Integrated Disease and Insect Management in Organic Grape Production Systems

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This project focused on the evaluation and development of integrated disease management strategies in order to provide more reliable options for organic grape production and develop research-based pest management guidelines for organic viticulture in Pennsylvania and New York.

Objectives

1. Evaluate organic approved materials for efficacy against grape diseases (with emphasis on black rot) in greenhouse screening and field trials.
2. Evaluate organic approved materials for efficacy against Grape Berry Moth
3. Develop strategies to reduce over-wintering inoculum of the black rot fungus.

Objective 1: Evaluate organic approved materials for efficacy against grape diseases (with emphasis on black rot) in greenhouse screening and field trials.

A) Greenhouse screening of approved material. Greenhouse screening trials in 2006 and 2007 revealed that several approved materials have activity against the black rot pathogen when applied to leaves just before infection. However, these materials (Milstop, Armicarb O, Lime sulfur, EF400, Citrex, and Serenade) have not been effective in whole vine trials and cluster inoculations in the field. Experiments in 2008, focused on the determination of residual activity of some of these materials to help explain their failure in the field, and on the potential for some of these materials to provide a measure of post infection black rot control that would not necessarily depend on rain-fastness.

1. Residual activity after subjection to simulated rainfall: Materials were applied to leaves of potted *Vitis labrusca* 'Concord', and allowed to dry before subjection to 0, 0.5, and 1.0 inch of simulated rainfall. The following day, leaves were inoculated with spores of the black rot fungus (5×10^4 spores per ml). Degree of symptom expression was used to determine degree of residual activity. EF400 (blend of plant extracts), Milstop (potassium bicarbonate), and Cueva (copper octanoate) provided excellent control of black rot on leaves after subjection to 0 inches simulated rainfall before inoculation (97, 96, and 93 % control, respectively). However, after subjection to 0.5 and 1.0 inch simulated rainfall, efficacy of EF400 and Milstop dropped dramatically; only 23 and 27 % control from EF400 and 14 and 0 % control from Milstop after 0.5 and 1 inch rainfall, respectively. In comparison, efficacy of Cueva dropped slightly, but still maintained significant control of the disease; 90 and 81 % control after 0.5 and 1 inch of rainfall, respectively. While this is just a simulation, it does suggest that lack of efficacy in the field may be tied to rapid loss of residue upon subjection to rainfall.

2. Post infection activity of allowed materials for controlling black rot: The application of potassium bicarbonate (Milstop) or lime sulfur, 24 hours after an infection period, has *suppressed* black rot development on inoculated leaves of 'Concord' and 'Vidal' in the greenhouse and field. Reductions in leaf disease symptoms have ranged from 56-75 % for Milstop and 66-82 % for lime sulfur, but they have not always been statistically significant. Post infection activity of Citrex and EF400 on leaves has been less efficacious and consistent. Efficacy on fruit has not been investigated.

B) Field evaluation of approved materials in whole vine field trials (juice and wine grapes). Over the course of this project, field evaluation of organic disease control materials was conducted with whole vine plots of mature juice (Concord and Niagara) and wine grapes (Vidal) trained to a single-curtain, high-wire cordon system. Trials were conducted at the Lake Erie Regional Grape Research and Extension Center (LERGREC) in North East PA and in a nearby certified organic commercial vineyard.

Evaluation of organic fungicides for control of black rot, powdery mildew, and downy mildew of Concord and Niagara grapes, 2006-2008 (tables 1-5). Treatments were applied to 3 to 4-vine plots (Concord; 2006 and 2007), 7 to 10-vine plots (Concord 2008) or 8 to 12-vine plots (Niagara; 2006-2008) in a randomized complete block design with four replications. In some years, black rot fruit mummies were hung from the trellis wire to increase inoculum and the most severe black rot fruit disease occurred on clusters directly beneath mummies. Therefore, black rot disease pressure on fruit was largely governed by weather conditions and the presence of fruit mummies in the trellis. Black rot, downy mildew, and powdery mildew incidence (percent clusters with infected fruit) and severity (percent area fruit infected) were determined from 50 clusters per plot. The percent control of these three diseases from a variety of materials, rates, and spray intervals, under varying disease pressure over three years, is summarized in tables 1-5 (only solo treatments are included).

Table 1. Percent Control of Black Rot on fruit of Concord grape by solo programs of allowed materials. Numbers in parenthesis (x) denote number of applications made during fruit susceptibility period (immediate pre bloom to end of program).

Treatment and rate/A (# applications)	Disease Pressure	Spray Interval	% Control
Champion WP 4 lb + lime 8 lb (4)	High	10-12 days	63
Champion WP 2 lb + lime 4 lb (4)	High	10-12 days	49
Champion WP 2 lb + lime 4 lb (2, 4)	Low	7-8 days	78, 81
Champion WP 2 lb + lime 4 lb + NuFilm P 8 oz (4)	Low	7-8 days	88
Champion WP 2 lb + lime 4 lb + Yucca Ag Aide 16 fl oz (4)	High	10-12 days	40
Citrex 0.1 % (4)	High	10-12 days	8
Cueva 2 % (1), then 1 % (3)	Low	7-8 days	45
Cueva 4 % (1), then 2 % (3)	Low	7-8 days	44
Cueva 1 % (6)	High	6-8 days	39
Cueva 1 % (3)	High	6-8 days	9
Kocide 3000 0.75 lb + lime 1.5 lb (4) - no longer organic	Low	7-8 days	67
Kocide 3000 1.75 lb + lime 3.5 lb (4) - no longer organic	Low	7-8 days	75
EF400 0.25 % (4)	High	10-12 days	0
GC-3 1 % (4)	High	10-12 days	0
GC-3 1 % + Yucca Ag Aide 16 fl oz (4)	High	10-12 days	0
Lime Sulfur 0.5 % (4)	High	10-12 days	18
Lime Sulfur 0.5 % + Yucca Ag Aide 16 fl oz (4)	High	10-12 days	6
Milstop 2.5 lb (4)	High	10-12 days	0
Milstop 2.5 lb (1) , then 5 lb (5)	High	6-8 days	0
Neptune's Harvest 5 % (5)	High	6-8 days	0
NuFilm P 8 oz (4)	Low	7-8 days	33
Serenade AS 1 % + Yucca Ag Aide 16 fl oz (4)	High	10-12 days	0
Serenade AS 1 % + NuFilm P 0.12 % (6)	High	6-8 days	0
Yucca Ag Aide 16 fl oz (4)	High	10-12 days	0
Yucca Ag Aide 32 fl oz (4)	High	10-12 days	1
Yucca Ag Aide 0.5 % (6)	High	6-8 days	0

Table 2. Percent Control of Powdery mildew on fruit of Concord grape by solo programs of allowed materials. Numbers in parenthesis (x) denote number of applications made during fruit susceptibility period.

