10-2-2009

Evaluation of Alternative Fungicides for Organic Apple Production in Vermont

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EVALUATION OF ALTERNATIVE FUNGICIDES FOR ORGANIC APPLE PRODUCTION IN VERMONT

A Thesis Presented

by

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to

The Faculty of the Graduate College

of

The University of Vermont

In Partial Fulfillment of the Requirements
for the Degree of Master of Science
Specializing in Plant and Soil Science

May, 2009

Accepted by the Faculty if the Graduate College, The University of Vermont, in partial fulfillment of the requirements for the degree of Master of Science, specializing in Plant and Soil Science.

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ABSTRACT

A major challenge in organic apple production in Vermont is the available fungicide options for apple scab management. The standard lime sulfur/sulfur fungicide program used can be injurious to the applicator, the apple ecosystem, and the apple tree itself. Because of these drawbacks of the standard program it is necessary to evaluate potential alternative fungicides for organic apple production. The objectives of this study were to: (i) compare the efficiency of potassium bicarbonate, neem oil, and *Bacillus subtilis* to a standard organic lime sulfur/sulfur fungicide program and a non-sprayed treatment for control of apple scab and other fungal diseases; (ii) evaluate potential non-target impacts of these fungicides on pest and beneficial insect populations; and (iii) conduct a preliminary experiment evaluating the potential of raw milk as a fungicide in organic apple production in Vermont. Five treatments (potassium bicarbonate, neem oil, *Bacillus subtilis*, lime sulfur/sulfur, and a non-sprayed treatment) were applied to 'Empire' trees arranged in a completely randomized design with five single-tree replications at the University of Vermont Horticultural Research Center in South Burlington, VT. Fungicides were applied with a handgun to drip, using maximum label rates. Applications began on 26 April 2007 and 23 April 2008 and continued on approximately a weekly schedule through the end of June and then every two weeks through 23 July 2007 and 17 July 2008, respectively. Data obtained were analyzed by analysis of variance and significance between means was determined by Fisher's Protected LSD Test ($P \leq 0.05$). None of the alternatives managed disease as well as the standard lime sulfur/sulfur fungicide program. The neem oil treatment showed more activity against apple diseases than the other alternative fungicides. Both the lime sulfur/sulfur and neem oil treatments had disadvantages, including phytotoxic burning and/or significantly more russetting on the fruit at harvest. The neem oil treatment had significantly more fruit clean of insect damage than the other alternatives and the non-sprayed treatment in 2007 and more than all treatments in 2008, which is attributable to its insecticidal properties. However, the insect management from the neem oil treatment was not commercially acceptable. The overall quality of the fruit was not at commercially acceptable levels. No treatment had above 40% of the harvested fruit placed in marketable grades. This research shows that potassium bicarbonate, *Bacillus subtilis*, and neem oil do not offer substantial advantages over the standard lime sulfur/sulfur fungicide program in organic apple production in Vermont. In a preliminary study at the University of Vermont Horticultural Research Center, the efficiency of a 30% v/v raw milk dilution was compared to a non-sprayed treatment. Treatments were applied to 'McIntosh' trees in a completely randomized design with three single-tree replications. Milk applications were made on approximately a weekly schedule from 26 Apr 2007 to the end of June and every two weeks through 23 Jul 2007. Overall, milk did not provide management of disease and caused premature leaf yellowing and defoliation of the apple trees.

CITATION

Material from this thesis has been published in the following form:

Cromwell, M.L., L.P. Berkett, T. Ashikaga, H.M. Darby, T.L. Bradshaw and S.L. Kingsley-Richards. 2008. Evaluation of alternative fungicides for organic apple production in Vermont, 2007. Plant Disease Management Reports 2:PF048.

Cromwell, M.L., L.P. Berkett, T. Ashikaga, H.M. Darby, T.L. Bradshaw and S.L. Kingsley-Richards. 2008. Evaluation of alternative fungicides for organic apple production in Vermont, 2007. Phytopathology 98:S42.

ACKNOWLEDGEMENTS

I would like to thank Lorraine Berkett for all the guidance and direction, but most importantly for all the opportunities she has given me during my time here at UVM. This research could not have been completed without the field expertise, support, and advice from Terry Bradshaw. I would also like to thank Sarah Kingsley-Richards for everything she has helped me with. In addition, Takamaru Ashikaga and Heather Darby are greatly appreciated for serving on my committee and providing continued guidance for my future and much needed perspective from outside the "apple world". Finally, I would like to thank my friends and family for supporting and encouraging me always and especially those people who helped me with my research in all kinds of weather without too much complaining.

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CHAPTER 1. COMPREHENSIVE LITERATURE REVIEW

INTRODUCTION

The United State Department of Agriculture (USDA) National Organic Standards Board (NOSB) defined organic agriculture as "an ecological production management system that promotes and enhances biodiversity, biological cycles, and soil biological activity. It is based on minimal use of off-farm inputs and on management practices that restore, maintain, or enhance ecological harmony…The primary goal of organic agriculture is to optimize the health and productivity of interdependent communities of soil life, plants, animals and people" (61). The production system is managed with only materials approved as organic by the USDA and the National Organic Program (NOP). A National List of Allowed and Prohibited Substances was established under the Organic Foods Production Act of 1990, enacted under Title 21 of the 1990 Farm Bill (25). Most approved materials are non-synthetic, or termed "natural", however there are exceptions. The list indicates what synthetic materials are allowed and what non-synthetic materials (i.e., "natural" materials) are prohibited (60). Each state's organic certifying agency can produce their own stricter, but not more lenient, list of approved materials for organic production. For example, the Northeast Organic Farming Association (NOFA) and its specific state chapters oversee the approved materials for New England and New York (62).

