall, all treatments provided more control than the untreated, however, there were five treatments (Rot. 10, 15, 17, 19 and 21) that were statistically similar to the repeated DMI treatment (Table 2). Rotation #18 was statistically worse than the repeated DMI treatment (Table 2). Rotation #18 included the PGR Trimmit (10oz/A) each application and the DMI Torque (tebuconazole) applied twice. Rotation #19 consisted of the same program with Curalan (vinclozolin) substituted for Torque and showed a 23% improvement in overall control. Two of the top three (#4, 11 and 12) DMI placement treatments contained one DMI application, however, #4 was the only treatment in the top three to repeat from 2012.

Hickory Ridge Country Club

2012

Disease pressure was moderate (17-76 average infections centers) throughout the duration of the trial in the untreated plots. Despite this disease pressure in untreated plots, low disease was observed in all rotation treatments (0-28 average infection centers) throughout the duration of the trial. Moreover, all of the rotation treatments provided significantly better control than the untreated and all rotation treatments all rotation treatments were statically similar to each other. One factor that may have increased the variability among treatments was the presence of colonial bentgrass within the experimental plot. Colonial bentgrass is less susceptible to dollar spot and we observed plots with high colonial bentgrass percentages developing reduced dollar spot infection.

2013

Fungicide treatments were initiated under curatively (7 infection centers or less) and dollar spot pressure was low (2-28 average infection centers) on untreated plots for the first three fungicide application intervals. Disease pressure increased significantly (20 to 135 average infection centers) on untreated plots over the final two application intervals. Overall, all treatments provided more control than the untreated, however, there were four treatments

(Rot. 3, 15, 17, and 18) that were statistically similar to the repeated DMI treatment (Table 2). Rotations # 4, 6 and 13 were the top 3 DMI placement rotations and each rotation used a single DMI application. Rotation #4 was the only rotation to appear in the top 3 for both locations. Rotation #19 showed a 55% improvement in overall control over rotation #18.

Conclusion

Overall, this experiment highlights the benefits of rotating fungicides with different modes of action throughout the season for dollar spot control. We observed that DMI fungicides can still be used on sites with DMI resistance and timing is a critical factor in achieving acceptable control. DMI placement rotations that applied a DMI in the first or second application performed better than DMI's applied in the fourth or fifth application. Moreover, disease pressure was consistently highest in the latter applications (4^{th} and 5^{th}) and suggests that DMI's are not suited for this timing. DMI placement rotations tank-mixed with chlorothalonil did not perform markedly better in the top performers, but the bottom performers favored non-chlorothalonil rotations.

Treatments 15, 16 and 17 examined the effects tank-mixing multi-site fungicides (chlorothalonil and mancozeb) throughout the rotation. This portion produced interesting results, in the 3 trials in which statistical separation among treatments was observed, rotation #16 was consistently the best rotation of the three. We did not expect this result since rotation # 16 did not include a multi-site. We suspect, tank-mixing incompatibility may have been issue with mancozeb, however, the increased disease observed in rotation #15 compared to # 16 was not expected.

Rotations #18 and #19 included the PGR Trimmit (paclobutrazol), which is similar to DMI fungicides in chemistry and has shown to add to dollar spot control. However, some questions regarding the potential for DMI selection pressure exerted by paclobutrazol remain. Rotations #18 and 19 were a direct comparison of a DMI and dicarboximide based rotation with the PGR Trimmit (10oz/A) applied all season. Rotation #18 included the DMI Torque (tebuconazole) applied twice and rotation #19 consisted of the same program with Curalan (vinclozolin) substituted for Torque. In general, the dicarboximide program performed better than DMI program when tank-mixed with Trimmit. Improved control from the dicarboximide program may be due to paclobutrazol selecting DMI resistant isolates prior to the DMI application. Moreover, in both 2013 trials, the dicarboximide program had lower dollar spot incidence at the end of the intervals 2 and 4 compared to the DMI program. Consequently, these intervals were when Torque (tebuconazole) and Curalan (vinclozolin) were applied. While this data is not definitive, it does suggest season long programs that include Trimmit may contribute to DMI resistance selection pressure.