Treatment and rate/A (# applications)	Disease Pressure	Spray Interval	% Control

Champion WP 4 lb + lime 8 lb (4)	moderate	10-12 days	67
Champion WP 2 lb + lime 4 lb (4)	moderate	10-12 days	73
Champion WP 2 lb + lime 4 lb (2, 4)	Low	7-8 days	38, 23
Champion WP 2 lb + lime 4 lb + NuFilm P 8 oz (4)	Low	7-8 days	43
Champion WP 2 lb + lime 4 lb + Yucca Ag Aide 16 fl oz (4)	moderate	10-12 days	77
Citrex 0.1 % (4)	moderate	10-12 days	13
Cueva 1 gallon (4)	Low	7-8 days	26
Cueva 2 gallon (4)	Low	7-8 days	60
Kocide 3000 0.75 lb + lime 1.5 lb (4) - no longer organic	Low	7-8 days	40
Kocide 3000 1.75 lb + lime 3.5 lb (4) - no longer organic	Low	7-8 days	26
EF400 0.25 % (4)	moderate	10-12 days	27
GC-3 1 % (4)	moderate	10-12 days	54
GC-3 1 % + Yucca Ag Aide 16 fl oz (4)	moderate	10-12 days	55
Lime Sulfur 0.5 % (4)	moderate	10-12 days	89
Lime Sulfur 0.5 % + Yucca Ag Aide 16 fl oz (4)	moderate	10-12 days	90
Milstop 2.5 lb (4)	moderate	10-12 days	59
NuFilm P 8 oz (4)	moderate	10-12 days	7
Serenade AS 1 % + Yucca Ag Aide 16 fl oz (4)	moderate	10-12 days	65
Yucca Ag Aide 16 fl oz (4)	moderate	10-12 days	0
Yucca Ag Aide 32 fl oz (4)	moderate	10-12 days	0

Table 3. Percent Control of Black Rot on fruit of Niagara grape by solo programs of allowed materials. Numbers in parenthesis (x) denote number of applications made during fruit susceptibility period (immediate pre bloom to end of program).

		% Control	
Treatment and rate/A (# applications)	Spray Interval	High disease	Low disease
Champion WP 2 lb + lime 4 lb (4)	10-12 days	31	97
Champion WP 2 lb + lime 4 lb (2)	7-11 days	49	74
Champion WP 2 lb + lime 4 lb (4)	7-11 days	76	57
Citrex 0.1 % (4)	10-12 days	0	14
Cueva 1 % (7)	7-8 days	23	0
Lime Sulfur 1 % (4)	10-12 days	28	71
Lime Sulfur 2 % (4)	7-11 days	41	49
Lime Sulfur 0.5 % + NuFilm P 0.12 % (7)	7-8 days	8	80
Quillaja 32 fl oz (4)	10-12 days	0	9
Serenade AS 1 % + NuFilm P 0.12 % (7)	7-8 days	0	0
Yucca Ag Aide 32 fl oz (4)	10-12 days	0	14
Taegro 1.75 oz (1), then Taegro 3.5 oz (6)	7-8 days	0	0

Table 4. Percent Control of Downy mildew on fruit of Niagara grape by solo programs of allowed materials. Numbers in parenthesis (x) denote number of applications made during fruit susceptibility period (immediate pre bloom to end of program).

Treatment and rate/A (# applications)	Disease Pressure	Spray Interval	% Control
Champion WP 2 lb + lime 4 lb (4)	High	10-12 days	98
Citrex 0.1 % (4)	High	10-12 days	0
Cueva 1 % (7)	Low	7-8 days	93
Lime Sulfur 1 % (4)	High	10-12 days	29
Lime Sulfur 0.5 % + NuFilm P 0.12 % (7)	Low	7-8 days	85
Quillaja 32 fl oz (4)	High	10-12 days	0
Serenade AS 1 % + NuFilm P 0.12 % (7)	Low	7-8 days	42
Yucca Ag Aide 32 fl oz (4)	High	10-12 days	0

Taegro 1.75 oz (1), then Taegro 3.5 oz (6)	Low	7-8 days	39

Table 5. Percent Control of <u>Powdery mildew</u> on fruit of Niagara grape by solo programs of allowed materials. Numbers in parenthesis (x) denote number of applications made during fruit susceptibility period (immediate pre bloom to end of program).

Treatment and rate/A (# applications)	Disease Pressure	Spray Interval	% Control
Champion WP 2 lb + lime 4 lb (4)	High	10-12 days	91
Citrex 0.1 % (4)	High	10-12 days	26
Cueva 1 % (7)	Low	7-8 days	0
Lime Sulfur 1 % (4)	High	10-12 days	84
Lime Sulfur 0.5 % + NuFilm P 0.12 % (7)	Low	7-8 days	100
Quillaja 32 fl oz (4)	High	10-12 days	44
Serenade AS 1 % + NuFilm P 0.12 % (7)	Low	7-8 days	75
Yucca Ag Aide 32 fl oz (4)	High	10-12 days	19
Taegro 1.75 oz (1), then Taegro 3.5 oz (6)	Low	7-8 days	0

<u>Summary of efficacy of materials under test:</u>

<u>Biologicals:</u> Serenade, Sonata, and Taegro. All of these products are formulations of *Bacillus* bacteria. In greenhouse trials, Serenade provided fair to good control of black rot leaf and shoot infections and was more effective than Sonata on leaves (Taegro was not tested on leaves in the greenhouse). None of these products provided any control of black rot fruit infections in the field. Serenade (applied with an adjuvant) provided fair to good control of powdery mildew in the field (65 and 75 % control on Concord and Niagara fruit under moderate and low disease pressure, respectively). Taegro and Serenade suppressed downy mildew on Niagara fruit by 39 and 42 % (not significant), respectively, when field tested under low disease pressure in 2008.

<u>Potassium bicarbonates:</u> Milstop and Armicarb O. – These products are registered for control of powdery mildew, and can provide modest control of the disease when applied frequently (7-10 day intervals). We have also reported good control of black rot leaf and shoot infection in greenhouse trials with these materials. However, they have not been effective against black rot fruit infections in any field trials we have conducted over the course of this project.

<u>Plant extracts, oils –</u> Citrex 100, EF400, GC-3, Sporan, Vineyard magic. Most of these products worked well against black rot on leaves and shoots in greenhouse trials. In the field, most materials worked best for the control of powdery mildew but provided little or no control of black rot on fruit.

