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TITLE: Efficacy of biochemical and microbial biofungicides for the management of late blight on tomatoes

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INTRODUCTION:

Late blight caused by the fungal-like oomycete pathogen *Phytophthora infestans* continues to be an annual concern for tomato growers both in Pennsylvania and across the Northeast and mid-Atlantic regions. Until a wider selection of late blight resistant tomato cultivars become commercially available, fungicides will continue to be the primary in-season late blight management tool for both organic and conventional production. Recent efforts to understand shifts in pathogen genotype and their sensitivity to mefenoxam as well as the development of a more centralize outbreak reporting system at the USAblight.org website provide growers, extension educators and other stakeholders with additional information to make in-season management decisions. Furthermore, improvements in BLITECAST to help time fungicide applications using real-time mesoscale weather data from ZedX, Inc. and further integration of forecasting, host resistance, fungicide use, and pathogen characteristics into the Cornell Decision Support System can help time fungicide applications when needed and reduce the total number of fungicide applications when environmental conditions are less favorable for disease. Funding from a USDA/NIFA late blight project will enable the continued evaluation of these disease forecasting systems this upcoming season.

Currently available late blight specific fungicides (e.g. Ranman, Revus Top, Previcur Flex, Zampro, etc.) are effective for managing late blight when applied in a timely manner and with adequate coverage however, there is increasing interest in the use of “softer, reduced-risk” fungicides (e.g. Actinovate and Regalia) either in combination with copper as part of an organic program or as part of a conventional program in response to the increasing consumer demand for reduced pesticide use. Is there a place for these products earlier in the season when disease pressure is low before switching to products like Ranman (0d PHI, 12h REI, FRAC group 21) or Revus Top (1d PHI, 12 h REI, FRAC group 3+40) later in the season when there is greater disease pressure and 0 or 1d PHIs and short REIs are needed for harvest? How about the use of these products later in the season to reduce visible copper residues on the fruit at harvest? Additional questions regarding the efficacy of hydrogen peroxide-based products like Oxidate frequently arise. Hydrogen peroxide is a strong oxidizing agent that kills instantly on contact but has no residual efficacy. Can it be effectively used to manage late blight? Does it have a role in a late blight fungicide program?

Additional knowledge about the efficacy of these fungicides and other biochemical and microbial biofungicides enables growers to make more informed decisions about how to manage late blight during the season and directly addresses two research priorities identified by the PAVMRB survey and Board discussion regarding the management of late blight and evaluation of OMRI approved pesticides. To fill the gap in knowledge, in 2014 we conducted a replicated field trial to evaluate the use these products alone and in fungicide programs for managing late blight and are in the process of disseminating the information at

grower meetings, in newsletters and in the Plant Disease Management Reports, a central publication portal for sharing of this type of data with the broader research community.

TRIAL DESCRIPTION AND RESULTS:

A replicated field trial was conducted at the Pennsylvania at the Pennsylvania State University Russell E. Larson Agricultural Research and Extension Center in PA Furnace, PA on a Hagerstown silty clay loam. The field was plowed on 1 Jul. No pre-plant fertilizer was applied based on soil test reports. Tomato transplants were transplanted on 7 Jul. A starter fertilizer 20-20-20 (N-P-K) along with Admire 2F (1.0 pt/A) was applied in the transplant water. Each plot was 12-ft long and separated by a 5-ft break within the row and 5-ft between rows centers. Guard rows planted with processing cv. H4007 separated each treatment row. Each plot was planted with 8 transplants spaced 18-in. apart. Treatments were replicated four times and arranged in a randomized complete block design. Weeds were managed with an application of Dual Magnum (1.5 pt/A) and Sencor DF (0.33 lb/A) on 1 Jul and supplemented with hand weeding. Plots were fertigated regularly (N-P-K, 20-20-20, 7 lb N/A) with a single line of drip irrigation tubing placed adjacent to the base of the plant. Fungicide applications were made using a tractor mounted, R&D CO_2 powered side boom sprayer calibrated to deliver 28 gpa at 32 psi at the tank through one center and two drop TX-18 nozzles for all applications. Foliar late blight severity was evaluated on 16, 22, 26 and 28 Aug based on the percentage of the plot showing symptoms. Rainfall totals (in.) were 3.66 and 5.52 for 7 to 31 Jul and 1 to 28 Aug, respectively.