All in all, this study highlights the complexity of comparing season long fungicide rotation programs. Fluctuations in disease pressure at the end of control intervals often exerted a large impact on the level control observed. Despite some of these variables, we have a better understanding of how to use still use DMI fungicides for sites that do have DMI resistance and the type of rotations that courses with chlorothalonil restrictions will find helpful.

Table 1. Fungicide Rotation programs and application rate (oz/1,000 ft^2).						
Rot #	**1st Spray**	**2nd Spray**	**3rd Spray**	**4th Spray**	**5th Spray**	Program Concept
1	**Untreated**					
2	Emerald (0.18 oz)	**Torque (0.6 oz)**	Velista (0.5 oz) + Secure (0.5 oz)	Curalan (1.0 oz)	Emerald (0.18 oz)	DMI in the Middle
3	Emerald (0.18 oz)	Curalan (1.0 oz)		**Torque (0.6 oz)**	Emerald (0.18 oz)	
4	Emerald (0.18 oz)	**Torque (0.6 oz)** + Daconil Ultrex (3.2 oz)		Curalan (1.0 oz)	Emerald (0.18 oz)	
5	Emerald (0.18 oz)	Curalan (1.0 oz)		**Torque (0.6 oz)** + Daconil Ultrex (3.2 oz)	Emerald (0.18 oz)	
6	Curalan (1.0 oz)	**Torque (0.6 oz)**	Velista (0.5 oz) + Secure (0.5 oz)	Curalan (1.0 oz)	Emerald (0.18 oz)	2 DMI apps beginning
7	**Torque (0.6 oz)**	Curalan (1.0 oz)		**Torque (0.6 oz)**	Emerald (0.18 oz)	
8	Curalan (1.0 oz)	**Torque (0.6 oz)** + Daconil Ultrex (3.2 oz)		Curalan (1.0 oz)	Emerald (0.18 oz)	
9	**Torque (0.6 oz)**	Curalan (1.0 oz)		**Torque (0.6 oz**) + Daconil Ultrex (3.2 oz)	Emerald (0.18 oz)	
10	Emerald (0.18 oz)	**Torque (0.6 oz)**	Velista (0.5 oz) + Secure (0.5 oz)	Curalan (1.0 oz)	**Torque (0.6 oz)**	2 DMI apps end
11	Emerald (0.18 oz)	Curalan (1.0 oz)		**Torque (0.6 oz)**	Curalan (1.0 oz)	
12	Emerald (0.18 oz)	**Torque (0.6 oz)** + Daconil Ultrex (3.2 oz)		Curalan (1.0 oz)	**Torque (0.6 oz)**	
13	Emerald (0.18 oz)	Curalan (1.0 oz)		**Torque (0.6 oz)** + Daconil Ultrex (3.2 oz)	Curalan (1.0 oz)	
14	**Torque (0.6 oz)**	**Torque (0.6 oz)**	**Torque (0.6 oz)**	**Torque (0.6 oz)**	**Torque (0.6 oz)**	DMI repeat
15	Emerald (0.18 oz)	Curalan (1.0 oz)	Velista (0.5 oz)	Curalan (1.0 oz)	Emerald (0.18 oz)	Chlorothalonil Comparison
	Daconil Ultrex (2.3 oz)					
16	Emerald (0.18 oz)	Curalan (1.0 oz)	Velista (0.5 oz)	Curalan (1.0 oz)	Emerald (0.18 oz)	
17	Emerald (0.18 oz)	Curalan (1.0 oz)	Velista (0.5 oz)	Curalan (1.0 oz)	Emerald (0.18 oz)	
	Pentathalon (10 oz)					
18	Emerald (0.18 oz)	**Torque (0.6 oz)**	Velista (0.5 oz) + Daconil Ultrex (3.2 oz)	**Torque (0.6 oz)**	Emerald (0.18 oz)	PGR Programs
	Trimmit (10 fl oz/A)					
19	Emerald (0.18 oz)	Curalan (1.0 oz)	Velista (0.5 oz) + Daconil Ultrex (3.2 oz)	Curalan (1.0 oz)	Emerald (0.18 oz)	
	Trimmit (10 fl oz/A)					
20	Emerald (0.18 oz)	Curalan (1.0 oz)	Honor (1.1oz)	Curalan (1.0 oz)	Emerald (0.18 oz)	
21	Curalan (1.0 oz)	Daconil Ultrex (3.2 oz)	Concert (3 oz)	Daconil Ultrex (3.2 oz)	Curalan (1.0 oz)	
22	Velista (0.5 oz) + Secure (0.5 oz)					