<u>Wetting agents:</u> Foliar friend, Natural wet, NuFilm P, Quillaja, Raingrow superflow, Yucca AgAide. The testing of wetting agents relates to the inability of spores of the black rot fungus (*Phyllosticta ampelicida*) to attach to, and subsequently infect, hydrophilic plant surfaces. One of these materials, Yucca AgAide 50 was very effective at controlling black rot leaf infections in greenhouse trials. Microscopy of leaves treated with Yucca and subsequently inoculated with spores of *P. ampelicida* showed a 93 % reduction in appresorium formation (fungal attachment/penetration structures) when compared to a water sprayed check. Unfortunately, subsequent field trials have found them relatively ineffective at preventing black rot in the field.

<u>Lime sulfur:</u> To no surprise, lime sulfur was very effective on powdery mildew in field trials. In greenhouse trials, it provided very good to excellent control of black rot leaf and shoot infection. It also provided some control of black rot and downy mildew fruit infections in the field, but control levels were erratic and not always significant. As with any material with modest black rot efficacy, level of fruit rot control with lime sulfur was highly dependent on inoculum pressure; under high inoculum pressure (mummies in the trellis) lime sulfur failed to provide adequate protection (8, 28, and 41 % control) whereas at low pressure, better control was achievable (49, 71, and 80 %) . Although somewhat unpleasant to work with, lime sulfur can play a useful and cost effective role in an organic disease management program on sulfur tolerant varieties.

Copper products: Champion WP, Cueva, Kocide 3000. Copper products provided the highest levels of black rot control in the field and will continue to make up the core of grape disease control chemical recommendations in organic vineyards in Pennsylvania and New York. Although not as effective as lime sulfur and sulfur for powdery mildew control, coppers are highly effective for downy mildew control. Unfortunately, Kocide 3000 is no longer allowable for organic. Black rot fruit rot control with coppers in the field was somewhat dependent on copper content of the application, especially when disease pressure was high (wet year, mummies in the trellis). Cueva, a liquid formulation (copper octanoate), contains a much lower concentration of copper than Champion (copper hydroxide) and was generally not as effective as Champion at standard application rates. However, they were only compared side by side in one year.

Bottom line: There are no highly effective materials for black rot control. And, while there are several effective chemical options for powdery mildew control, there is but one effective material for downy mildew; copper. Sustainable disease control in organic vineyards demands a fully integrated approach that includes strict sanitation, canopy manipulation to reduce the length of wetting periods, disease resistance (*Vitis vinifera* has virtually none), and proper site selection in addition to fungicides.

Evaluation of organic fungicides for control of diseases on wine grapes in Pennsylvania

- Efficacy on Vidal grape in Erie county PA: Powdery mildew disease pressure was light to moderate on Vidal in 2008. Two pre and three post bloom applications of a Champion WP 2 lb/Lime 2 lb/Microsulf 2 lb tank mix provided 83 % (significant) and 99 % (significant) control of powdery mildew fruit and leaf infection, respectively. Downy mildew fruit infection was extremely light, even in the unsprayed check plots (0.045 % of fruit infected), and the organic program provided complete control of downy mildew on fruit. However, we eventually began observing some downy mildew leaf infections developing by late summer (5.6 % severity on unsprayed leaves). The organic program provided nearly complete control of downy mildew leaf infections. These results are similar to those of an identical trial in 2007, and demonstrate the potential for organic production of Vidal in the Lake Erie region of Pennsylvania. Vidal appears to offer more resistance to black rot than Concord/Niagara; pre bloom shoot inoculations of Vidal in 2008 resulted in very limited leaf and shoot infection and little or no subsequent fruit infection.

- Efficacy on *Vitis* interspecific hybrids 'Chancellor', 'Chambourcin', and 'Vidal', and *Vitis vinifera* 'Chardonnay', 'Pinot noir', and 'Riesling' in Adams county PA. Organic disease management programs based on copper hydroxide (Champion WP with lime) and organic formulations of sulfur (Microsulf) or lime sulfur were evaluated for efficacy on ripe rot, sour rot, downy mildew, powdery mildew, and *Botrytis* in southern PA. A season long rotation of copper, lime sulfur, and sulfur significantly reduced the incidence of ripe rot on 'Chancellor' clusters and the incidence and severity of ripe rot on 'Chambourcin' clusters, but did not control ripe rot or sour rot on 'Vidal'. This same program significantly reduced the incidence and severity of sour rot on 'Chancellor' clusters. A rotation of copper and sulfur significantly reduced the incidence and severity of downy mildew on 'Chancellor' shoots. Season long rotations of copper and sulfur significantly reduced the severity of powdery mildew on shoots and clusters of 'Chardonnay' and 'Pinot noir'. A copper/sulfur tank mix at bloom, pre-close, veraison, and pre-harvest significantly reduced Botrytis on 'Chardonnay' clusters, but not on clusters of 'Pinot noir' or 'Riesling'. Overall, efficacy with copper and sulfur based organic pesticides was fair to poor on ripe rot and sour rot, modest on downy mildew (with minimal use of copper fungicide), and good to excellent on powdery mildew. Sulfur and lime sulfur were very effective on powdery mildew, demonstrating that this disease can be controlled in organic grape production systems in Pennsylvania on susceptible varieties despite the high disease pressure in southern Pennsylvania. It is advised that varietal disease resistance be included in any effort to produce wine grapes organically in Pennsylvania.

Evaluation of organic fungicides and site selection in commercial organic vineyards. Approved fungicide programs were compared in two commercial organic vineyards of mature 'Concord' in Erie County PA. Vineyard 1 is a remote, relatively wet site bordered by woods on two sides and has a history of heavy black rot pressure. Treatment plots consisted of 8 vines each, replicated 4x in a randomized complete block design. Due to the accumulation of high levels of over-wintering inoculum in these plots, treatments (Serenade AS 1 %, Milstop 0.75 %, and Cueva 1 %) were applied weekly from 3 May (2" shoots) to 18 July with a back pack sprayer at 60 psi. Pre bloom sprays were applied at 40 gal/A, whereas post bloom sprays were increased to 60 gal/A. A background program of Neptune's harvest at 5 % (fish/seaweed extract) and JMS Stylet oil (organic) was applied to all plots with an air blast sprayer for powdery mildew control, to which all other treatments were overlaid. Disease was rated on 13 August by examining 50 clusters per plot.

Vineyard 2 is a sunny, well drained open site surrounded by conventional vineyards. Plots consisted of 3 vines each replicated 8 times. A single disease control program was evaluated: one pre bloom and two post bloom applications (about 2 weeks apart) of Cueva at 1 %. Black rot and powdery mildew were rated on 26 August from 25 clusters per plot.