The list of products used in the trial, their active ingredients, and FRAC codes are listed in Table 1. The specific treatments and application timings can be found in Table 2. For comparison, the treatments included an untreated control (Trt 15) and a conventional fungicide program consisting of a rotation among late blight specific fungicides (Trt 1). Six fungicide applications were made on a weekly basis on the 18, 24, 31 Jul and 7, 14, 21 Aug. Each plot was rated for overall disease severity four times on 16, 22, 26 and 28 Aug and then those rating were used to calculate the area under the disease progress curve (AUDPC) value which is a measure of disease over the course of the season so the larger the value the more severe the symptoms were during the season.

Late blight symptoms resulting from natural infection (US23) were first observed in the trial on 14 Aug and disease progressed rapidly. From the time that the first symptoms were observed on 14 Aug to when the untreated controls reached over 90% disease severity was 14 days (28 Aug). The conventional fungicide program (Trt 1) which rotated between the targeted fungicides was most effective at managing late blight (Figure 1; Table 2). Not surprisingly, the biopesticide products Serenade Max (Trt 14), Oxidate (Trt 13), OxiPhos (Trt 11), Actinovate (Trt 10) applied alone did not manage late blight as effectively as when they were used in a program with a copper-based fungicide like Champ WG or Badge X2 although this difference was often not statistically significant. In this trial, Bravo Weather Stik 6SC alternated with Oxidate reduced foliar disease severity in the plots by 60% compared to the untreated control and was the only treatment that held disease severity below 50% by the end of the trial (Figure 2). It is interesting to note that OxiPhos alternated with Champ (Trt 4) was significantly better at managing late blight than when OxiPhos was tank-mixed with Champ and applied weekly (Trt 12) or OxiPhos was applied alone (Trt 11) across all evaluation dates. No phytotoxicity was observed with any of the treatments. Yield data was not collected for this trial due to the delayed planting.

Table 1. The list of products and active ingredients used in the 2014 tomato late blight fungicide trial.

Product	Active ingredient	Category	OMRI approved	Company	FRAC code
Actinovate AG	*Streptomyces lydicus* WYEC 108	Microbial biopesticide	Yes	Novozymes	Bio
Badge X2	Copper oxychloride + copper hydroxide	Biochemical biopesticide		Gowan Company	M1
Bravo Weather Stik 6SC	Chlorothalonil	Synthetic	No	Syngenta	M5
Champ WG	Copper hydroxide	Biochemical biopesticide	Yes	Nufarm	M1
Oxidate	Hydrogen dioxide	Biochemical biopesticide	Yes	BioSafe Systems	n/a
OxiPhos	Phosphorus acid + hydrogen peroxide	Biochemical biopesticide	No	BioSafe Systems	n/a
Previcur Flex 6F	Propamocarb	Synthetic	No	Bayer CropScience	28
Ranman 400SC	Cyazofamid	Synthetic	No	FMC	21
Regalia SC	Extract of *Reynoutria sachalinensis*	Biochemical biopesticide	Yes	Marrone BioInnovations	P5
Revus Top 4.17SC	Mandiopropamid + difeniconazole	Synthetic	No	Syngenta	40 + 3
Serenade Max	*Bacillus subtilis* QST 713	Microbial biopesticide	Yes	AgraQuest	Bio
Tanos 50WG	Famoxadone + cymoxanil	Synthetic	No	DuPont Crop Protection	11 + 27
Zampro SC	Ametroctradin + dimethomorph	Synthetic	No	BASF Corporation	45 + 40