The Northeast Organic Farming Association also has organizations in each state that are accredited by the USDA to verify that agricultural products are raised according to the organic standards. Vermont Organic Farmers is the certification branch of NOFA-VT that certifies farmers as organic producers, which ensures that the NOP standards have been met for the required three year period prior to certification. The standards state that all inputs and practices used in the three years prior to certification must be in accordance with the national and state list of approved materials and practices.

Organic agriculture has increased significantly over recent years (93, 63). More than 120 countries around the world have certified organic farms, and even more countries have farms managed with organic practices but are not certified (93). Almost 77 million acres (31 million ha) are currently managed organically, which is 0.7% of the agricultural land in the countries that were surveyed (93). Along with the United States, Australia, Argentina, and China are among the countries with the most certified organic land; Europe has the highest proportion of organic farms compared to conventionally-managed land (93). In 2005, all 50 states in the U.S. had some certified organic farmland, totaling over 4 million acres (1.6 million ha) (19). California is the leading state in certified organic cropland, with over 220,000 acres (89,000 ha), mostly for fruit and vegetable production (19).

Global sales of organic food and drink have increased by 43%, from $23 billion in 2002 to $33 billion in 2005, and it was estimated that sales reached $40 billion in 2006 (93). In the U.S., sales of organic food and beverages have grown from $1 billion in 1990 to an estimated $20 billion in 2007, and were projected to reach $23 billion in 2008 (63).

Organic apples are among the top five fresh fruits purchased in the U.S. and per capita spending on organic apples ranks behind only organic tomatoes and carrots (79). The U.S. apple crop, both organic and standard-conventional, was valued between $1 and $2 billion dollars from 2005-2007 (58). Four thousand metric tons (nine million pounds) of apples were harvested in 2007 and 4,500 metric tons (10 million pounds) were harvested in 2008 in the United States (57). In terms of organic apples, California and Washington are the biggest producers of organic apples in the U.S. In 2005, California had about 3,400 of the 12,772 acres (1,375 of 5,169 ha) of organic apples in the U.S. (19). Washington state has more that half of the country's organic apple acreage having over 6,600 acres (2,671 ha) of organic apple orchards in 2005 (19).

Apples are one of the most popular crops in New England, with over 19,000 total acres (7,689 ha) (56). There were only about 150 acres (61 ha) of organic apple orchards throughout New England in 2005 although this acreage was expected to have increased by 2008 (19).

In Vermont, apples are one of the major crops, with 156 farms having bearing apple trees and 3,418 acres (1,383 ha) of agricultural land in apple production (56). However, the percentage of this acreage that is in organic apple production is very small. There are many challenges facing organic apple production in Vermont and therefore, only 5 apple orchards are organically certified in the state (17). A major limitation to organic apple production is the available fungicide options for management of apple scab, which is one of the most important apple diseases in New England (47, 13). Apple scab is caused by the fungus *Venturia inaequalis* (Cooke) Wint., and can have devastating results, including a decrease in fruit quality and yield. Severe foliar infection can lead to premature defoliation and reduced tree vigor, which in turn may restrict or prevent formation of fruit buds for the following year. Fruit infection causes deformities, cracks, and fruit drop (39). There are Integrated Pest Management (IPM) methods to reduce inoculum; however, disease management on scab susceptible cultivars requires fungicide use.

There are a number of fungicides which are organically approved by NOFA of Vermont. The fungicides containing copper, sulfur, or lime sulfur as active ingredients are the most commonly used in organic apple production systems in the United States (13). Historically, one of the first fungicides used against apple scab in the U.S. was Bordeaux mixture, a solution of copper sulfate and lime (47). However, copper- and lime sulfur- based fungicides are highly caustic. Both are registered as Category I pesticides, the most toxic class, and are labeled with the "danger" signal word (23). Sulfur is registered as a Category III pesticide, the least toxic class, but sulfur is only rated as "fair" in its effectiveness against apple scab. Sulfur is a contact fungicide with only weak protective activity (22, 44).

Liquid lime sulfur was a highly recommended fungicide in the early twentieth century and was effective as a protectant fungicide, and could also be used to eradicate established infections (31). However, it can be injurious to the tree and can result in lower fruit yields (47). Consequently, wettable sulfur fungicides replaced lime sulfur even though they were less effective and lacked the eradicative capability of lime sulfur (47).

Copper-based fungicides can be highly phytotoxic when applied in apple orchards. The 2008 Cornell University Pest Management Guidelines for Commercial Tree-Fruit Production cautions that copper applied to apples between half-inch green and bloom may cause fruit russetting, and applications after bloom through the beginning of July may cause blackening at the lenticels. Applications of copper for summer diseases also may cause severe fruit discoloration of yellow cultivars (1). In addition, the use of copper in agricultural systems poses environmental risks. The use of Bordeaux mixture as the main fungicide treatment in French vineyards caused the metal to accumulate in the soil (6). A study by Kaplan (40) in Turkey, found critically high levels of accumulated copper in soils of tomato greenhouses, where copper-containing fertilizers, fungicides, and bactericides were used for decades. Copper fungicides used in avocado orchards were found to be detrimental to phylloplane microorganisms that played a key role in suppression of a disease causing fungus, *Colletotrichum gloeosporioides*; a single copper-fungicide spray on a previously non-sprayed avocado tree reduced populations of beneficial filamentous fungi, yeasts, and bacteria that played a role in foliar disease suppression (81). In addition, accumulations of heavy metals like copper can have negative effects on the earthworm populations in the soil. In field experiments in southeastern United Kingdom, copper was found to significantly influence earthworm reproduction and compromise lysosomal membrane stability when the organisms were exposed to the metal in outdoor conditions (78). A copper oxychloride fungicide was found to decrease the growth and survival of earthworms in South African vineyards (20). It must be remembered that these results in different crops could be due to copper exposure much greater than in apple orchards treated with copper-containing fungicides. However, these studies suggest the possibility and risk of copper accumulation and toxicity to microorganisms in ecosystems in which copper-containing materials are used repeatedly.

