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Alternative Disease Management Approaches: Best Implemented Before the "Critical Window" for *Erysiphe necator* in Eastern Washington?

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1 Introduction. In eastern Washington (WA), United States, wine grape (*Vitis vinifera)* vineyards use approximately 4 to 7 fungicide applications to control grapevine powdery mildew (*Erysiphe necator)* (Hoheisel and Moyer, 2020). In many other grape growing areas of the country, the typical spray program for powdery mildew management can be as high as 15 annual sprays for disease control. This lower-than-average spray scenario in this region is due to the generally hot, and dry, in-season growing conditions. Prosser, WA, USA averages 1,600 growing degree days (Fig. 1A) with the average daily maximum in-season temperatures ranging from 12 – 35° C (10-yr average, 1 Apr – 31 Oct). Annual precipitation averages 164 mm, with 76 mm falling in season (Fig. 1B) (Washington State University-AgWeatherNet, "Prosser NE" station; weather.wsu.edu).

With such low disease pressure, comes the opportunity to evaluate alternative management strategies that might be less effective in higher disease pressure climates. These alternatives come with added benefits of potentially reducing total pesticide inputs, reducing the risk of fungicide residue on fruit, or providing an alternative management approach that may assist in fungicide stewardship.

The challenge to successfully adopting alternative pest management approaches is figuring out how they integrate (or not) into existing approaches. Are there particular periods of plant development where alternative strategies should be used, or should be avoided? For example, based on work related to ontogenic resistance of grape berries to *E. necator*, we know that the peak period of susceptibility of *V. vinifera* berries to *E. necator* infection occurs from 2 weeks pre-bloom to 4 weeks post-bloom (Gadoury *et al.,* 2003; Moyer *et al*., 2016). This means that most growers will choose to use their most-effective chemistries during this period, and that most of the season-long disease control on fruit occurs during this narrow window.

This could also mean that lesser-known tools, or tools with reduced efficacy, may show promise if used during periods of lower infection risk, such as budbreak to pre-bloom (approx. 1 Apr – 31 May). This early season is still an important time to reduce pathogen inoculum to avoid berry infection but provides a time window where alternatives can be used at low risk relative to weather patterns for eastern WA. Pre-bloom weather patterns in eastern WA are characterized by low night-time temperatures ranging from 2 - 11°C and receives 20% (32 mm) of the annual precipitation, (10-yr average, 2009-2019). Though this pre-bloom period provides sufficient precipitation for an epidemic to occur the low night-time temperatures keep disease low due to the night-time temperature routinely dropping below 8°C (Gadoury *et al*., 1990; Moyer *et al*., 2010). This low risk period is a time where risk-adverse growers can test and integrate new tools into their fungicide program while still utilizing efficient fungicide during the critical bloom period.

Ozonated water is one such potential powdery mildew management alternative that is not noted for high efficacy, but has potential. Ozonated water has been reported for its ability to suppress cucumber powdery mildew (*Sphaerotheca fuliginea* Pollacci) in a controlled greenhouse (Fujiwara and Fujii, 2002; Fujiwara *et al*., 2009). Recent studies on grapevine diseases has concluded that ozonated water reduced fungal microflora on grape leaves when applied in field and reduced truck disease *Phaeoacremonium*