Results: Relatively cool and dry conditions in May and early June left early shoot tissues and rachises relatively clean in both vineyards. However, dense canopies, frequent wetting periods throughout peak fruit susceptibility (mid June through July), and high levels of over-wintering inoculum made black rot and other diseases difficult to control on fruit in vineyard 1 (table 6). More than 44 % of the crop was lost in plots under the background program of Neptune's harvest/JMS Stylet oil. Only the addition of 6 or 11weekly copper octanoate (Cueva) sprays provided even a modest level of control of black rot. Downy mildew was found on more than half of Concord clusters in plots under the background program alone, but was controlled to a large extent under Milstop and Cueva programs. The background program kept powdery mildew severity under 2 % on fruit, but control was further enhanced by Milstop and Cueva. Serenade provided no further improvement in powdery mildew control (on fruit) over the background program alone.

Table 6: Vineyard 1, Control of grape diseases on Concord fruit in a commercial organic vineyard.

	Black rot			Downy mildew			Powdery mildew		
Treatment	% Infected	% Area infected	% Control	% Infected	% Area infected	% Control	% Infected	%Area infected	% Control
Serenade AS 1 %	99.5	53.19	0	42.0	3.41	40	24.0	2.24	0
Milstop 0.75 %	91.0	36.15	18.5	12.5	0.76	87	0.5	0.01	100
Cueva 1 %	80.5	15.63	65	1.5	0.08	99	0.5	0.22	87
Background program	98.0	44.37		56.5	5.71		28.5	1.71	

There was almost no black rot or powdery mildew and no downy mildew to be found on fruit in vineyard 2 (0.01 % and 0.06 % severity of black rot and powdery mildew on fruit, respectively) despite the use of only about one half as many copper sprays as in Vineyard 1. These results continue to support the superiority of copper in organic vineyards when compared with other materials for black rot and downy mildew control. More importantly however, are the obvious effects of site selection, an important element of disease control in organic viticulture.

C) Activity of organic materials on fruit: Replicated treatments were applied to individual clusters 8-10 hours and 3 days before inoculation with the black rot pathogen (5×10^4 spores per ml). In support of the results of whole vine field trials and rainfall simulation experiments, these cluster inoculations provided further evidence of the lack of residual protection afforded by many of the materials that failed in the field despite having performed well under greenhouse screening trials. Cluster inoculations showed that even with near complete coverage (material was applied thoroughly by hand), and no rainfall between application and infection, black rot fruit rot control with potassium bicarbonates (Armicarb O and Milstop), EF400, and Citrex diminished sharply between applications made 3 days before infection and applications made just 10 hours before infection (table 7). For example, after 3 rainless days, efficacy of Milstop and Armicarb diminished by 65 and 80 %, respectively. Over the same 3 day period, the efficacy of EF400 and Citrex diminished by 90 and 100 %, respectively. On the other hand, the efficacy of Cueva (copper octanoate) and lime sulfur diminished by only 13 and 40 %, respectively, despite having been subjected to small amounts of rainfall (0.16 and 0.12") between applications made 3 days and 10 hours before inoculation. These latter two materials have provided some control of black rot, albeit modest, in replicated whole vine field trials.

One of the mechanisms for the deterioration of fungicidal control in the absence of rainfall may relate to rapid berry expansion coupled with lack of subsequent redistribution of fungicide residue during the wetting/infection process. The surface area of grape berries increases rapidly during the first weeks following bloom (the peak susceptibility period). Measurements of Concord berry diameter during this time showed that over a 3 day span, berry surface area can increase by as much as 200 % during the first week after bloom, 60-100 % during the second week after bloom and by 20-25 % during the third week after bloom. Unless fungicide residues stretch with berry expansion or are redistributed during wetting, substantial portions of expanding berries could become unprotected. At best, residues are thinned by berry expansion and runoff by rainfall. With this in mind, materials with modest activity could quickly become ineffective at protecting rapidly expanding, extremely susceptible tissues (ie, young berries). From a management perspective, control of black rot fruit rot with organic fungicides could be improved by adjusting frequency of application to rate of berry expansion during the susceptibility period.

Table 7. Severity and % control of black rot on Concord clusters inoculated 10 hours or 3 days after fungicide application.

Rate/100 gal	10 hrs	% Control	3 days	% Control	Rate/100 gal	10 hrs	% Control	3 days	% Control
Milstop 5 lb	3.7 a[*]	96	56.6 d	34	Cueva 8 qts	1.0 a[*]	98	7.2 a	85
Armicarb O 5 lb	11.3 b	87	70.6 e	17	Lime sulfur 2 % + Nufilm P 8 oz	6.1 a	88	23.2 b	53
EF400 0.375 %	28.6 c	67	79.2 f	7					
Citrex 0.2 %	72.2 e	15	85.6 g	0	Milstop 5 lb + Nufilm P 8 oz			46.4 c	6
Nufilm P 8 oz			96.8 h	0					
Check	85.3 fg		85.3 fg		Check	49.2 c		49.2 c	

[*]Means followed by the same letter within experiments are not significantly different according to Fisher's Protected LSD ($P \leq 0.05$).

Objective 2. Evaluate organic approved materials for efficacy against Grape Berry Moth

During the 2006 growing season, organic insecticides were screened for activity against grape berry moth (GBM) *Paralobesia viteana* (*Endopiza viteana) (Clemens)* using laboratory bioassays and partial field trials. Evaluations included commercially available, OMRI registered, formulations of pyrethrum (PyGanic), neem (Aza Direct), essential oils (EF300), a biological (Dipel 2x), and Spinosad (Entrust). In the laboratory, label rates of materials were applied to grape clusters bearing eggs using a hand-held sprayer. Clusters were moved to emergence cylinders in a growth chamber 25+ 5 °C, and a photoperiod of 18:6 (L:D). Thirty-two days after egg hatch, adult emergence was counted and analyzed. In the field, Concord clusters with approximately 30 berries each were sprayed with the test materials and enclosed in mesh bags containing ten moths of the same age (from the in-house colony) for 14 days to allow for mating and maximum egg laying. One week later, the clusters were placed into individual growth cylinders and held in growth chambers at laboratory conditions. Fifteen days later, the clusters were removed and adult moth hatch assessed.

In 2007, three new products (Deliver, Neemix, and CYD-X) and two of the products tested during the 2006 season (Entrust Naturalyte Insect Control and EF 300) were evaluated for control of GBM. Clusters were moved to cylinders and placed in a growth chamber in the same manner as 2006. Partial field trials were then conducted eliminating the two poorest performers in the laboratory bioassays.