Lime sulfur and sulfur also have non-target effects on beneficial organisms. An elemental sulfur-based fungicide was found to reduce the numbers of a stigmaeid mite, *Zetzellia mali* (Ewing), a predator of the European red mite, *Panonychus ulmi* (Koch) in apple orchards (37). In another study on potted apple rootstocks in the Netherlands, wettable sulfur (0.25%) was found to have a 90% mortality rate on the predatory mites, *Typhlodromus tiliae* Oudms. and *Typhlodromus tiliarum* Oudms. (90). Sulfur and lime sulfur applications in apple orchards in Nova Scotia were found to reduce numbers of predatory mites in the subclass Acarina and practically eliminate populations of the mussel scale parasite, *Aphytis mytilaspidis* (Le Baron); wettable sulfur reduced numbers of predatory insects in the Miridae family and predacious thrips, as well (50). Also in Nova Scotia, sulfur applications were found to drastically reduce numbers of the mealybug destroyer, *Cryptolaemus montrouzieri* Muls. in addition to species of parasitic Hymenoptera (49). Sulfur has also been shown to have negative impacts on beneficial organisms in other crops. Sulfur sprays in a noncommercial vineyard were shown to reduce the *Metaseiulus occidentalis* predator mite populations throughout the season and over the winter (9). Sulfur applied repeatedly as a fungicide for powdery mildew control in a previously abandoned vineyard in Washington State had direct suppressive effects on both pest and predatory mites (69).

Lime sulfur has some additional non-target effects on fruit production. Liquid lime sulfur (LS, calcium polysulfate) is frequently used as a bloom thinning agent in organic apple systems in countries where its use is permitted, and is increasingly being used in non-organic production systems for the same purpose (52). McArtney *et al*. (52) determined that treatments of lime sulfur during bloom inhibited embryo germination by decreasing the number of pollen tubes per flower resulting in reduced fruit set. The exact mode of action is not known, but sulfur sprays may reduce pollen germination in apples (46). This is beneficial when thinning effects are desirable, but the lime sulfur concentrations that are most effective against scab produce these results (47).

It was also found that lime sulfur suppressed the rate of light-saturated photosynthesis, contributing to the thinning response (52, 64, 8). It has been shown that using lime sulfur (applied at 1L/100L) or sulfur (applied at 180g/100L) as a fungicide over the whole season can reduce photosynthesis of 'Braeburn' apples by almost 50% in mid-summer (64). Burrell (8) found that photosynthesis was reduced for a few days after lime sulfur applications and the applications may cause visible scorching of the leaves; low-vigor trees had poor ability to recover from these phytotoxic effects of the fungicide. Burrell explains the grower must decide whether the risk of scab is sufficient to offset the anticipated injury of lime sulfur.

Palmiter and Smock (65) found that sulfur fungicide treatments caused fruit injury, with 12 percent of the harvested fruit showing symptoms of phytotoxicity (i.e., russetting). Holb *et al.* (36) evaluated the efficacy and phytotoxicity of lime sulfur in organic apple production and found lime sulfur, applied either curatively or preventively (at 0.75-2%), significantly lowered scab damage on leaves and fruit compared to 0.5% wettable sulfur treatments. However, all curative lime sulfur treatments (1.5-2%) showed high phytotoxicity, in the form of fruit russetting and leaf necroses, and reduced leaf size and fruit yield. The preventative treatments did not decrease fruit yield compared to wettable sulfur, but fruit quality was significantly less in the lime sulfur treatments.

Because of the potential non-target impacts of currently used organically approved fungicides on apple trees and the surrounding ecosystem, it is important to evaluate alternative fungicides for apple disease management in Vermont. There are a number of other fungicides approved and registered for organic apple production in Vermont by the USDA and Environmental Protection Agency; however, there are few tests of their performance in the Northeast. It is important with the increasing growth of organic apple production to provide growers and the research community with evaluations of fungicides currently on the market.

The objectives of this study were:

1. To evaluate the efficacy of alternative fungicides (potassium bicarbonate *Bacillus subtilis*, and neem oil) against apple scab and other apple diseases compared to a standard lime sulfur/sulfur fungicide program.
2. To evaluate the potential non-target effects of the fungicide treatments on beneficial and harmful arthropod pest populations.
3. To conduct a preliminary experiment evaluating the potential of raw milk as a fungicide in organic apple production in Vermont.

APPLE DISEASE MANAGEMENT

The National Integrated Pest Management (IPM) Forum defined IPM as "the coordinated use of pest and environmental information along with available pest control methods, including cultural, biological, genetic and chemical methods, to prevent unacceptable levels of pest damage by the most economical means, and with the least possible hazard to people, property, and the environment" (59). Integrated pest management is a holistic, ecological approach, based on knowledge of the crop, the life cycles of pests, and knowledge of other organisms that influence an agricultural ecosystem. Integrated pest management is an important component of sustainable agriculture, which is an economically viable, environmentally sound, and socially acceptable form of farming (18). Organic integrated pest management follows the traditional IPM approach, but uses only organically-approved materials and practices.

