Title: Evaluating organic fungicides for control of blueberry diseases in the southeastern U.S.

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Public Abstract

Blueberries are an economically important fruit crop in the southeastern U.S., and Georgia (#3) and North Carolina (#7) rank among the top 7 states nationally in terms of blueberry production. Within the southeastern region, Georgia and North Carolina also rank first and second, respectively, in organic blueberry production. The warm, wet climate of the southeastern U.S. is quite conducive for disease development, making disease issues a major problem for blueberry production in the region. Disease management in organic blueberry production can be especially challenging. Relatively few fungicides exist that are approved for use in organic systems, and limited efficacy information is available for many of these fungicides with respect to the specific disease issues that affect blueberry in the Southeast. To help address this, field trials were carried out in Georgia and North Carolina during the 2022 growing season to assess the efficacy of several organic fungicides for controlling fruit rots and leaf spots under typical southeastern U.S. blueberry production conditions. Trial results suggested that some of the tested products may be suitable for use in organic blueberry production in the southeastern U.S. Accordingly, it is expected that recommendations regarding the use of these products will be incorporated into future editions of the Southeast Regional Organic Blueberry Pest Management Guide. Taken together, the results generated from these trials are expected to help organic blueberry growers in the southeastern U.S. make informed decisions regarding the use of organic fungicides for disease management.

Introduction:

Organic fruit crop production in the United States (U.S.) is growing at an annual rate of 20%, with U.S. organic retail sales totaling $61.9 billion in 2020 (Karst 2021). In Georgia, organic blueberries are the second highest organic commodity in annual sales ($8.5 million in 2019), and in North Carolina, organic blueberry sales account for $5.6 million dollars annually (NASS 2020). This ranks Georgia first and North Carolina second in organic blueberry production among U.S. states in the southeastern region. The warm, wet climate in this region is conducive for disease development, and disease issues can be a major problem in blueberry production. In organic production systems in particular, disease issues remain difficult to control. Relatively few fungicides exist that are approved for use in organic systems, and limited efficacy information is available for many of these fungicides with respect to the specific disease issues that affect blueberry in the Southeast.

Among the diseases that significantly affect organic blueberry production are several fruit rots (**Figure 1**). Botrytis fruit rot (caused by the fungus *Botrytis cinerea*), Anthracnose ripe rot (caused by the fungal species *Colletotrichum gloeosporioides* and *C. acutatum*), Alternaria fruit rot (caused by the fungus *Alternaria tenuissima*), and Phomopsis fruit rot (caused by the fungus *Phomopsis vaccinii*) are important diseases that regularly impact blueberry production worldwide (Bristow et al. 2017a; Milholland 2017; Milholland and Cline 2017; Milholland and Schilder 2017). These diseases are prevalent in blueberry production systems in Georgia (Mehra et al. 2013) and North Carolina (Bill Cline, personal communication), and targeted sprays from bloom through harvest are necessary to manage these disease issues in commercial production. If unmanaged, infection with the fungal organisms causing these diseases can lead to significant pre- and post-harvest rots, and significant losses, on a regular basis.