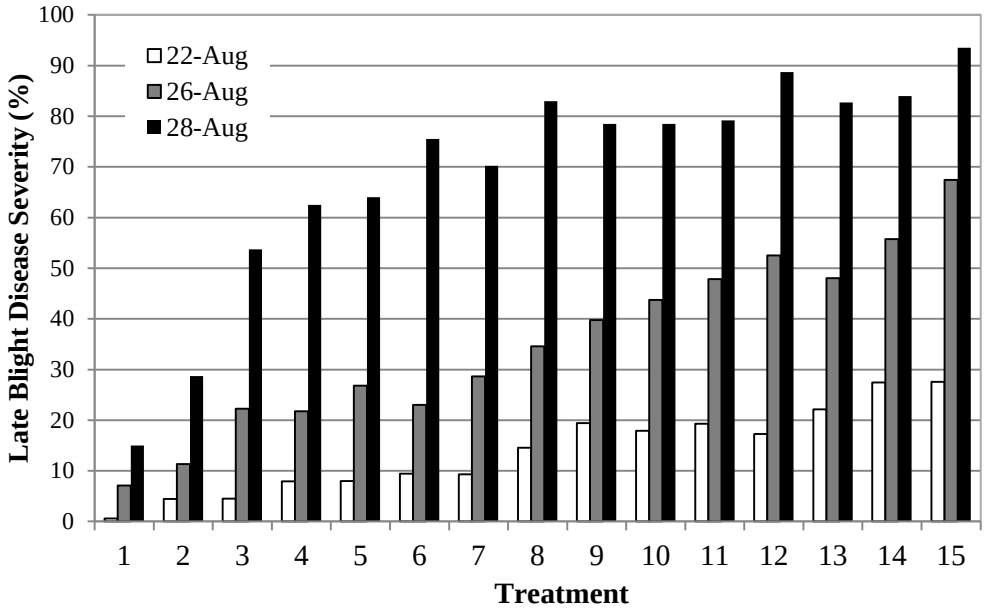

Figure 1. Efficacy of select fungicides and fungicide programs for managing late blight. Disease severity (%) was measured as the percent of plant tissue showing symptoms per plot on 22, 26 and 28 August 2014. Treatment numbers correspond to those listed in Table 2.

Table 2. Efficacy of select fungicides and fungicide programs for managing late blight. Disease severity (%) is the percent of plant tissue showing symptoms per plot and the area under the disease progress curve (AUDPC) is a measure of disease severity over the course of the season so the higher the number the more disease was observed in the plot.

	Fungicide(s) and rate/A	Application timing[z]	Disease severity (%)				AUDPC[y]	
			22 Aug		28 Aug			
1	Tanos 50WG 0.5 fl oz + Bravo Weather Stik 6SC 2.0 pt	1						
	Previcur Flex 6F 1.5 pt + Bravo Weather Stik 6SC 2.0 pt	2						
	Zampro SC 14.0 oz + Penetrator Plus 0.5% v/v + Bravo Weather Stik 6SC 2.0 pt	3						
	Ranman 400SC + Induce 0.25%v/v + Bravo Weather Stik 6SC 2.0 pt	4,6						
	Revus Top 4.17SC 7.0 oz + Induce 0.25%v/v	5	0.61	e[x]	15.0	f	40.8	f
2	Bravo Weather Stik 6SC 2.0 pt	1,3,5						
	Oxidate 35.7 fl oz	2,4,6	4.47	cde	28.7	f	90.1	ef
3	Champ WG 1.06 lb	1-6	4.54	cde	53.7	e	143.8	de
4	Champ WG 1.06 lb	1,3,5						
	OxiPhos 11.8 fl oz	2,4,6	7.93	b-e	62.5	de	168.8	cde
5	Badge X2 28DF 28.0 oz	1-6	7.96	b-e	64.0	cde	187.2	b-e
6	Actinovate AG 12.0 oz + Induce 0.25% v/v + Champ WG 1.06 lb	1,3,5						
	Oxidate 35.7 fl oz	2,4,6	9.44	a-d	75.5	a-d	199.1	b-e
7	Champ WG 1.06 lb	1-6						
	Actinovate AG 12.0 oz + Induce 0.25% v/v	1,3,5						
	Regalia SC 3.0 qt	6	9.33	a-e	70.2	b-e	209.3	b-e
8	Champ WG 1.06 lb	1-6						
	Serenade Max 3.0 lb + Induce 0.25% v/v	1,3,5						
	Regalia SC 3.0 qt	6	14.57	abc	83.0	a-d	268.7	a-d
9	Badge X2 28DF 28.0 oz	1-6						
	Actinovate AG 12.0 oz + Induce 0.25% v/v	1,3,5						
	Regalia SC 3.0 qt	6	19.44	abc	78.5	a-d	296.7	abc
10	Actinovate AG 12.0 oz	1-6	17.93	abc	78.5	a-d	303.1	abc
11	OxiPhos 11.8 fl oz	1-6	19.32	abc	79.2	a-d	321.9	abc
12	OxiPhos 11.8 fl oz + Champ WG 1.06 lb	1-6	17.25	abc	88.7	ab	339.6	ab
13	Oxidate 35.7 fl oz	1-6	22.15	ab	82.7	a-d	347.7	ab
14	Serenade Max 3.0 lb	1-6	27.44	a	84.0	abc	394.9	a
15	Untreated control	NA	27.54	a	93.5	a	426.0	a

[z] Application dates were: 1 = 18 Jul; 2 = 24 Jul; 3 = 31 Jul; 4 = 7 Aug; 5 = 14 Aug; 6 = 21 Aug. NOTE: The 21 Aug applications were made 25 min prior to a rain event.

[y] Area under the disease progress curve (AUDPC).

[x] Values within each column followed by the same letter are not significantly different (P=0.05) according to Fisher's Least Significant Difference test (SAS v.9.2, SAS Institute, Cary, NC). Disease severity data on 22 Aug as well as AUDPC values were square root transformed prior to analysis. Table contain de-transformed values.