Apple ecosystems harbor many pests and therefore, intensive management is necessary to produce marketable fruit. A cornerstone of IPM is the application of knowledge of the arthropods, pathogens, and surrounding environment to manage pests below threshold levels. The foundation of disease management is knowledge of the virulent pathogen, the susceptible host plant, and the type of environment favorable for disease development (i.e., the disease triangle). All components of the disease triangle must be present for disease development; all the cultural, mechanical, and chemical disease management practices target at least one component of the triangle to manage disease. For example, planting disease resistant cultivars or applications of fungicides target the pathogen; proper pruning allows more air and light penetration into the canopy making the environment less favorable for disease development; and, providing appropriate nutrition for balanced and healthy growth may lower the susceptibility of the plant to disease. Based on knowledge of the pathogen(s), host plant, and environmental conditions that influence the pathogen-plant interaction, the most appropriate cultural, mechanical, and/or chemical practices are chosen to successfully manage disease using an integrated approach.

One of the most important diseases and one of the greatest threats to New England orchards is apple scab (47, 11, 13). Apple scab is caused by the fungus *Venturia inaequalis* (Cooke) Wint., and can have devastating results, including decrease in fruit quality and yield. Severe foliar infection can lead to premature defoliation and reduced tree vigor, which in turn may restrict or prevent formation of fruit buds for the following year. Fruit infection causes deformities, cracks, and fruit drop (39). Fungal reproductive fruiting bodies, pseudothecia, are produced in the fallen, infected leaves in the autumn, and overwinter in the leaf litter on the orchard floor. In the spring, mature ascospores are produced in these pseudothecia and are released into the orchard when there is sufficient rain (47). The duration of the primary scab season (i.e., period when ascospores are released) in any one year depends on temperatures and frequency of rain and generally lasts about 6-8 weeks (11, 13). The probability of the discharged ascospores causing infection depends on temperature and length of time susceptible tissue remains wet. The scab lesions that result from the ascospore infection are important because the lesions produce asexual spores, conidia, that are spread by rain and heavy dew to susceptible tissue on the same tree or to other trees and can continue to produce lesions over the duration of the growing season. These additional infections, secondary infections, are characteristic of the polycyclic disease cycle of apple scab (47).

The overall disease management program in New England apple orchards is often driven by the management of apple scab. The risk of apple scab can be reduced by planting orchards away from potential *V. inaequalis* inoculum sources, like non-sprayed orchards with susceptible cultivars or susceptible crabapple trees. Scab resistant cultivars are an example of genetic management of the disease (22). There are a number of scab resistant cultivars available that produce fruit of commercially acceptable quality. Some growers and retailers are reluctant to dedicate time, space and money to these newer cultivars because consumers are loyal to their old-time favorite varieties. However, taste panel evaluations conducted by Sustainable Agriculture Research and Education (SARE) project participants around the northeastern United States indicate increasing consumer acceptance of scab resistant cultivars (53). Some of these cultivars are resistant to other apple diseases such as powdery mildew (*Podosphaera leucotricha* (Ellis & Everh.) Salmon,), cedar apple rust (*Gymnosporangium juniperi-virginianae* (Schwein)), and fire blight (*Erwinia amylovora* (Burrill)), adding to their possibilities in organic and reduced-fungicide production. However, most scab resistant cultivars are susceptible to summer diseases including fruit rots (*Botryosphaeria* spp. and *Colletotrichum* spp.), and sooty blotch (caused by the complex: *Peltaster fructicola* (Johnson, Sutton, Hodges); *Geastrumia polystigmatus* (Batista & M.L. Farr); *Leptodontium elatus* (G. Mangenot) De Hoog; and *Gloeodes pomigena* (Schwein) Colby), and flyspeck (*Zygophiala jamaicensis*

(E. Mason)), and therefore, disease management is still necessary (53). In addition, disease management practices on scab resistant cultivars, should take into consideration the development of new strains of *Venturia inaequalis* (Cooke) Wint. that may be virulent on the cultivars resistant to only one strain of the pathogen (66).

Integrated management of apple scab includes cultural and biological practices to reduce the pathogen populations. For example, flail mowing or mulching the leaf litter under trees reduces overwintering inoculum of *V. inaequalis* (47, 83). Applications of urea to the leaf litter in November or April reduces the amount of ascospores in the orchard during the primary ascospore season and thus can help to reduce the number of lesions on leaves and fruit (83). Pruning in combination with fungicide use has been shown to significantly decrease leaf scab because it improved spray deposition in the tree canopy (35). Biological control methods are being researched to manage diseases. For example, *Microsphaeropsis ochracea* (Carisse & Bernier), a coelomycete isolated from dead apple leaves, has been shown to reduce the inoculum of *Venturia inaequalis* when applied in late summer and used in conjunction with a delayed fungicide program (10). However, this potential biological control method is not commercially available yet. These cultural and potential biological practices would have to be used in combination with a fungicide spray program and are not solely sufficient for management of apple scab to commercially acceptable levels (47).

Determining if and when measures of control are necessary for scab disease management depends on estimations of inoculum levels and monitoring of weather conditions. To predict the orchard’s inoculum level, or scab risk, the potential ascospore dose (PAD) is estimated. Potential ascospore dose is the predicted number of ascospores that would be produced per square meter of the orchard floor during primary scab season. Scab risk is estimated by counting the number of scabbed leaves on 10 shoots from each of 60 trees. If less than 50 leaves with lesions are counted, the orchard is considered at "low risk" and the first fungicide spray can be delayed until the pink stage or after three infection periods have ocurred, whichever comes first (47, 73). During the growing season, monitoring for disease potential, in general, is highly dependent on observing the weather conditions in the orchard. The key to managing diseases, such as apple scab, is preventing primary infections. Therefore, it is important to determine when an infection period has occurred, which takes into account the temperature and number of hours of leaf wetness to determine if the minimum conditions have been met for infection to occur (54, 48).