Field trails using a Random block design were conducted in 2008. For the purpose of this experiment only the insecticides demonstrating the highest efficacy were evaluated in the vineyard trials. Entrust (spinosad), Deliver (*Bacillus thuringiensis*), and Aza Direct (Azadirachtin neem oil) were used. These insecticides were compared to the two most commonly used conventional insecticides in the Lake Erie grape growing region; Intrepid and Danitol. The experimental design consisted of 8'x5' plots for each treatment and an untreated control. Treatments were replicated four times. Treatments were sufficiently separated to prevent spray drift. These treatments were applied twice at the onset of the second flight of males in July and again at the onset of the third flight of males in early August. The treatments were evaluated by destructively counting the number of infested berries on 25 grape clusters per treatment plot two weeks after each application, and 25 clusters at harvest. Blocks were scouted before the pesticide applications, and infested berries were removed to minimize double counting of stung berries.

RESULTS

In 2006 and 2007, laboratory bioassays of all of the insecticides tested reduced development of adults and berry infestation. Deliver and Entrust exhibited the greatest efficacy in these experiments. (*See table A*)

Partial field experiments were also conducted in 2006 and 2007. Aza Direct appeared to have repellent properties, (egg deposition was reduced) and demonstrated efficacy similar to Entrust and Deliver. Dipel, CYD-X, and EF300 did not show significant efficacy when compared to the control clusters, although they did outperform the control. Deliver and Entrust were most effective, reducing eggs hatched, when compared to controls, by 82% and 91 % and grapes damaged by 76 % and 90%, respectively. Other materials provided some control of grapes damaged (*See table B*).

Field experiments were conducted in 2008 comparing the organic insecticides demonstrating the highest efficacy with the most commonly used insecticides in the Lake Erie grape growing region. All insecticides showed significant efficacy in percent of berry damage when compared to the control, with Aza direct and Intrepid outperforming the other insecticides (*See table C*).

2006/2007	Eggs	Larvae Survival	Infested Grapes	Total Grapes	% Larvae Survival	% Grapes Infested
Deliver	198	2	39	193	1.01%	20.21%
Entrust	158	12	43	225	7.59%	19.11%
Dipel	259	51	122	189	19.69%	64.55%
Neemix	184	36	119	164	19.57%	72.56%
PyGanic	181	50	132	179	27.62%	73.74%
AZA Direct	200	45	97	111	22.50%	87.39%
EF 300	242	73	176	232	30.17%	75.86%
CYD-X	294	100	225	251	34.01%	89.64%
Control	248	156	309	360	62.90%	85.83%

Table A: Results of the laboratory bioassays showing emergence o moths from eggs laid before the insecticide application and number of grapes damaged by GBM larvae infestation.

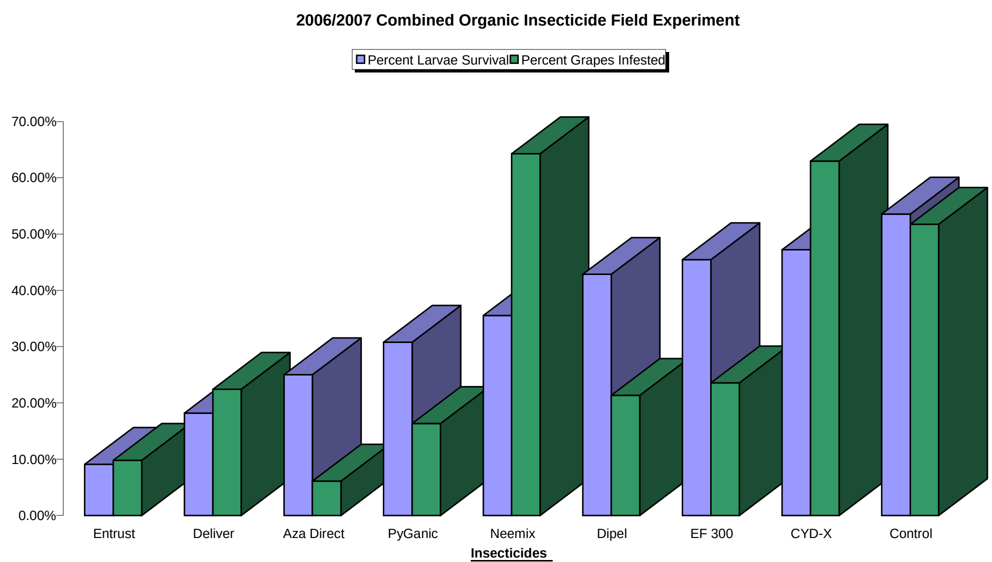
2006/07	Damaged Berries	Total Berries	Eggs	Eggs Hatched	% Larvae Survival	% Grapes Infested
Entrust	23	235	22	2	9.09%	9.79%
Deliver	39	174	44	8	18.18%	22.41%
Aza Direct	11	180	8	2	25.00%	6.11%
PyGanic	23	141	13	4	30.77%	16.31%
Neemix	63	98	45	16	35.56%	64.29%
Dipel	35	164	21	9	42.86%	21.34%
EF 300	33	140	22	10	45.45%	23.57%
CYD-X	80	127	36	17	47.22%	62.99%

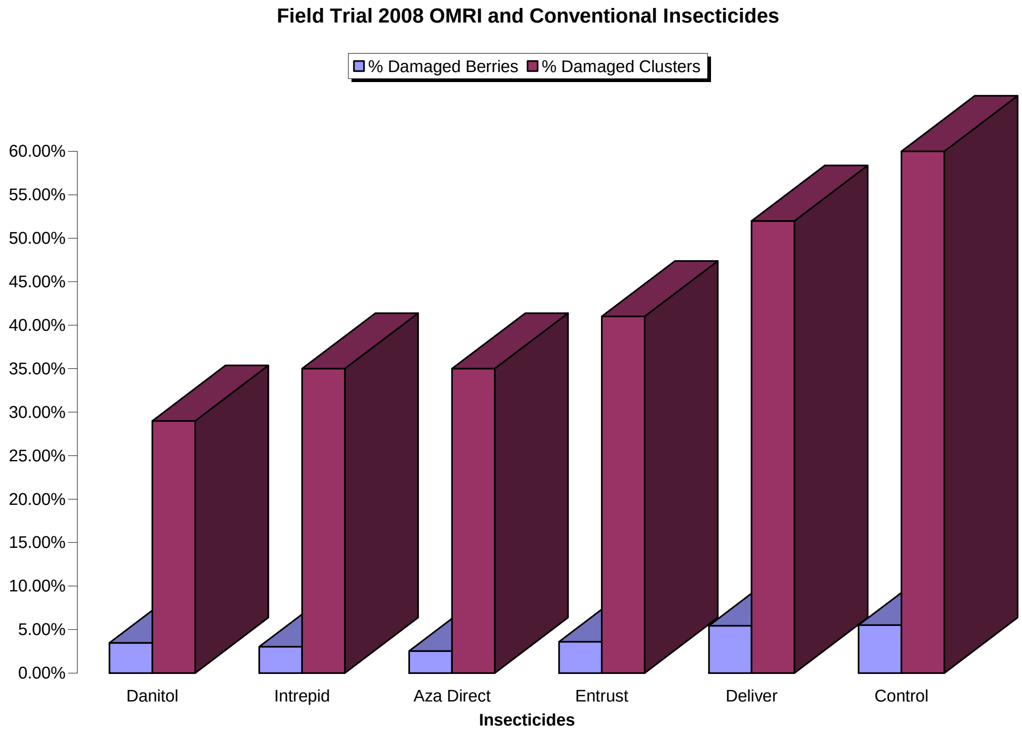
Control	180	348	84	45	53.57%	51.72%

Table B: Results of the partial field trials showing larvae survival and number of grapes damaged by GBM infestation after insecticide application.