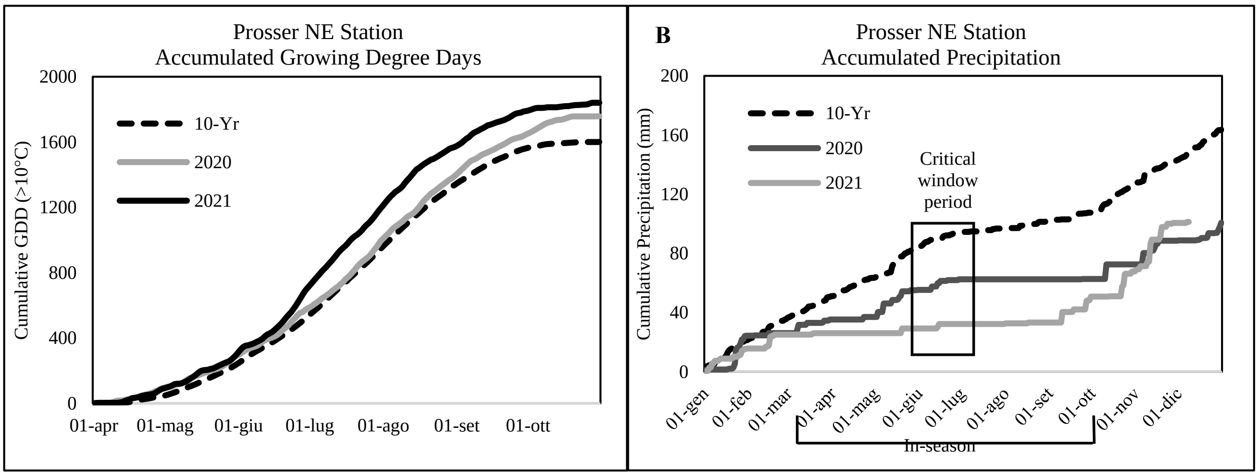

Figure 1: Weather data was acquired from AgWeatherNet, Washington State University, Prosser NE station. 10-Yr: 10-year average from 2009-2019. **A)** Accumulated Growing Degree Days (GDD). GDD was calculated with 10°C base temperature, from 1 Apr – 31 Oct. **B)** Accumulated Precipitation is calculated on the sum of daily average precipitation. Critical window is 2 weeks pre-bloom to 4 weeks post-bloom, approximately 23 May to 4 July.

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aleophilum spore germination under *in vitro* conditions (Pierron *et al*., 2015; Raio *et al*., 2016; Modesti *et al*., 2018). There are limited field studies that look at season-long disease control, and how the ozonated water based alternative approach can potentially integrate into standard fungicide programs. Currently, ozonated water systems are commercially available and marketed to grape growers (AgriOzien, Nebraska, USA). In this trial, we evaluated the efficacy of ozonated water spray (OWS), applied during the grape pre-bloom period for its potential to control grape powdery mildew (*E. necator).*

2 Methods. The trial occurred in an experimental *V. vinifera* 'Chardonnay' (own-rooted) block at the Washington State University Irrigated Agricultural Research and Extension Center, Prosser, WA, USA for two growing seasons (2020 and 2021). Treatments consisted of a grower standard control that represented typical eastern Washington growers' fungicide program, pre-bloom unsprayed control, OWS, and a full season unsprayed control where no fungicides were applied all season. Treatments started at 10-20 cm shoot growth (BBCH 13), and continued at the intervals, as listed in Table 1. For most treatments, last applications were at pre-bloom (BBCH 55-57), then reverted to the grower standard spray program for the remaining of the season (pre-bloom unsprayed, OWS, grower standard) or continued untreated (full season unsprayed). These treatments were chosen to test if OWS would compare with the grower standard or perform better than the pre-bloom unsprayed. The full season unsprayed control was used to assess the overall disease pressure for the season. Treatments plots consisted of 6 vines with data collected from the center 4 vines and were replicated 4 times within a complete block design. To reduce potential drift between treatment plots, buffers of 6 vines inter-row and one row between were used.

Ozonated water was applied with a commercial retrofitted unit seen in Fig. 2. OWS was optimized for our vineyard with three D5DC25 TeeJet hollow cone nozzles per side, to apply 702 liters/hectare without air-assist (i.e., axial fan off). Ozone concentration in tank was measured with Chemetrics I-2019 Dissolved Ozone Meter (Virgina, USA) and sprayed once tank reached peak ozone concentration of 1 ppm. Fungicides in 2020 were applied using an ATV-mounted tank sprayer (ATV2507 ATV Sprayer, WorkHorse Sprayers, Indiana, USA) until 21 May at 468 liters/hectare, then applied with a Rears Manufacturing Powerblast Pul-Tank airblast sprayer at 702 liters/hectare with D5DC25 TeeJet nozzles, without air-assist on 4 June, and with air-assist for the last two sprays. In 2021 fungicides were applied with a Rears custom built over-the-row multi-tank with air shear nozzles. Sprays up to 19 May were applied at 468 liters/hectare with 3 nozzles per side, then 702 liters/hectare with 4 nozzles per side for the remainder of the applications.

Figure 2**:** The OWS system consisted of a commercially available generator, injector and recirculating pump (AgriOzien, Nebraska, USA) retrofitted to a Rears Manufacturing Powerblast Pul-Tank airblast Sprayer (Oregon, USA), by Washington State University - Center for Precision and Automated Agricultural Systems.