The timing of fungicide applications is targeted at primary scab infections to prevent initial infections and reduce the potential for disease development later in the growing season. In the spring, ascospore maturity can be estimated using the ascospore maturity model (26). This allows for the estimation of the percentage of the season's ascospores that have matured based on the accumulation of degree days prior to the start of a wetness period in which these ascospores would be released. Degree days are calculated as the number of degrees the average daily temperature is above $0^{o}C$ (26). The ascospore maturity model estimates when the peak release of ascospores will occur and when the last ascospores are released and therefore, when the primary scab season is complete and the intervals between fungicide applications can be extended, or applications are no longer necessary if there are no lesions present to produce secondary inoculum (i.e., conidia) in the orchard.

Fungicide applications for apple scab management, depending on what fungicides are used, may also contribute to management of other important apple diseases including: cedar apple rust; black rot (*Botryosphaeria obtusa* (Schwein.) Shoemaker); and the summer diseases of sooty blotch and flyspeck. These diseases can cause economic damage to the fruit and fungicide applications are often necessary. Cedar apple rust, caused by *Gymnosporangium juniperi-virginianae* (Schwein) fungus, requires two hosts: the apple tree and a red cedar tree. The disease causes yellow and orange leaf spots and fruit lesions; defoliation can occur when the tree is severely infected (39, 68). Black rot, also called frogeye leaf spot on the foliage of apple trees, is caused by the fungus *Botryosphaeria obtusa* (Schwein.) Shoemaker. Leaf infections begin as purple lesions that then become brown in the center, resembling a frog's eye. Heavily infected leafs will become chlorotic and defoliation occurs. Fruit infections result in firm rot lesions that render the fruit unmarketable (39). Sooty blotch, caused by the complex of fungi (*Peltaster fructicola* (Johnson, Sutton, Hodges); *Geastrumia polystigmatus* (Batista & M.L. Farr); *Leptodontium elatus* (G. Mangenot) De Hoog; and *Gloeodes pomigena* (Schwein) Colby) results in topical blemishes on the fruit reducing the quality of the fruit at harvest (39, 21). The other summer disease, flyspeck, which is caused by *Zygophiala jamaicensis* (E. Mason), also produces topical symptoms that reduce fruit quality (39, 21).

In addition to target impacts on other diseases, the fungicide applications necessary in integrated apple scab disease management can have non-target impacts on arthropods present within the apple ecosystem. Fungicides which have been used in IPM orchards such as mancozeb, benomyl, and captan have been found to reduce numbers of predacious and phytophagous mites in apple orchards (5, 51, 32). Fungicides most commonly used in organic apple production, lime sulfur and sulfur, also have non-target effects on arthropods. As previously mentioned, sulfur and lime sulfur have been found to reduce the numbers of predator mites and insects (37, 90, 50, 49).

The potential non-target arthropod impacts of alternative fungicides for organic apple production are unknown. An objective of this experiment was to evaluate the possible impacts of the alternatives on the following arthropods and/or their damage: the spotted tentiform leafminer (*Phyllonorycter blancardella* (Fabr.)) or apple blotch leafminer (*Phyllonorycter crataegella* (Clemens)); lyonetia leafminer (Lepidoptera: Lyonetiidae); green apple aphid (*Aphis pomi*); European red mite (*Panonychus ulmi* (Koch)); two-spotted spider mite (*Tetranychus urticae* (Koch)); white apple leafhopper (*Typhlocyba pomaria* (McAtee)); potato leafhopper (*Empoasca fabae* (Harris)); Japanese beetle damage (*Popillia japonica* (Newman)); European apple sawfly (*Hoplocampa testudinea* (Klug)); plum curculio (*Conotrachelus nenuphar* (Herbst)); tarnished plant bug (*Lygus lineolaris* (Palisot de Beauvois)); apple maggot fly (*Rhagoletis pomonella* (Walsh)); stink bug (Hemiptera: Pentatomidae); and internal and surface feeding Lepidoptera, including codling moth (*Cydia pomonella* (L.), oriental fruit moth (*Grapholita molesta* (Busck), and lesser appleworm (*Grapholita prunivora* (Walsh). Part of the objective of this study was to also evaluate potential impacts of the alternatives on beneficial arthropods including: lady beetle adults (Coleoptera: Coccinellidae), lady beetle larvae, cecidomyiid larvae (Diptera: Cecidomyiidae), syrphid fly larvae (Diptera: Syrphidae), and chrysopid eggs (Neuroptera: Chrysopidae).

POTENTIAL ALTERNATIVE FUNGICIDES FOR ORGANIC APPLE PRODUCTION

Since the standard materials used in organic apple production (i.e., lime sulfur and sulfur fungicides) can have adverse non-target impacts on the apple trees and the orchard ecosystem, it is important to evaluate the effectiveness of alternatives. Some potential alternatives currently available and approved for organic apple production are potassium bicarbonate (Armicarb® 'O'), *Bacillus subtilis* (Serenade® MAX), neem oil (Trilogy®), and milk.

Potassium bicarbonate, in the formulation Armicarb "O" ®, which was used in this research study, was removed from the national and Vermont state list of organically-approved materials in 2008. However, other potassium bicarbonate materials such as Kaligreen® and Milstop®, are currently on the national and Vermont lists of approved materials for organic apple production. According to the Helena Chemical Company label and Material and Safety Data Sheet for Armicarb "O" ®, the formulation has very low to no mammalian acute toxicity and no mammalian chronic toxicity risk (34). A preliminary study has shown potassium bicarbonate to significantly control apple scab and sooty blotch in Switzerland orchards (85). In a two year trial, Tamm *et al*. (85) found severe stunting in trees after five applications of 1% potassium bicarbonate, but concentrations of 0.5% showed no stunting and no other phytotoxic symptoms. The efficacy of the lower concentration of potassium bicarbonate was as good as the control treatments of sulfur. Potassium bicarbonate has also been shown to have antifungal properties against powdery mildew disease in other crops. Smither-Kopperl *et al*. (77)

found potassium bicarbonate, sulfur, and seaweed extract to significantly reduce powdery mildew, *Podosphaera xanthii* (formerly known as *Sphaerotheca fuliginea* Schlech ex Fr. Poll.) in Beit Alpha cucumber. Lunden and Grove (45) found reductions in powdery mildew in grapes, *Uncinula necator* (Schwein) Burrill with potassium bicarbonate treatments, although, it was not as effective as sulfur fungicides treatments.