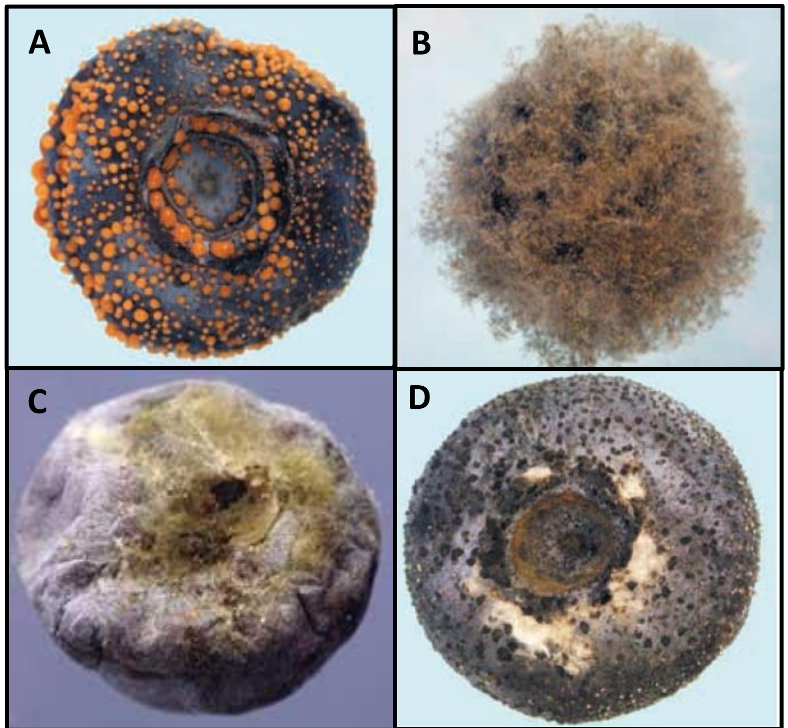

Figure 1. Major blueberry fruit rots: (A) Anthracnose ripe rot, (B) Botrytis fruit rot, (C) Alternaria fruit rot, and (D) Phomopsis fruit rot. Photos from Wharton, P. and Schilder, A. 2015.

Foliar diseases of blueberry, including Septoria leaf spot (caused by *Septoria albopunctata*) and blueberry leaf rust, also impact organic production, and blueberry leaf rust has emerged as a particular problem in recent years. Blueberry leaf rust is caused by the fungal species *Thekopsora minima* (aka *Pucciniastrum vaccinii*) (Bristow et al. 2017b). While this disease is a well-known disease in the late summer and fall, it can also cause significant issues in the spring if mild winters allow for overwintering of infected leaves on plants. Leaf rust is typically recognized by the bright orange (rust-colored) spores produced from reproductive structures (pustules) formed on the underside of the leaf (**Figure 2A**). Above the pustule (on the upper side of the leaf) spots are formed which turn reddish brown (**Figure 2B**). Fungal spores produced within these pustules are responsible for the spread of rust from plant to plant. In severe cases, rust can lead to premature defoliation of the plant, which can negatively impact flower bud set and return yield the following year.

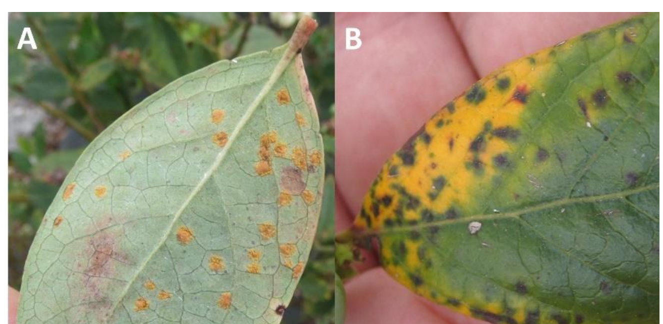

Figure 2. Symptoms of blueberry leaf rust: (A) leaf rust pustules on the leaf underside, and (B) spots on the leaf surface. Photos from MyIPM App.

As stated previously, available fungicide options for use in organic blueberry production are limited. According to the *Southeast Regional Organic Blueberry Pest Management Guide* (Little et al. 2021), the only organic fungicide currently listed to have efficacy against Botrytis, Alternaria, and

Anthracnose fruit rots is Serenade, and for management of blueberry leaf rust this guide only lists copper fungicides and Serenade as materials known to have fair efficacy against this issue. Nonetheless, in addition to the fungicide Serenade, which contains the bacterium *Bacillus subtilis* strain QST713, other OMRI-listed organic "biofungicides", including Double Nickel (the bacterium *Bacillus amyloliquefaciens* strain D747) and Howler (*Pseudomonas chlororaphis* strain AFS009), are labeled for use on blueberry. Furthermore, other organic fungicides are available as well, including OSO 5% SC (a polyoxin D salt), which was only recently OMRI-listed in 2020, and PureSpray Green (a mineral oil). Unfortunately, there is little/no data from replicated field trials to determine the relative effectiveness of these products for disease management in blueberry. Accordingly, since relative efficacy information is not available for these products from southeastern U.S. blueberry production sites, we conducted efficacy trials in Georgia and North Carolina during the 2022 growing season. These trials were carried out at a certified organic blueberry production site in Baxley, Georgia and at the Horticultural Crops Research Station in Castle Hayne, North Carolina. Our objective was to determine the efficacy of these fungicides for controlling fruit rots (primarily Anthracnose ripe rot, Botrytis, Alternaria, and Phomopsis) as well as leaf spots (primarily blueberry leaf rust) under typical southeastern U.S. blueberry production conditions. Where efficacy was indicated in these trials, it is expected that recommendations regarding the use of these products will be incorporated into future editions of the Southeast Regional Organic Blueberry Pest Management Guide.