Table 2. Ranch Golf Club AUDPC Summary of Fungicide Rotation programs.									
Rot	**1st Spray**	**2nd Spray**	**3rd Spray**	**4th Spray**	**5th Spray**	**2012 AUDPC[z]**		**2013 AUDPC[z]**	
1	**Untreated**					9296	a[y]	6700	a
2	Emerald	**Torque**	Velista + Secure	Curalan	Emerald	578	fg	1100	gh
3	Emerald	Curalan	Velista + Secure	**Torque**	Emerald	926	fg	913	h
4	Emerald	**Torque** +Daconil	Velista + Secure	Curalan	Emerald	702	fg	682	h
5	Emerald	Curalan	Velista + Secure	**Torque** +Daconil	Emerald	977	e-g	1125	f-h
6	Curalan	**Torque**	Velista + Secure	Curalan	Emerald	1008	e-g	1073	gh
7	**Torque**	Curalan	Velista + Secure	**Torque**	Emerald	1319	d-g	1301	f-h
8	Curalan	**Torque** +Daconil	Velista + Secure	Curalan	Emerald	663	fg	1210	f-h
9	**Torque**	Curalan	Velista + Secure	**Torque** +Daconil	Emerald	1191	d-g	1270	f-h
10	Emerald	**Torque**	Velista + Secure	Curalan	**Torque**	731	fg	1592	e-h
11	Emerald	Curalan	Velista + Secure	**Torque**	Curalan	1436	d-f	801	h
12	Emerald	**Torque** +Daconil	Velista + Secure	Curalan	**Torque**	891	fg	814	h
13	Emerald	Curalan	Velista + Secure	**Torque** +Daconil	Curalan	1119	d-g	832	h
14	**Torque**	**Torque**	**Torque**	**Torque**	**Torque**	2807	c	2496	c-e
15	Emerald	Curalan	Velista	Curalan	Emerald	2330	cd	1961	d-g
	Daconil								
16	Emerald	Curalan	Velista	Curalan	Emerald	894	fg	1352	f-h
17	Emerald	Curalan	Velista	Curalan	Emerald	2185	c-e	3231	bc
	Pentathalon								
18	Emerald	**Torque**	Velista + Daconil	**Torque**	Emerald	1564	d-f	3499	b
	Trimmit								
19	Emerald	Curalan	Velista + Daconil	Curalan	Emerald	1412	d-g	2699	b-d
	Trimmit								
20	Emerald	Curalan	Honor	Curalan	Emerald	742	fg	836	h
21	Curalan	Daconil	Concert	Daconil	Curalan	4084	b	2080	d-f
22	Velista + Secure					185	g	764	h

[z] Area under the disease progress curve were reported as the mean of 4 replications.