A second potential fungicide alternative is *Bacillus subtilis*, a soil-borne bacterium that secretes antifungal and antibacterial metabolites which are toxic to many fungi, including those commonly found on apple leaves (84). A study on ‘Rome Beauty’, ‘Golden Delicious’, ‘Stayman’, ‘Cortland’, and ‘Red Delicious’ apple trees found *Bacillus subtilis*, along with one early copper spray, to significantly reduce the percent incidence and severity of apple scab compared to the non-treated water check (88). In addition, a study on ‘Jonagold’ trees found applications of Serenade® MAX (common formulation of *Bacillus subtilis*) with an enhancing adjuvant, Biotune, to have a significant effect on incidence of sooty blotch and flyspeck compared to the non-sprayed control (12). In the lab, *Bacillus subtilis* has been found to reduce post-harvest infections of grey mold on apples caused by *Botrytis cinerea* (pers.) ex Fr. (86).

Extracts from the neem tree, *Azadirachta indica*, have antifungal properties as well. Neem seed oil was found to be as effective as calcium chloride in controlling *Botrytis cinerea* (pers.) ex Fr., *Penicillium expansum* Thom., and *Glomerella cingulata* (Ston.) Spauld. & Schrenk, which cause the postharvest apple diseases of gray mold, blue mold, and bitter rot, respectively (55). On barley, Paul and Sharma (67) found neem leaf extract provided control of the leaf stripe pathogen, *Drechslera graminea*, and that it was as effective as the conventional control. The treated leaves also had increased enzyme activity and accumulation of fungitoxic phenolic compounds, increasing the barley's defense against the pathogen. Extract from the neem seed kernel controlled powdery mildews as well as sulfur on zucchini, barley and wheat (*Sphaerotheca fuliginea, Erysiphe graminis* f. sp. *tritici*, and *Erysiphe graminis* f. sp. *hordei*, respectively) (75).

Other possible alternative materials with antifungal properties are milk and whey. The lactoperoxidase system in milk has antimicrobial properties. The peroxidase oxidizes available halides or thiocyanate to reactive oxidizing compounds, which attach sulfhydryl groups in essential proteins in microbes, such as fungi (71, 28). In a study of the mode of action of milk and whey in the control of grapevine powdery mildew, Crisp *et al.* (16) showed that the milk produced oxygen radicals when exposed to natural light and this, in conjunction with the action of lactoferrin (an antimicrobial component of milk), collapsed the hyphae and damaged the conidia of *Erysiphe (Uncinula) necator* (Schwein) Burrill. Exposure of milk to the ultraviolet radiation in sunlight resulted in the reduction of oxygen to superoxide anion, which is highly reactive (42). Milk and whey have been found to effectively treat grapevine powdery mildew, *Erysiphe (Uncinula) necator* (Schwein) Burrill, (70, 15, 33). Pscheidt and Kenyon (70) found whey powder applied 12.5 to 19 lb per acre (14-21.3 kg per ha) significantly reduced the severity of powdery mildew on leaves and clusters compared to non-treated and water treatments. Crisp *et al*. (15) tested the efficacy of milk, whey, and sulfur against grapevine powdery mildew in Australia. All test materials significantly reduced the severity of powdery mildew on leaves and bunches compared to non-treated vines. There was no significant difference in severity of the disease on vine leaves sprayed with milk, whey, or sulfur. Hed and Travis (33) found whole milk (20%) provided control of powdery mildew on Concord grapes that was statistically superior to the water check and equivalent to the conventional fungicide program.

In addition, Bettiol (4) found milk to be an effective alternative for control of powdery mildew on zucchini squash, *Podosphaera xanthii* (formerly known as *Sphaerotheca fuliginea* Schlech ex Fr. Poll.), in greenhouse conditions. Milk applied twice a week at concentrations of 10% and higher controlled powdery mildew at least as effectively as the conventional fungicides, fenarimol and benomyl. Mold grew on the upper surfaces of leaves treated with 30% and higher, but the plants did not appear to be injured. The main toxicity risk associated with milk and other dairy products is the potential that they are allergens to some humans (24).

Few or no known studies to date document the efficacy of these alternatives (potassium bicarbonate, *Bacillus subtilis*, and neem oil) on apple diseases in New England; therefore the objective of the proposed research project is to evaluate the efficacy of alternative fungicides previously approved and on the market for organic apple production in Vermont and investigate the potential of milk as a possible alternative.