Materials and Methods:

Georgia fungicide efficacy field trial methods. At a commercial organic blueberry production site near Baxley, Georgia, an on-farm trial was set-up to evaluate organic fungicides for control of fruit rot diseases (Anthracnose ripe rot and Alternaria fruit rot) and leaf spot diseases (Anthracnose leaf spot, blueberry leaf rust, and Septoria leaf spot) on southern highbush (SHB) blueberry (*V. corymbosum* interspecific hybrids) cultivar 'Farthing'. Treatments were applied every 7-10 days beginning at early bloom (10% bloom). Applications were made on 27 Jan, 14 Feb, 21 Feb, 3 Mar, 14 Mar, 22 Mar, 29 Mar, 4 Apr, 13 Apr, and 22 Apr. All treatments were applied until runoff (equivalent to 75 gal water/A) using a CO_2-powered backpack sprayer fitted with a cone nozzle at 40 psi. Fungicide treatments consisted of: Serenade Opti, ThymeGuard, PureSprayGreen, TimorexACT, Double Nickel LC, OSO 5% SC, and Howler. For applications of OSO 5% SC and Double Nickel, the OMRI-listed non-ionic surfactant Kinetic was added at 0.05% v/v. For applications of Howler, Kinetic was added at 0.094% v/v. Five replications of each treatment and an untreated control were applied to a randomized complete block design with each plot consisting of four sprayed plants, with one or more unsprayed plants separating each plot. All cultural practices throughout the trial were consistent with organic highbush blueberry production methods commonly observed in the Southeast.

On March 13th, the trial site was hit by a severe late freeze event. Overnight temperatures in the area dropped into the mid-20's. Though extensive freeze damage was observed on blueberry blooms and fruit throughout the region, the full extent of the freeze's impact on these on-farm trials was not immediately evident. However, within the next few weeks, it became obvious that the freeze had severely impacted the trial plants used in these trials. As a result, no fruit could be harvested from any of the trial plots for evaluation of fruit rots. Nonetheless, despite these impacts on fruit, fungicide applications were continued through late April to allow for the evaluation of fungicides versus spring leaf spot development. For evaluation of leaf spots, ~50 leaves per plot were collected on 16 May. Prior to leaf collection, the area of the leaf surface affected by leaf spots in each treated plot was also estimated in the field using the Horsfall-Barratt scale. Data was analyzed using analysis of variance (ANOVA) followed by Tukey's honest significant different (HSD) using the package agricolae in R (R v. 3.4.2, The R Foundation, Vienna, Austria).

North Carolina fruit rot fungicide efficacy field trial. This experiment was conducted on 11-yr-old bushes planted on 3 × 10-ft spacing at the Horticultural Crops Research Station in Castle Hayne. A randomized complete block design was used with five replications per treatment. Each plot consisted of three adjacent bushes in a row. Spray treatments were applied using a CO_2-powered backpack sprayer delivering the equivalent of 50 gallons per acre (gpa) at approximately 60 psi. A spray boom with two hollow cone nozzles spaced 20 inches apart was used. On each spray date, applications were made in a single timed pass down one side of each plot. Fungicide treatments consisted of the organic fungicides OSO 5% SC, PureSprayGreen, Double Nickel, Howler, and Theia, the conventional fungicides Cevya and Miravis Prime, and an untreated control. For applications of Howler and Theia, the non-ionic surfactant B1956 was added at 0.125% v/v. Treatments were applied at pre-bloom (7 Mar), full bloom (18 Mar), flower drop (29 Mar) and small green fruit (8 Apr). Mummy berry was evaluated on 8 Apr (primary or shoot strike stage) and on 18 and 25 May (secondary or fruit infection stage) by counting visibly infected berries (mummies) on the center bush in each plot as well as on the ground underneath that bush. For evaluation of Anthracnose ripe rot, Alternaria rot, and soft rot, ripe berries were harvested by hand on 18 and 25 May when an estimated 25% and 50% of berries were ripe. All ripe (blue) fruit was harvested at each picking date from the center bush in each plot into a clean one-gallon bucket, immediately refrigerated at 40°F for one to three days, then held at approximately 72°F for four days to allow rots to develop. Specifically, berries from the first picking were poured into flat cardboard trays in a single layer for the 72°F incubation period, then evaluated visually and by feel for signs and symptoms of fruit rots. For the second picking, only ripe rot was evaluated -- the top, undisturbed layer of berries in each bucket (approximately 1 pint equivalent) were visually rated *in situ* for the presence of orange-colored ripe rot sporulation on individual infected berries (see results section for information regarding refrigeration failure). Leaf diseases (Septoria leaf spot, blueberry rust) and Botrytis flower blight were also monitored in this experiment, but data were not recorded due to low disease incidence. Statistical analysis was performed using PROC ANOVA (www.sas.com).