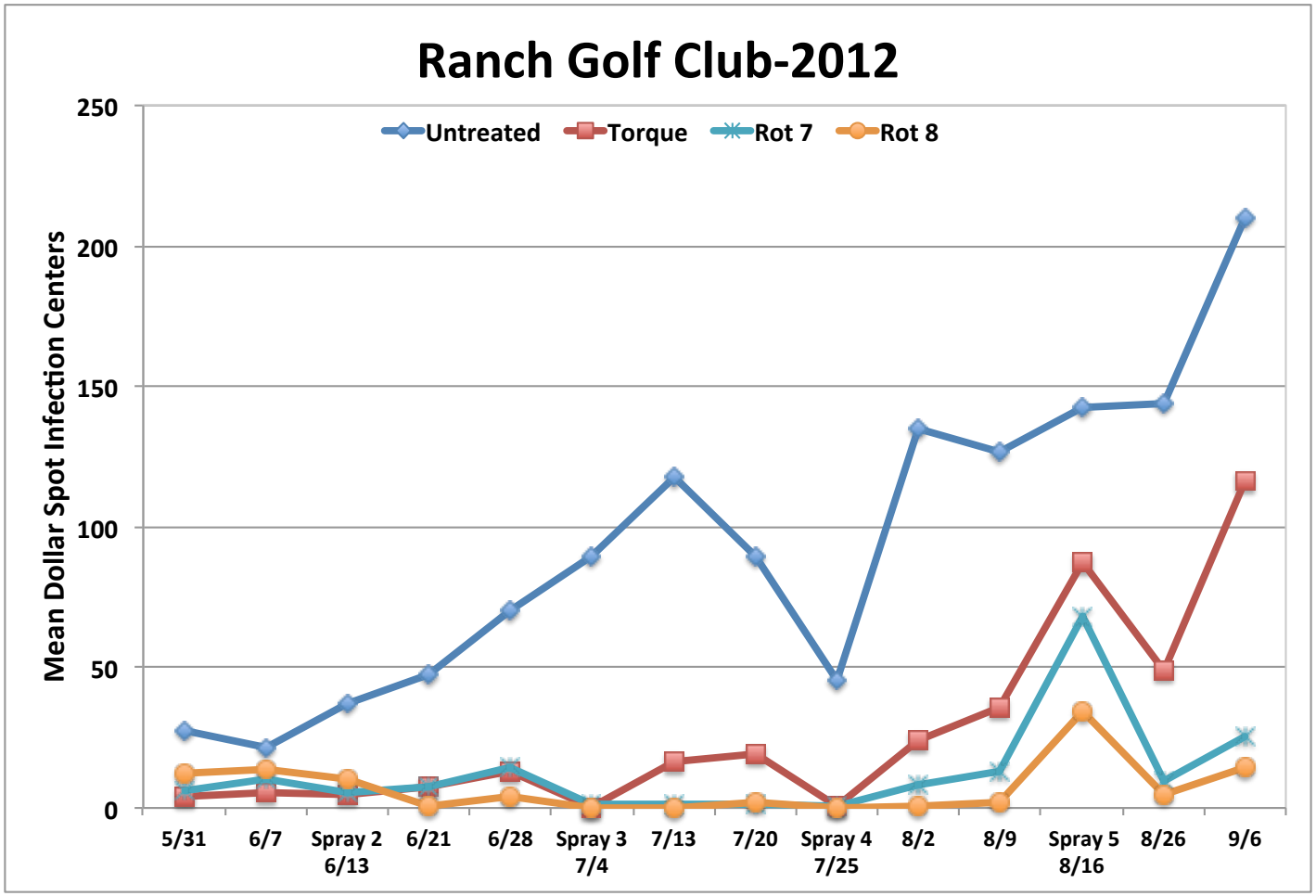
[y] Means followed by the same letter are not significantly different according to Fisher's protected least significant difference test (α = 0.05).