CHAPTER 2. JOURNAL ARTICLE

EVALUATION OF ALTERNATIVE FUNGICIDES FOR ORGANIC APPLE PRODUCTION IN VERMONT

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Abstract

A major challenge in organic apple production in Vermont is the available fungicide options for apple scab management. The standard lime sulfur/sulfur fungicide program can be injurious to the applicator, the apple ecosystem, and the apple tree itself. Because of these drawbacks of the standard program, it is necessary to evaluate potential alternative fungicides for organic apple production. The objective of this study was to compare the efficiency of potassium bicarbonate, neem oil, and *Bacillus subtilis* to a standard organic lime sulfur/sulfur fungicide program and a non-sprayed treatment for control of apple scab and other fungal diseases and to evaluate potential non-target impacts on pest and beneficial arthropod populations. Treatments were applied to 'Empire' trees arranged in a completely randomized design with five single-tree replications at the University of Vermont Horticultural Research Center in South Burlington, VT. Fungicides were applied with a handgun to drip, using maximum label rates. During two growing seasons, applications began on 26 April 2007 and 23 April 2008 and continued on approximately a weekly schedule through the end of June and then every two weeks through 23 July 2007 and 17 July 2008, respectively. Data obtained were analyzed by analysis of variance and significance between means was determined by Fisher's Protected LSD Test ($P \leq 0.05$). None of the alternatives managed disease as well as the standard lime sulfur/sulfur fungicide program. The neem oil treatment showed more activity against apple diseases than the other alternative fungicides. However, both the lime sulfur/sulfur and neem oil treatments had disadvantages, including phytotoxic burning and/or significantly more russetting on the fruit at harvest. Although no significant differences of European red mite populations were found among the treatments in either year, the two-spotted spider mites were numerically higher in the lime sulfur/sulfur treatment than all other treatments in 2007 and significantly higher in 2008. However, predatory mites were not assessed and very low levels of other beneficial organisms were observed and therefore, no assumptions can be made on the potential impact of lime sulfur/sulfur or the other alternatives on beneficial populations. The overall quality of the fruit was not at commercially acceptable levels. No treatment had above 40% of the harvested fruit placed in marketable grades. This research shows that potassium bicarbonate, *Bacillus subtilis*, and neem oil do not offer substantial advantages over the standard lime sulfur/sulfur fungicide program in organic apple production in Vermont.

INTRODUCTION

A major limitation to organic apple production in Vermont is the available fungicide options for apple scab management. Apple scab, a fungal disease caused by *Venturia inaequalis* (Cooke) Wint., is a major disease of apples in New England. Apple scab is one of the greatest threats to New England orchards and can have devastating results, including decrease in fruit quality and yield (21, 6). Fruit infection causes deformities, cracks, and fruit drop. Severe foliar infection can lead to premature defoliation and reduced tree vigor, which in turn may restrict or prevent formation of fruit buds for the following year (16). There are integrated pest management methods to reduce inoculum; however, disease management on scab susceptible cultivars requires fungicide use.

There are a number of fungicides which are organically approved by the Northeast Organic Farming Association (NOFA) of Vermont. The fungicides containing sulfur or lime sulfur active ingredients are the most commonly used against *Venturia inaequalis* in organic apple production systems (6). However, lime sulfur-based fungicides are highly caustic (8). Sulfur-based materials are less caustic to the applicator, but are less effective, with only weak protective activity against apple scab (7, 18, 6). Liquid lime sulfur was a highly recommended fungicide in the early twentieth century and was effective as a protectant fungicide, and could also be used to eradicate established infections (12). However, it can be injurious to the tree, lowers photosynthesis rates, and reduces fruit set and pollen germination (25, 27, 4, 20, 21).

Lime sulfur applications can also result in lower fruit yields and premature fruit drop, and causes russetting and phytotoxic burns on the fruit, thus lowering fruit quality (21, 4, 28, 13). Consequently, wettable sulfur fungicides were incorporated into programs with lime sulfur even though they were less effective and lacked the eradicative capability of lime sulfur (21). However, sulfur- and lime sulfur-based fungicides used in apple orchards have adverse, non-target effects on beneficial predatory mites (14, 41, 24, 23).

Since the standard fungicides used in organic apple production in Vermont can be harmful to the applicator, as well as the apple tree and orchard ecosystem, it is necessary to evaluate the effectiveness of alternative organically-approved fungicides. Potassium bicarbonate (Armicarb® “O”), *Bacillus subtilis* (Serenade® MAX), and neem oil (Trilogy®) are fungicides that were approved for organic apple production, but have not been fully evaluated and compared to the standard lime sulfur/sulfur fungicide program in New England. Potassium bicarbonate has been shown to have activity against apple scab (*Venturia inaequalis* (Cooke) Wint.) and sooty blotch (fungal disease complex) in Switzerland apple orchards (37). In addition, the material has shown to manage powdery mildew in other crops such as cucumbers (*Podosphaera xanthii* (formerly known as *Sphaerotheca fuliginea* Schlech ex Fr. Poll.) and grapes (*Uncinula necator* (Schwein) Burrill) (33, 19). Past research evaluating *Bacillus subtilis* on apple trees in Pennsylvania, showed that trees treated with Serenade® MAX had significantly lower apple scab incidence and severity than a non-treated water check treatment (39). Extracts from the neem tree, *Azadirachta indica*, have shown antifungal properties against postharvest apple diseases (*Botrytis cinerea* (pers.) ex Fr., *Penicillium expansum* Thom., and *Glomerella cingulata* (Ston.) Spauld. & Schrenk) (26). These materials are currently labeled as organically-approved fungicides for management of apple scab and other fungal diseases such as cedar apple rust (*Gymnosporangium juniperi-virginianae* (Schwein)), fruit rots, and sooty blotch (a complex of *Peltaster fructicola* (Johnson, Sutton, Hodges), *Geastrumia polystigmatus* (Batista & M.L. Farr), *Leptodontium elatus* (G. Mangenot) De Hoog, and *Gloeodes pomigena* (Schwein) Colby), and flyspeck (*Zygophiala jamaicensis* (E. Mason)), but their effectiveness in New England is not fully known.