North Carolina leaf spot fungicide efficacy field trial. This experiment was conducted simultaneously on 14-yr-old 'Star' bushes planted on 3 × 10-ft spacing and 10-yr-old 'Vernon' planted on 4 × 10-ft spacing at the Horticultural Crops Research Station in Castle Hayne. A randomized complete block design was used with five ('Star') or four ('Vernon') replications. Each plot consisted of three adjacent bushes in a row. Spray treatments were applied using a CO_2-powered backpack sprayer delivering the equivalent of 50 gallons per acre (gpa) at approximately 60 psi. A spray boom with two hollow cone nozzles spaced 20 inches apart was used. On each spray date, applications were made in a single timed pass down one side of each plot. Fungicide treatments consisted of the organic fungicides OSO 5% SC, PureSprayGreen, Double Nickel, Howler, and Theia, the conventional fungicides Cevya, Orbit, and Pyraziflumid, and an untreated control. Treatments were applied postharvest on 6 Jun, 21 Jun, 5 Jul, 15 Aug and 27 Aug. As part of normal horticultural practices, the test rows were hedged at a 45-degree angle from each side of the row in late June after harvest, creating a "housetop" row shape with a peak in the center approx. 4 ft above the ground. Visual ratings of only the oldest (Spring) growth flush were used throughout. Disease ratings include incidence (percentage of leaves with at least one spot), severity (maximum number of spots observed on a single leaf), and percent defoliation. Rust ratings include an estimate of flower bud formation on 'Vernon'-- blueberries form flower buds in late Fall, and early defoliation visibly reduces bud set (and yield the following year). Evaluations were performed on 17 Sep and 14 Oct. Statistical analysis was performed using PROC ANOVA (www.sas.com).

Results:

Georgia fungicide efficacy field trial. Conditions were adequate for the development of leaf spot diseases, with a moderate to high incidence (61.3%) of blueberry leaf rust observed on the untreated control plots (**Table 1**). A low incidence of other leaf spot diseases, including Septoria leaf spot and Anthracnose leaf spot, were also observed. Among all treatments, the lowest numerical incidence and severity of blueberry leaf rust was observed following applications with OSO 5% SC and PureSprayGreen, however no significant differences among treatments were noted in this trial. With respect to all leaf spots, the lowest severity and leaf area affected were also observed in the OSO 5% SC and PureSprayGreen treated plots, but these values were not significantly different than the untreated control. No phytotoxicity was observed at any time following treatment applications.

Table 1. Georgia fungicide efficacy trial results for leaf spot assessments.

		All Leaf Spots			Blueberry leaf rust	
Treatment and amount/A	Application timing^{z}	Incidence (%)^{y}	Severity (spots/leaf)^{y}	Leaf Area Affected (% of surface area)^{x}	Incidence (%)^{y}	Severity (spots/leaf)^{y}
Untreated control	----	70.7 a	2.9 a	26.1 ab	61.3 a	2.2 a
Howler 5 lb	1-10	76.2 a	3.7 a	46.8 a	67.9 a	3.1 a
ThymeGuard 1.5 qt	1-10	70.1 a	2.9 a	29.9 ab	60.4 a	2.4 a
TimorexACT 17 fl oz	1-10	71.2 a	2.5 a	24.2 ab	60.3 a	2.0 a
Serenade Opti 20 oz	1-10	66.6 a	3.0 a	21.4 ab	58.1 a	2.3 a
Double Nickel LC 4.5 pt	1-10	67.8 a	2.7 a	34.2 ab	56.9 a	2.2 a
PureSprayGreen 1.5 gal	1-10	69.4 a	2.5 a	10.0 b	50.3 a	1.6 a
OSO 5% SC 6.5 fl oz	1-10	59.8 a	1.8 a	11.9 b	45.3 a	1.2 a

^{z}Treatments were applied on (1) 27 Jan, (2) 14 Feb, (3) 21 Feb, (4) 3 Mar, (5) 14 Mar, (6) 22 Mar, (7) 29 Mar, (8) 4 Apr, (9) 13 Apr, and (10) 22 Apr.