Treatment	% Damaged Clusters	Incidence Mean	% Damaged Berries	Severity Mean
Aza Direct	35%	35.0 (a)	2.53%	2.61 (a)
Intrepid	35%	35.0 (a)	3.02%	3.04 (a)
Entrust	41%	41.0 (a)	3.62%	3.47 (a,b)
Danitol	29%	42.0 (a)	3.46%	3.61 (a,b,c)
Deliver	52%	52.0 (a,b)	5.44%	5.48(b,c)
Control	65%	65.0 (b)	5.52%	5.64 (b,c)

Table C: Results of the field trials showing damage results on plots sprayed with insecticides three times during the growing season. Results with different letters are statically different.





Objective 3: Strategies to reduce over-wintering inoculum of the black rot fungus.
A) Impact of soil amendments and timing of mummy drop on spore release from mummies on the ground. Removal of black rot mummies from the trellis to the ground is essential to good black rot control in organic grape production and is most economically accomplished during or after dormant hand pruning. Once on the ground, black rot infected mummies are subject to microbial degradation and pose much less of a threat, but can still eject spores into the air (up to 5 mm in our lab tests) during wetting periods. Ejected spores can be splashed or caught up in air currents and transported to susceptible tissue. In this study, mummies placed on the ground commonly caused infections on nearby shoot growth up to 10 inches above the soil. This suggests that sucker control is also important for black rot control in organic systems. Infected suckers can serve as stepping stones for the pathogen to reach the canopy from the ground. This project has examined two strategies to reduce mummy viability on the ground.

i) The application of soil amendments to mummies on the ground: Compost (10 tons/A banded), compost tea (50 gallons/A banded), dried chicken manure (0.25 tons/A banded), or grape pomace (10 tons/A banded (waste skins, stems, and seeds from processing)) were applied to mummies on the ground during the dormant period. The effects of soil amendments on spore release from mummies, was assessed the following spring and summer by quantifying spore release in water with a hemacytometer. Spore release was recorded from samples collected at three times: shortly after bud break in early May; just before bloom in June; shortly after fruit set in early July. Compost tea reduced ascospore release in the immediate pre-bloom sample (just before commencement of the fruit susceptibility period) by about 60 % (2006) and 69 % (2007), with smaller reductions in the early May sample. Chicken manure reduced ascospore release in the early May sample by 12 % (2007) and 25 % (2008) and at immediate pre-bloom by 81 % (2007). Raw pomace reduced ascospore release at all three sampling dates in 2007; by 29.5, 18, and 47 % on 15 May, 11 June, and 10 July, respectively. But in 2008, pomace treatments actually increased ascospore release in comparison to the check (no soil amendment). Bottom line: over two seasons, compost tea provided the most consistent reductions, but only in the immediate pre bloom sample when spore counts in the check were highest. Grape pomace, chicken manure, and compost utilized in this study did not consistently reduce spore release from mummies on the ground.

ii) Timing of mummy drop: Over two seasons, the earlier mummies were dropped to the ground after dormancy, the greater the reduction in spores released (both ascospores and conidia) later in spring. For example, mummies dropped during October or November consistently produced fewer spores than mummies dropped in January or March. This suggests that the timing of dormant pruning, (when mummies are most cost effectively removed from the trellis in machine harvested vineyards) may be an important consideration in black rot management among juice varieties. For more cold sensitive wine varieties that are typically pruned later in March and April, mummy removal may need to be implemented earlier as a separate activity at greater cost.

<u>B) Timing and prevention of black rot shoot infections.</u> Pre bloom inoculations over the past two years have shown that early black rot shoot infections can contribute to crop loss where effective fungicides are lacking (e.g. organic viticulture), and result in maintaining the presence of the pathogen in the trellis from year to year even when hand pruning is accompanied by mummy removal. Our objective was to determine the susceptibility of basal shoot tissue during the pre bloom period (tissue in the cluster zone that is closest to over-wintering inoculum sources in the current season, and that is typically retained during dormant pruning after the end of the season) and examine the importance of early shoot infections to subsequent fruit rot.

In 2007 and 2008, pre-bloom shoot inoculations helped to determine the period of susceptibility of the most basal internodes. The resulting shoot, leaf, and rachis infections led to major reductions in berries/cluster and increases in fruit rot later in the season. In 2007, shoots were inoculated on 18 May (2-3 leaves per shoot, 10 days after 50 % bud burst) and 29 May (5-6 leaves per shoot). Shoots inoculated on 18 May produced black rot leaf, shoot, rachis, and petiole lesions with pycnidia (spore producing structures) by early bloom (table 8). Internode 1 was nearly resistant and internode 3 most susceptible. All leaves were susceptible, but leaf 3 (youngest, least expanded) was most susceptible (table 9). Shoots inoculated on 29 May (10-12” shoot stage) produced black rot leaf, shoot, rachis, and petiole lesions with pycnidia by the end of bloom. Internodes 1 and 2 were fully expanded and were resistant. Internode 3 was almost fully expanded and nearly resistant. Internodes 4-6 were still expanding and susceptible.

Table 8. 2007 Concord shoot inoculations: Phenology x incidence of black rot on <u>shoot internodes</u>

Date	Shoot Length	Internodes from oldest to youngest 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
May 18	3.45”	4	11	27	19	8										
May 29	10.85”	0	0	7	40	74	60									

Table 9. 2007 Concord shoot inoculations: Phenology x incidence of black rot on <u>leaves</u>

Date	Shoot Length	Internodes from oldest to youngest 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
May 18	3.45”	13	42	56	11											
May 29	10.85”	0	17	63	90	52	7									

In 2008, shoots of ‘Chardonnay’, ‘Concord’, and ‘Niagara’ were inoculated on 8 (Chardonnay and Concord only), 15, and 25 May, and 2 June. Shoots inoculated on 8 May (13 days after 50 % bud burst), produced tan lesions on leaves of ‘Chardonnay’ and ‘Concord’ within 4 weeks. Subsequently, internode lesions also developed. This was notable as average temperature during the 24 hour infection period was only 48.8 F, and little or no infection was expected at this time. Our long term average temperature for May 8 is 55 F. On 15 May average temperature during infection was 50 F (also colder than average) and symptoms of black rot on leaves and shoots were observed on Chardonnay, Concord, and Niagara, 3 weeks after inoculation. For the 25 May and 2 June inoculation, average temperature during the 24 hour infection period was nearly 60 F (9-12 hours needed for infection) and 66.3 F (8 hours needed for infection), respectively.