Table 3. Hickory Ridge Golf Club AUDPC Summary of Fungicide Rotation programs.									
Rot	**1st Spray**	**2nd Spray**	**3rd Spray**	**4th Spray**	**5th Spray**	**2012 AUDPC[z]**		**2013 AUDPC[z]**	
1	**Untreated**					5235	a	5867	a
2	Emerald	**Torque**	Velista + Secure	Curalan	Emerald	649	b	697	de
3	Emerald	Curalan	Velista + Secure	**Torque**	Emerald	507	b	1741	b-d
4	Emerald	**Torque** +Daconil	Velista + Secure	Curalan	Emerald	377	b	294	e
5	Emerald	Curalan	Velista + Secure	**Torque** +Daconil	Emerald	514	b	802	de
6	Curalan	**Torque**	Velista + Secure	Curalan	Emerald	665	b	591	e
7	**Torque**	Curalan	Velista + Secure	**Torque**	Emerald	625	b	839	de
8	Curalan	**Torque** +Daconil	Velista + Secure	Curalan	Emerald	593	b	626	e
9	**Torque**	Curalan	Velista + Secure	**Torque** +Daconil	Emerald	423	b	1003	c-e
10	Emerald	**Torque**	Velista + Secure	Curalan	**Torque**	220	b	989	c-e
11	Emerald	Curalan	Velista + Secure	**Torque**	Curalan	765	b	1019	c-e
12	Emerald	**Torque** +Daconil	Velista + Secure	Curalan	**Torque**	349	b	1109	c-e
13	Emerald	Curalan	Velista + Secure	**Torque** +Daconil	Curalan	197	b	450	e
14	**Torque**	**Torque**	**Torque**	**Torque**	**Torque**	668	b	2183	b
15	Emerald	Curalan	Velista	Curalan	Emerald	343	b	1193	b-e
	Daconil								
16	Emerald	Curalan	Velista	Curalan	Emerald	425	b	683	de
17	Emerald	Curalan	Velista	Curalan	Emerald	495	b	1346	b-e
	Pentathalon								
18	Emerald	**Torque**	Velista + Daconil	**Torque**	Emerald	300	b	2018	bc
	Trimmit								
19	Emerald	Curalan	Velista + Daconil	Curalan	Emerald	345	b	918	de
	Trimmit								
20	Emerald	Curalan	Honor	Curalan	Emerald	645	b	589	e
21	Curalan	Daconil	Concert	Daconil	Curalan	620	b	650	e
22	Velista + Secure					342	b	800	de