Treatment		**2020 Dates (and Products)**	**2021 Dates (and Products)**
Grower Standard	Pre-bloom	8 May – Sulfur (2.3 kg) 14 May – Sulfur (1.8 kg) 21 May – Vivando + Sulfur (0.9 kg)	5 May – Sulfur (1.8 kg) + Cinnerate + Complex 12 May – Sulfur (1.8 kg) + Cinnerate + Complex 19 May – Vivando + Complex
	Post-bloom	4 June – Quintec + Cinnerate 18 June – Torino + Cinnerate 2 July – Gatten + Cinnerate	1 June – Quintec + PureSpray Green (0.25%) 15 June – Torino + PureSpray Green (0.25%)
Pre-bloom Unsprayed Control	Pre-bloom	8 May – 28 May unsprayed	5 May – 25 May unsprayed
	Post-bloom	Grower Standard post-bloom	Grower Standard post-bloom
Ozonated Water Spray (OWS)	Pre-bloom	7 May, 14 May, 21 May, 28 May – OWS	5 May, 12 May, 19 May, 26 May - OWS
	Post-bloom	Grower Standard post-bloom	Grower Standard post-bloom
Full Season Unsprayed		Unsprayed all season	Unsprayed all season
Phenology (BBCH Scale)		8 May – BBCH 15 (10-20 cm shoot); 14 May – BBCH 55 (inflorescence compact); 21 May – BBCH 57 (inflorescence separating); 4 June – BBCH 68 (80% bloom); 18 June – BBCH 71; 2 July – BBCH 75	5 May – BBCH 15 (10-20 cm shoot); 12 May – BBCH 19; 19 May – BBCH 55 (inflorescence compact); 1 June – BBCH 69 (100% bloom); 15 June – BBCH 73

Table 1: Early-Season Trial. OWS and Pre-bloom unsprayed control treatments were applied up to bloom, then converted to grower standard spray program for the remaining season. Fungicides were applied at near or at max rates unless listed

Starting 10 June 2020 and 8 June 2021 until harvest, visual disease incidence and severity ratings of powdery mildew were recorded. Ratings were done by a trained rater, and evaluated 40 leaves and 20 clusters in 2020, increasing to 40 clusters in 2021 per treatment replicate. Leaves were selected randomly, and ratings occurred every 7 to 14 days.

Statistical Analyses. Foliar and cluster disease ratings were examined by area under the disease progress curve (AUDPC) (Madden *et al*., 2017) then analysed with JMP 15 statistical program. ANOVA and Tukey's HSD were used to determine significance.

3 Results. *Weather data.* In 2020 and 2021, in-season growing degree days (GDD, >10°C) were both higher than the 10-yr average indicating warm years, though 2021 patterns reached extremes (Fig. 1A). In June 2021 daytime maximum temperatures peaked at 38°C in an unprecedented "heat dome" event in western North America. From 26 to 30 June 2021, there were 5 consecutive days above 37.8°C The standout difference from both years to the 10-yr average is the overall in-season cumulative precipitation, 2020 receiving 37 mm and 2021 with 42 mm, well below the 10-yr average of 76 mm. For both 2020 and 2021 there was very little accumulated precipitation during the critical window time (Fig. 1B).

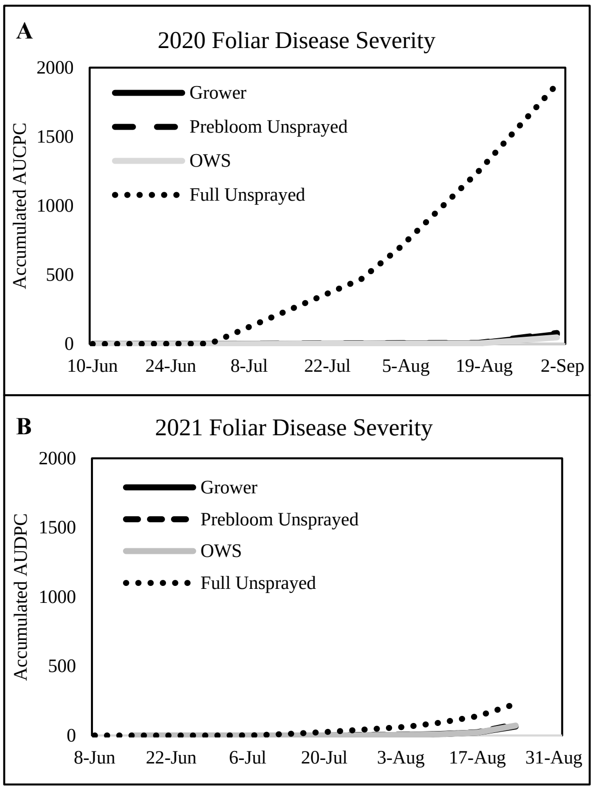

Figure 3: Grower: Grower Standard Control, Pre-bloom Unsprayed, OWS: Ozonated water spray system, Full Unsprayed: Full season long unsprayed control. Graphs represent accumulated AUDPC throughout the season. **A)** 2020 Foliar Disease Severity. Full season unsprayed was higher than all other treatments (p=0.0009**) B)** 2021 Foliar Disease Severity. Full season unsprayed trended higher than other treatments (p=0.06).

Disease. In 2020, the end of season foliar disease severity for the full season unsprayed was 43%, pre-bloom unsprayed was 21%, grower standard was 17%, and OWS was 11%. Disease severity was converted to AUDPC to capture season-long disease progress. At harvest, AUDPC for treatments that received a fungicide treatment at bloom (grower standard, pre-bloom unsprayed, and OWS) were not different from each other, though all were significantly lower than full season unsprayed (Fig. 3A; p=0.0009).