^{y}Recorded for~50 leaves per plot on average on 16 May. 'Incidence' refers to the percentage of leaves with spots. 'Severity' refers to the number of spots per leaf. Means in each column followed by the same letter are not significantly different according to Tukey's honest significant different (HSD) (α=0.05).

^{x}Leaf area affected was visually assessed in the field using the Horsfall-Barratt scale. Values were converted to mid-percentages prior to statistical analyses. Means in each column followed by the same letter are not significantly different according to Tukey's test (HSD)(α=0.05).

North Carolina fruit rot fungicide efficacy field trial. Disease pressure was adequate for fruit rot evaluations but not for mummy berry, leaf spots, or Botrytis. Evaluation of rots from the first picking was initiated prematurely on 19 May and halted after two replications had been sorted; the remaining three replications were rated on 23 May, and only data from these three replications are shown (N=3). Berries from the second harvest were stored at 40°F over the Memorial Day weekend when the walk-in cooler failed, and storage temperatures rose to approximately 72°F. These berries had to be evaluated *in situ* without disturbing the fruit in buckets, and only ripe rot could be distinguished by this method. Some treatments caused faint spotting on the pale, waxy surface of berries that was noticeable prior to picking but not after berries had been handled during harvest. PureSprayGreen caused unacceptable darkening around the calyx end of berries that remained visible after picking and handling. The "grower standard" conventional (non-organic) fungicide Miravis Prime did not cause spotting on berries and consistently never had more than two ripe rot symptomatic berries per bush, while all other treatments resulted in highly variable ripe rot incidences. Among the organic treatments, applications of OSO 5% SC also resulted in a significant reduction in total rots and ripe rot incidence at both harvests (**Table 2**). Both treatments utilizing surfactants (Howler and Theia) appeared to increase ripe rot incidence. No other phytotoxic effects were observed for any treatment.

Table 2. North Carolina fungicide efficacy trial results for fruit rot assessments.

Treatment and amount/A Applied 3/7, 3/18, 3/29, 4/8	First harvest on 18 May % Ripe rot	% Mold[z]	% Soft rot[y]	% Total rots	Second harvest on 25 May % Ripe rot
Untreated control	10.8 abc[x]	2.5 ab	8.9 a	22.2 a	4.8 ab
Howler 5 lb + surfactant	14.7 a	1.7 ab	4.0 bc	20.3 a	10.7 a
Theia 3 lb + surfactant	14.0 ab	1.9 ab	7.0 ab	22.8 a	9.1 a
Double Nickel 4.5 pt	9.9 abcd	1.9 ab	4.8 abc	16.5 ab	10.7 a
PureSprayGreen 1.5 gal	6.5 cde	4.1 a	7.2 ab	17.8 ab	3.2 ab
Cevya 5 fl oz	8.6 bcd	1.4 ab	2.0 c	11.5 bc	6.0 ab
Oso 5% SC 6.5 fl oz	4.4 de	2.4 ab	5.4 abc	12.1 bc	1.5 b
Miravis Prime 13.4 fl oz	0.4 e	0.2 b	5.2 abc	5.8 c	0.5 b
LSD	6.3	2.8	4.4	8.0	6.3

[z]Visible mold after 3 days was primarily *Alternaria*.
[y]Soft rots with no visible mold or spores after 3 days were attributed to *Phomopsis*.
[x]Means within a column followed by the same letter are not significantly different according to Fisher's Protected LSD (α=0.05).

North Carolina leaf spot fungicide efficacy field trials. Disease pressure was low early in the season due to dry conditions in southeastern North Carolina. Treatment differences were not visible on 'Star' on 17 Sep (data not shown) but were adequate on 'Star' for evaluation on 14 Oct. Rust was severe on 'Vernon' with defoliated bushes producing an abnormal, late-season flush of growth by 14 Oct as a stress response to loss of leaves. For blueberry leaf rust on 'Vernon', applications of conventional (non-organic fungicides) Cevya and Orbit resulted in the most significant reductions in numbers of spots per leaf and defoliation and increases in bud set (**Table 3**). Theia, Howler, PureSprayGreen, Pyraziflumid, Cevya, and Orbit all resulted in significant reductions in numbers of spots per leaf on 'Vernon'. In addition, Theia, Howler, PureSprayGreen, Pyraziflumid, Cevya, and Orbit also significantly reduced early-stage defoliation, while only PureSprayGreen, Pyrazilflumid, Cevya, and Orbit significantly reduced final defoliation and increased bud set. For Septoria leaf spot, conventional (non-organic) fungicides resulted in a significant reduction in leaves with spots and numbers of spots per leaf on 'Star', while all tested fungicides resulted in a significant reduction in defoliation on this cultivar. No phytotoxicity was observed with any treatment.