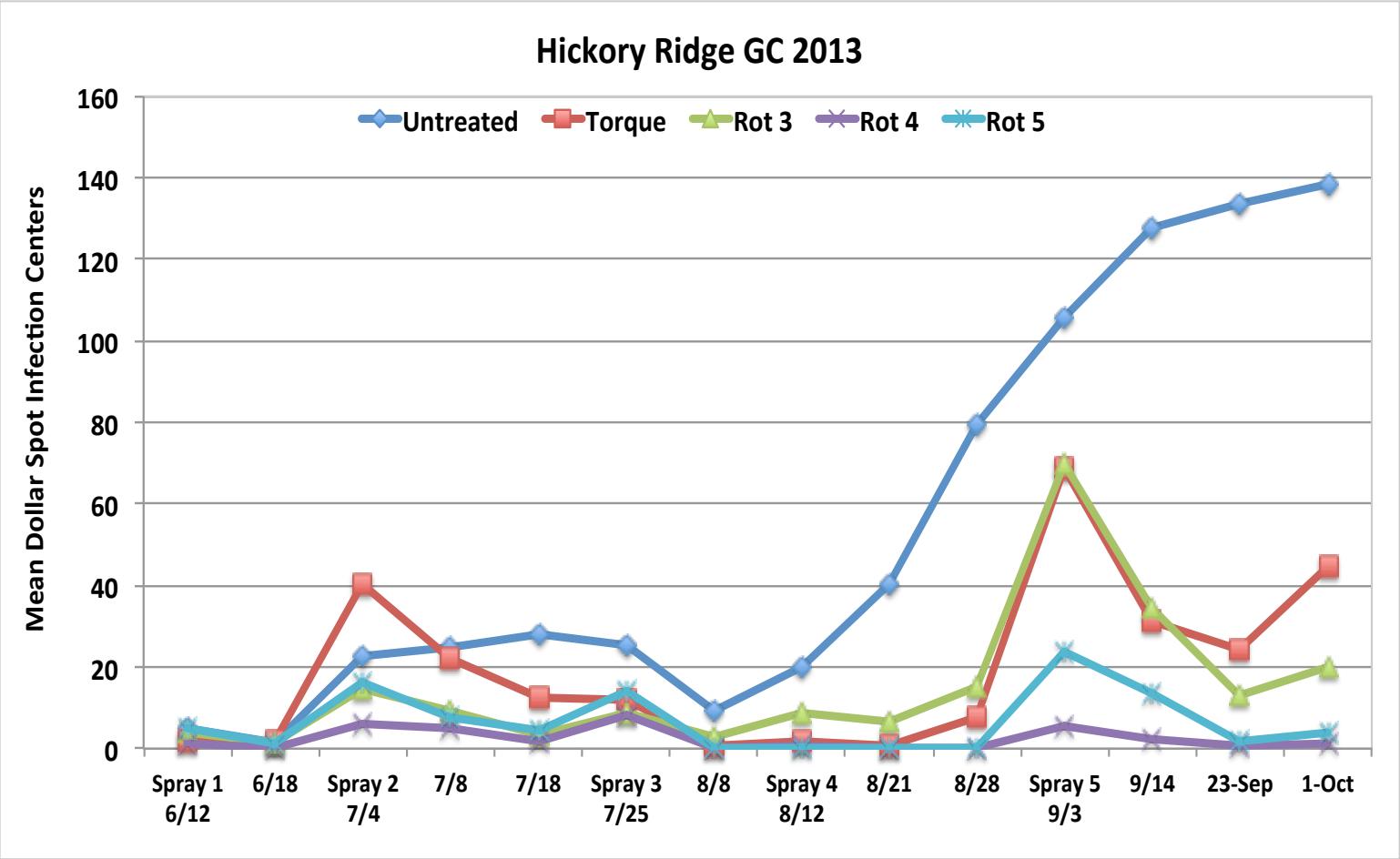
[z] Area under the disease progress curve were reported as the mean of 4 replications.

[y] Means followed by the same letter are not significantly different according to Fisher's protected least significant difference test ($\alpha = 0.05$).