Cluster disease severity for 2020 was low, with grower standard, OWS, and pre-bloom unsprayed being <1%, while the full season unsprayed was 4%. Though even with this low disease pressure on clusters, grower standard, pre-bloom unsprayed, and OWS AUDPC was lower than the full season unsprayed (Fig. 4; p=0.02).

In 2021, disease pressure was even lower. The end of the season foliar disease severity for the full season unsprayed was 16%, pre-bloom unsprayed was 12%, grower standard was 9%, and OWS was 11%. Cluster severity at harvest was 0% for all treatments. There was no significant difference between any of the treatments for foliar (AUDPC p=0.06; Fig. 3B) or cluster.

4 Discussion. In 2020, regardless of what treatment (or no treatment!) was implemented in the pre-bloom period, when efficacious fungicides were used during the critical window, disease on fruit was less than the unsprayed control. Due to the record-breaking hot and dry weather of 2021, it was hard to separate treatment differences due to such low disease

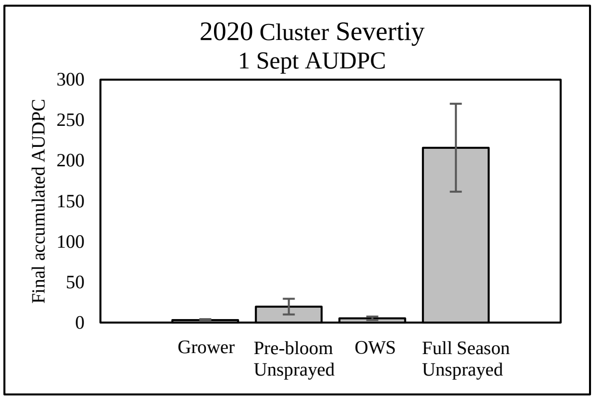

Figure 4: 2020 Cluster Severity. Final accumulated AUDPC at harvest, 1 Sept. Full season unsprayed was higher than other treatments (p=0.02). Grower: Grower Standard Control, Pre-bloom Unsprayed, OWS: Ozonated water spray system, Full Unsprayed: Full season long unsprayed control. 2021 was not represented as all treatments cluster disease severity were 0%.

pressure, but treatment performance trends mirrored that of 2020. Under these very low-pressure weather conditions, during a time of year that is routinely low-pressure, adjusting (or replacing) pre-bloom spray regimes to alternatives such as OWS can still result in acceptable disease control on fruit.

With this knowledge, growers in climates like eastern WA could either eliminate, or swap pre-bloom fungicides for approaches or products that are considered “lower-impact”. However, this approach would require grower to be aware of changing environmental conditions, to determining if the growing season is changing from lower disease pressure to higher disease pressure.

Using models such as the New York Model (Moyer *et al.,* 2016) to determine disease pressure could help growers make educated decisions on the types of products they might be willing to use during pre-bloom fungicide sprays. This model was designed to predict risk for powdery mildew disease severity based on weather conditions from 2-week pre-bloom to 4 weeks post-bloom. According to that model, 2020 had an 80% chance of being a mild year based on moderate in-season evapotranspiration (ET_o=5.53 mm), and cooler previous fall conditions (fall degree days summed from 1 Aug to the first killing frost; modification of the model). The model predicted 2021 to be 100% chance of mild year due to high in-season evapotranspiration (ET_o=6.14 mm). For a quick validation of model effectiveness in eastern Washington, the 2010 and 2011 vintages were also evaluated, due to the uncharacteristically high disease pressure growers in the region faced. Using the New York Model, 2010 and 2011 were given a 100% chance of severe year based on moderate in-season evapotranspiration (ET_o=5.32 mm and ET_o=5.73 mm, respectively), and conducive previous fall conditions.

New York or similar models could be used by growers to guide their own on-farm risk assessment, and make educated decisions on how to adjust their pre-bloom sprays. Using this models or others that predict disease risk for *E. necator* could be a way to help risk adverse growers make the change to swap their pre-bloom sprays for low impact alternatives such as OWS or to remove pre-bloom fungicides and thus reducing overall pesticide use.

5 Conclusions. This research cannot confirm OWS efficacy compared to fungicides for pre-bloom time period due to the low disease pressure present during the years of the study. But it does suggest that low impact alternatives such as OWS could be complementary alternatives in pest management programs. This 2-year trial also emphasizes the dominate role critical window sprays play for disease control on fruit; leaving the pre-bloom period open for experimentation in program adjustments. If there is a time to test products or methods for *E. necator* management while not risking crop loss, pre-bloom would be that time.

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