In all 3 varieties, internode 1 was completely expanded and resistant to black rot by 8 May (table 10). Internode 2 appeared resistant on Chardonnay at this point, but remained somewhat susceptible on Concord and Niagara until about the end of May (nearly 5 weeks after bud-break). By early June, symptom development was observed within 2 weeks of inoculation. Internodes 1-4 were resistant and internode 5 somewhat resistant on Chardonnay, whereas internodes 4 and 5 of Concord and Niagara were still somewhat, and highly susceptible, respectively. Leaves in the cluster zone maintained a high degree of susceptibility throughout May, particularly in Concord and Niagara (table 11). The 2 June inoculation on Chardonnay produced a surprising range of infection on internodes and leaves; a single infection event was capable of generating spore producing lesions on up to 8 consecutive internodes and 12 consecutive leaves on rapidly growing shoots, providing enormous potential for inoculum production during bloom and early fruit development on this variety. On Concord and Niagara, this infection event generated lesion development on 5-6 consecutive internodes and leaves on shoots.

Hairiness of leaves, degree of tissue expansion (fully expanded tissue does not develop lesions) and average temperatures during infection undoubtedly played an important role in the susceptibility of tissues and the amount of disease that developed from each infection event. Cool temperatures during early May typically limit infection during wetting events and help explain the generally lower incidence readings from the 8 and 15 May inoculations. The hairiness of new Concord and Niagara leaves can reduce contact of spore laden moisture droplets with the plant surface and limit lesion incidence on these otherwise extremely susceptible tissues.

Table 10. 2008 shoot inoculations: Incidence of black rot (susceptibility) on <u>shoot internodes</u> of Chardonnay (Char), Concord (Con), and Niagara (Niag) on four pre bloom inoculation dates.

	May 8			May 15			May 25			June 2		
Internode	Char (2.5)	Con (2.1)	Niag	Char (3.5)	Con (3.6)	Niag (3.5)	Char (4.3)	Con (6.2)	Niag (5.1)	Char (10.1)	Con (11.9)	Niag (11.9)
1 (oldest)	0	0		0	4	0	0	0	0	0	0	0
2	0	8		0	51	23	4	32	19	0	4	0
3	15	50		25	88	69	17	80	83	0	8	16
4	35	50		50	83	73	63	100	100	0	44	95
5	25	8		8	40	18	88	87	72	31	100	100
6							71	45		77	100	90
7							63	10		100	77	43
8							46	5		100	38	
9							25			100		
10							4			97		
11							4			71		
12										53		
13										19		
14										4		
15												

( ) = average shoot length in inches

Table 11. 2008 shoot inoculations: Incidence of black rot (susceptibility) on <u>leaves</u> of Chardonnay (Char), Concord (Con), and Niagara (Niag) on four pre bloom inoculation dates.

	May 8			May 15			May 25			June 2		
Leaf	Char (2.5)	Con (2.1)	Niag	Char (3.5)	Con (3.6)	Niag (3.5)	Char (4.3)	Con (6.2)	Niag (5.1)	Char (10.1)	Con (11.9)	Niag (11.9)
1 (oldest)	42	92		58	83	60	38	35	52	0	4	0
2	70	92		79	96	96	88	79	88	0	40	5
3	83	33		83	100	91	100	95	100	53	96	88
4	89	4		96	29	38	100	83	89	96	100	100
5	63			71			100	21	39	100	100	89
6				38			75			100	22	29
7							67			100		
8							54			100		
9							25			100		
10							4			93		
11										52		
12										31		
13										11		
14										7		
15										4		

( ) = average shoot length in inches

Pre bloom shoot inoculations established cluster stem infections that resulted in significant reduction in berries/cluster, and increased fruit rot. For example, in 2007, the 29 May inoculation reduced berries/cluster by 57.5 % with a subsequent 30 % loss of the remaining berries to fruit rot, for a total crop loss of about 70 % (table 12). The 3.9 % fruit rot on the non-inoculated shoots likely resulted from spread of the pathogen from nearby inoculated shoots. Infection of shoots and the subsequent crop loss was more severe from the 29 versus the 18 May inoculation and may be due to more optimal temperature during infection, greater susceptibility of the host on 29 May, or both.

Table 12. 2007: Relevance of black rot shoot/rachis infection on crop loss in Concord grape

	June		September	
Inoculation date	Rachis Incidence	Rachis Severity	Fruit Rot Severity	Berries/cluster
18 May	18.8	0.44	9.63	33.9
No inoculation	0	0	0.40	31.1
29 May	88.2 a	2.07 a	29.8 a	14.1 a
No inoculation	0 b	0 b	3.9 b	33.2 b

Means followed by the same letter within columns are not significantly different according to Fisher's Protected LSD ($P \leq 0.05$).

In 2008, the incidence and severity of black rot on cluster stems increased with each inoculation date from 8 May to 25 May (table 13). Again, cool temperatures may have been responsible for the relatively lower levels of cluster stem infection on 8 and 15 May, as compared to 25 May. Warmer temperatures would increase both the growth rate of the pathogen as well as that of the cluster stems, and lesion size and hence disease severity would be maximized if infection took place during periods of rapid tissue expansion. Chardonnay clusters (inflorescences) may be somewhat more susceptible than those of Concord/Niagara.

Table 13. 2008: Incidence and severity of black rot on cluster stems

Inoculation date	Incidence			Severity		
	Chardonnay	Concord	Niagara	Chardonnay	Concord	Niagara
8 May	8	36		0.5	2.2	
15 May	30	66	61	12.0	9.6	3.4
25 May	96	100	100	20.3	15.2	6.2
2 June	100	100	100	16.3	10.6	4.8

As in 2007, shoot inoculation in 2008 reduced berries/cluster and increased fruit rot to reduce yield per cluster. On Concord (table 14), the 8 May inoculation had the least effect; although fruit rot severity was significantly greater (over 7 fold greater) on inoculated shoots than on non-inoculated shoots, berry numbers and cluster weight were not significantly reduced (only 5 % reduction). However, yield loss per cluster increased greatly in subsequent inoculations, to 47, 70, and 77 % from the 15, 25 May, and 2 June inoculations, respectively. On Niagara (table 15), shoot inoculation had similar effects on fruit rot and cluster weight, although only the 2 June inoculation significantly reduced berry numbers per cluster. Cluster weights were reduced 62, 80, and 75 % by shoot inoculation at 15, 25 May, and 2 June, respectively. The relatively small percentage of fruit rot on the non-inoculated shoots resulted from spread of the pathogen from nearby inoculated shoots (background fruit rot levels in the experimental block were almost nil).