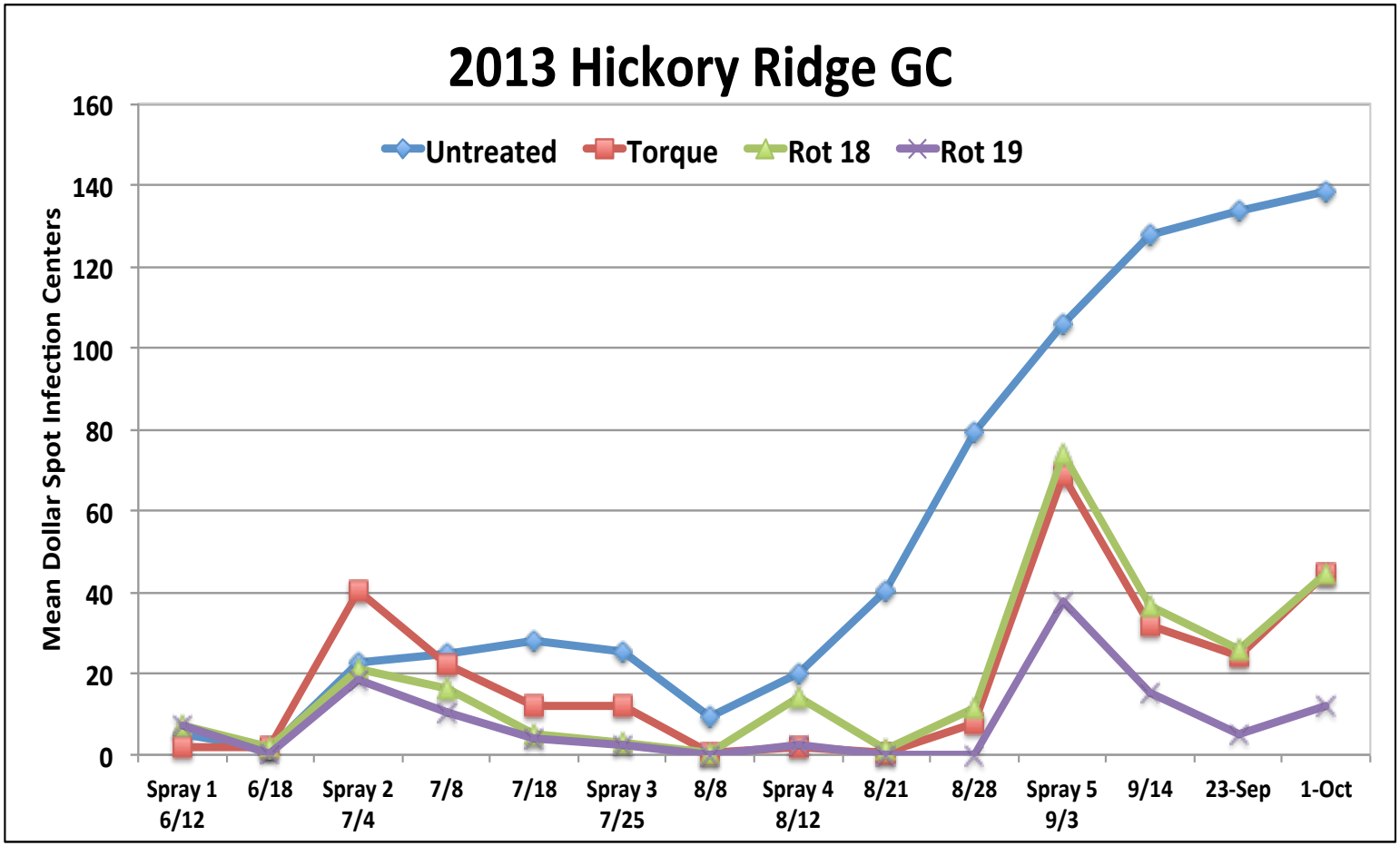
Appendix



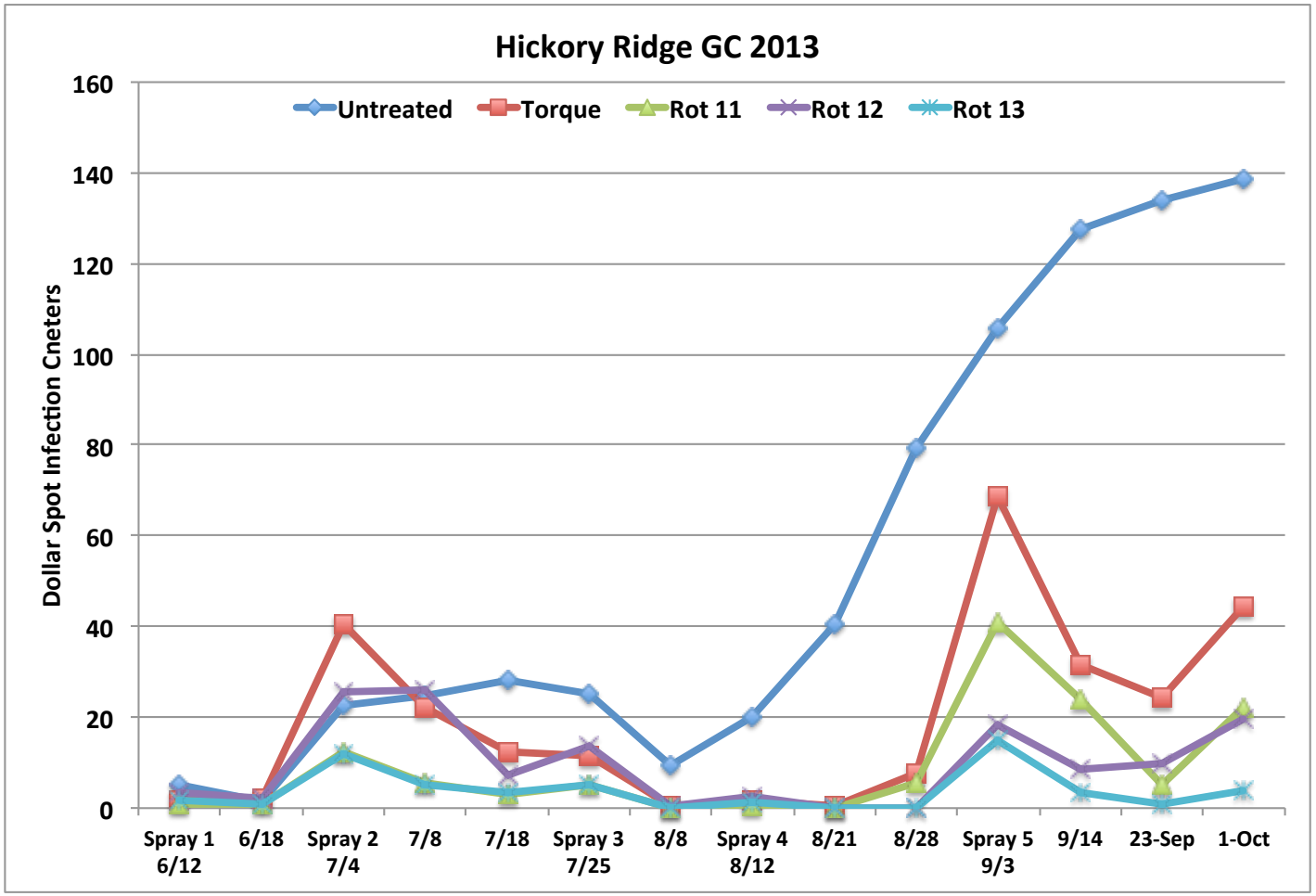
Rot	1st Spray	2nd Spray	3rd Spray	4th Spray	5th Spray	2012 AUDPC	
7	**Torque**	Curalan	Velista + Secure	**Torque**	Emerald	1319	d-g
8	Curalan	**Torque** +Daconil	Velista + Secure	Curalan	Emerald	**663**	fg
14	**Torque**	**Torque**	**Torque**	**Torque**	**Torque**	**2807**	c



Rot	1st Spray	2nd Spray	3rd Spray	4th Spray	5th Spray	2013 AUDPC	
3	Emerald	Curalan	Velista + Secure	**Torque**	Emerald	1741	b-d
4	Emerald	**Torque** +Daconil	Velista + Secure	Curalan	Emerald	294	e
5	Emerald	Curalan	Velista + Secure	**Torque** +Daconil	Emerald	802	de
14	**Torque**	**Torque**	**Torque**	**Torque**	**Torque**	2183	b



Rot	1st Spray	2nd Spray	3rd Spray	4th Spray	5th Spray	2013 AUDPC	
14	**Torque**	**Torque**	**Torque**	**Torque**	**Torque**	2183	b
18	Emerald	**Torque**	Velista + Daconil	**Torque**	Emerald	2018	bc
	Trimmit						
19	Emerald	Curalan	Velista + Daconil	Curalan	Emerald	918	de
	Trimmit						



Rot	1st Spray	2nd Spray	3rd Spray	4th Spray	5th Spray	2013 AUDPC	
11	Emerald	Curalan	Velista + Secure	**Torque**	Curalan	1019	c-e
12	Emerald	**Torque** +Daconil	Velista + Secure	Curalan	**Torque**	1109	c-e
13	Emerald	Curalan	Velista + Secure	**Torque** +Daconil	Curalan	450	e
14	**Torque**	**Torque**	**Torque**	**Torque**	**Torque**	2183	b

Literature Cited

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