Table 3. North Carolina fungicide efficacy trial results for leaf spot assessments.

Treatment and amount/A Applied 6/6, 6/21, 7/5, 8/15, 8/27	Blueberry leaf rust on 'Vernon' 17 Sep Leaves with spots (%)	No. of spots per leaf	Early-stage defoliation (%)	14 Oct Final defoliation (%)	Bud Set (1-5)[z]	Septoria leaf spot on 'Star' 14 Oct Leaves with spots (%)	No. of spots per leaf	Defoliation (%)
Untreated check	100 a[y]	90.0 a	72.5 a	94.2 a	1.4 a	69.8 a	10.4 a	10.6 a
Theia 3.0 lb + surfactant	100 a	37.5 cd	27.5 c	90.0 ab	1.8 a	71.8 a	10.4 a	2.6 bc
Howler 5.0 lb + surfactant	100 a	35.0 cde	37.5 bc	86.2 ab	2.1 abc	60.0 a	4.8 abc	2.0 bc
OSO 5% SC 6.5 fl oz	100 a	72.5 ab	55.0 ab	93.2 a	1.9 ab	70.0 a	8.0 ab	5.2 b
Double Nickel 4.5 pt	100 a	75.0 a	62.5 a	90.0 ab	2.0 abc	60.0 a	4.8 abc	3.4 bc
PureSprayGreen 1.5 gal	97.5 a	42.5 cd	26.2 cd	73.8 b	2.9 c	46.0 a	6.8 abc	1.8 bc
Pyraziflumid 3.2 fl oz	100 a	47.5 bc	36.2 bc	77.5 ab	2.8 bc	11.0 b	2.4 bc	0.4 bc
Cevya 5.0 fl oz	90 ab	18.8 de	6.2 d	27.5 c	4.4 d	3.0 b	0.6 c	0.6 bc
Orbit 3.6E 6.0 fl oz	85 b	10.0 e	6.2 d	36.2 c	4.0 d	2.2 b	1.2 c	0.2 bc
LSD	10.3	27.5	20.7	19.3	0.9	31.6	6.7	4.7

[z]Bud set rating scale: 1= poor, no buds visible; 2= fair, a few small buds; 3= good, acceptable bud set; 4= Very good, larger buds, mostly in axils of leaves that were still attached; 5= Excellent bud set, large buds visible in leaf axils, with little defoliation.
[y]Means within a column followed by the same letter are not significantly different according to Fisher's Protected LSD (α=0.05).

Discussion:

Managing disease issues in organic production can be challenging, and few organic fungicides exist with proven efficacy against diseases in southeastern U.S. blueberry production. Compared to conventional fungicides, organic fungicides often demonstrate substantially lower relative efficacies and require more frequent applications to have a measurable impact on disease. In addition, in situations where disease pressure is high, organic fungicides may fail to show consistent efficacy. While the lack of consistent efficacy demonstrated by many of the products in these trials suggests that additional efficacy testing will be required before they can be reliably recommended to growers, some of the materials tested here did demonstrate some degree of efficacy in at least some of these trials. Specifically, applications of OSO 5% SC did appear to significantly reduce the incidence of Anthracnose ripe rot and total rots in the North Carolina fruit rot fungicide trial (though not as effectively as the conventional grower standard fungicide, Miravis Prime). In addition, in the North Carolina leaf spot trials, many of the tested organic fungicides significantly reduced defoliation on cultivar 'Star', while PureSprayGreen also significantly reduced defoliation and increased bud set on cultivar 'Vernon'. Likewise, though not statistically different than the untreated control, applications of PureSprayGreen and OSO 5% SC in Georgia also resulted in the lowest numerical incidence and severity of leaf rust and leaf spots. Taken together, these trial results are expected to help growers make informed decisions regarding the use of organic fungicides for disease management in southeastern U.S. organic blueberry production.

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