Table 14. 2008: Relevance of black rot shoot/rachis infection on crop loss in Concord grape

Inoculation date	Rachis Incidence	Rachis Severity	Fruit Rot Severity	Berries/cluster	Cluster weight (grams)
8 May	36.3	2.19	**13.11 a**	51.8	81.1
No inoculation	0.0	0.00	**1.79 b**	47.6	85.6
15 May	**65.9 a**	**8.02 a**	**34.24 a**	**32.70 a**	**46.1 a**
No inoculation	**0.0 b**	**0.00 b**	**7.72 b**	**39.35 b**	**86.5 b**
25 May	**100.0 a**	**15.13 a**	**53.86 a**	**28.7 a**	**30.4 a**
No inoculation	**0.0 b**	**0.00 b**	**0.00 b**	**48.7 b**	**102.9 b**
2 June	**100.0 a**	**10.69 a**	**64.70 a**	**24.8 a**	**19.2 a**
No inoculation	**0.0 b**	**0.00 b**	**0.19 b**	**38.4 b**	**82.0 b**

Means followed by the same letter within columns are not significantly different according to Fisher's Protected LSD ($P \leq 0.05$).

Table 15. 2008: Relevance of black rot shoot/rachis infection on crop loss in Niagara grape

Inoculation date	Rachis Incidence	Rachis Severity	Fruit Rot Severity	Berries/cluster	Cluster weight (grams)
15 May	**61.4 a**	**3.38 a**	**58.67 a**	62.7	**71.4 a**
No inoculation	**0.0 b**	**0.00 b**	**6.94 b**	71.3	**188.2 b**
25 May	**100.0 a**	**5.82 a**	**73.24 a**	48.3	**34.8 a**
No inoculation	**0.0 b**	**0.00 b**	**0.83 b**	60.0	**174.3 b**
2 June	**100.0 a**	**4.84 a**	**64.75 a**	**31.8 a**	**35.0 a**
No inoculation	**0.0 b**	**0.00 b**	**0.80 b**	**49.0 b**	**139.4 b**

Means followed by the same letter within columns are not significantly different according to Fisher's Protected LSD ($P \leq 0.05$).

These results suggest that in organically managed vineyards of susceptible varieties, early pre bloom shoot protection may reduce current season fruit rot losses to black rot and reduce inoculum buildup in the cluster zone that later becomes wood borne over-wintering inoculum in the trellis. Pre bloom black rot shoot infection is likely to be minimal in more northern parts of the East where pre bloom temperatures are often well below optimum for the pathogen. However, pre bloom black rot infections are a serious threat in more southerly mid-Atlantic vineyards where pre bloom temperatures are more optimal and varieties of high susceptibility (*V. vinifera*) are grown.

TECHNOLOGY TRANSFER

This project has demonstrated that black rot can be controlled in organically managed juice grapes even in wet years, but that cultural measures, varietal resistance, and good site selection are as important (more important?) as pesticides. We have produced research based guidelines that address some of the concerns of interested growers, that we hope will contribute to the success of organic grape production in the Lake Erie region and other parts of the eastern U.S. The guidelines were first presented on September 6, 2007 at an Organic Grape Production Field Day held at the Lake Erie Regional Grape Research and Extension Center (LERGREC) in North East PA. The field day provided a forum for sharing information derived from research, and grower, processor, and marketing experience to improve future management decisions and profitability. It has stimulated inquiries from growers in other states in the East, and has generated invitations to present the information at several winter conferences. The organic production guidelines can be accessed at http://research.cas.psu.edu/Erie/plant_path.htm and focus mainly on disease management. Annual revision of these guidelines will help provide the latest information to interested producers.

The organic demonstration block at the LERGREC received organic certification in 2008 and the crop was sold as organic at a premium. The demonstration block will provide a platform for future meetings to educate growers, processors, and extension/research staff regarding requirements for organic certification and the latest developments from research and grower experience. The organic block will also present unique research opportunities for future proposals to examine and improve production costs, yields, juice quality, vine and soil nutrient status, weed and water management, vine vigor, and pest control in eastern organic viticulture. It is clear that more work is needed to address disease control issues like black rot. For control of this disease, good site selection, sanitation, cultural control, and varietal resistance are essential in organic vineyards. Weed control and the maintenance of vine size are major concerns for economically sustainable organic juice grape production. Currently, a local processor is offering a price premium of 44 % (when compared to 2008 juice grape prices). Coupled with a Pennsylvania reimbursement program for certification fees, organic production may be a viable option for growers wishing to diversify their farms.

Publications from this project:

B. Hed and J.W. Travis. Evaluation of organic fungicides for control of black rot and powdery mildew of Concord grapes, 2006. Plant Disease Management Reports Vol 1: SMF007

B. Hed and J.W. Travis. Evaluation of alternative and organic fungicides for control of Niagara grape diseases, 2006. Plant Disease Management Reports Vol 1: SMF008

B. Hed and J.W. Travis. Evaluation of organic fungicides for control of black rot and powdery mildew of Concord grapes, 2007. Plant Disease Management Reports Vol 2: SMF004

B. Hed and J.W. Travis. Evaluation of alternative and organic fungicides for control of black rot of Niagara grapes, 2007. Plant Disease Management Reports Vol 2: SMF005

B. Hed and J.W. Travis. Evaluation of organic fungicides for control of black rot and powdery mildew of Concord grapes, 2008. Plant Disease Management Reports Vol 3: SMF030.

B. Hed and J.W. Travis. Evaluation of alternative and organic fungicides for control of black rot, powdery mildew, and downy mildew of grapes, 2008. Plant Disease Management Reports Vol 3: SMF031

Black rot control in eastern organic grape production. B. Hed (1) and J.W. Travis (2). Dept. Plant Pathology, Penn State University, (1) North East, PA 16428; (2) Biglerville, PA 17307. Publication no. P-2008-008-NEA.

Disease Management Guidelines for Organic Grape Production in the Lake Erie Region. Penn State University. Bryan Hed and Jim Travis. http://research.cas.psu.edu/Erie/plant_path.htm

Bryan Hed and Jim Travis. 2007. Black Rot Control: The Key to Disease Management in Organic Grape Production in the Lake Erie Region. Wine East: July-August 13-23, 58.