The major objectives of this research were to: (i) evaluate the efficacy of alternative fungicides (potassium bicarbonate, *Bacillus subtilis,* and neem oil) against apple scab and other apple diseases compared to a standard lime sulfur and sulfur fungicide program; and (ii) evaluate the potential non-target effects of the fungicide treatments on beneficial and pest arthropod populations

MATERIALS AND METHODS

The study was conducted at the University of Vermont Horticultural Research Center in South Burlington, VT on ‘Empire’ trees, which were, on average, 3.0 m high x 3.0 m wide and planted at a spacing of 3.7 m x 5.5 m in 1990 on M.7 and Mark rootstocks. Previous research showed that the two rootstocks did not affect disease incidence and therefore, they were not considered a variable in this experiment (30). The other cultivars in this planting are not susceptible to apple scab (*Venturia inaequalis* (Cooke) Wint.) and were not included in this experiment. Treatments were arranged in a completely randomized design with five single-tree replications of the five treatments: potassium bicarbonate (Armicarb® "O"); *Bacillus subtilis* (Serenade® MAX); neem oil (Trilogy®); lime sulfur (Miller® Lime Sulfur)/sulfur (Microthiol® Sulfur); and non-sprayed. The experimental orchard was previously (before 2007) managed using standard integrated pest management practices. The research orchard is not organically certified. [NOTE: Armicarb® "O" was organically-approved for use in 2007, when this research began. In 2008, this formulation was removed from the national and Vermont lists of organically-approved materials; other potassium bicarbonate formulations are currently available for organic apple production in Vermont. However, to maintain the integrity of the treatments for the second year of the study, Armicarb® "O" was used in 2008.]

A 'scab risk' assessment was conducted for the study in the autumn of 2006 and 2007 to determine the potential risk for apple scab in the spring of 2007 and 2008, respectively (30, 6). Ten vegetative shoots on every 'Empire' tree in the orchard were examined for scab lesions. Shoots were selected from high, low, interior, and exterior sections of the tree (shoots were cut off to allow easier evaluation in 2006). On each shoot, the upper and lower surfaces of each leaf were examined and the number of leaves with at least one scab lesion was recorded. The tree was checked on a map of the orchard to ensure it was not sampled multiple times. A total of 43 'Empire' trees were assessed across the orchard on 27 September-2 October 2006 and on 29 September-7 October 2007. The 2006 'scab risk' assessment concluded the orchard was at a "low" risk for apple scab, however, the 2007 assessment determined the orchard was at a "high" risk for scab in spring 2008.

In autumn of 2007, sanitation measures were undertaken to reduce the amount of overwintering ascospores on fallen scabbed leaves (sanitation measures were unnecessary in autumn of 2006 because the inoculum level was low). Urea was applied (5% solution applied 150 gal water per acre) to the trees on 25 October 2007 as a pre-leaf fall spray instead of to the fallen leaves later in autumn because of the potential that temperatures would drop too low for sprayer use. Past research has shown that urea hinders perithecial (i.e., pseudothecial) development (3, 31). Urea, although not an organically-approved material, was used in this research trial to manage potential overwhelming inoculum levels due to the non-sprayed treatment that would not have been present in a commercial orchard. On 12-16 November 2007, when the trees were 40% defoliated, leaves were raked into the row middles of the orchard. The leaves were mowed with a chain flail mower which was set to mow down to soil level. Snow prevented further flail mowing when a higher percentage of leaves had fallen to the ground. Sutton *et. al.* (36) found that shredding all the leaf litter reduced the risk of apple scab by 80-90% and shredding 65-90% of the leaf litter reduced the risk of apple scab by 50-65%. In addition, the study showed application of urea to leaf litter in November reduced the number of ascospores trapped in the orchard the next spring by 50%.

Fungicide & Insecticide Applications

Fungicides were applied with a 189 liter, 3-point hitch PTO sprayer (Nifty Fifty, Rears Mfg Co., Eugene, OR) with an attached Green Guard handgun (model JD9-C) having an L tip, at a pressure of 100 lb/sq. in. (689.48 kpa). Maximum labeled rates were applied dilute to drip: potassium bicarbonate at 3.75 lb/A (4.2 kg/ha); *Bacillus subtilis* at 3 lb/A (3.4 kg/ha); neem oil at 2 gal/A (18.7 L/ha); sulfur at 15 lb/A (16.8 kg/ha); lime sulfur at 2 gal/A (18.7 L/ha). Fungicide applications in 2007 began on 26 April and continued on approximately a weekly schedule through the end of June and then every two weeks to the last fungicide application on 23 July (Table 1). Applications were made weekly in 2008 from 23 April through the end of June and every two weeks until 17 July (Table 1). Conditions were highly conducive for fire blight development in 2007, justifying an application of streptomycin sulfate (Agri-mycin® 17 at 1 lb/A (1.1 kg/ha)) on 11 May 2007 with a Rears Pak-Blast 100 sprayer (Rears Manufacturing, Eugene, OR). To target potential fire blight (*Erwinia amylovora*) inoculum in the orchard in 2008, copper (C-O-C-S® WDG at 6 lb/A (6.7 kg/ha)) was applied with the Rears Pak-Blast 100 sprayer at the silver tip phenological stage on 18 April 2008.

Weather was monitored with a Davis Vantage Pro Wireless Weather Station (Davis Instruments Corp., 3465 Diablo Ave., Hayward, California 94545 USA) and primary infection periods were calculated, according to formulas used by Reardon (29), which were based on the "revised" Mills table (22, 34, 30), with the exception that wetting periods starting with nightfall rains were included in the calculations because a portion of ascospores are released at night (10) (Appendix B). Secondary infection periods were determined similarly with the exception that leaf wetness hours caused by dew alone were also included. Ascospore maturity was calculated, following formulas used by Reardon (29) who used the New Hampshire model developed by Gadoury and

MacHardy (9) (Appendix C). The potential release of mature ascospores was determined according to criteria established by Gadoury *et. al.* and used by Reardon *et. al.* (10, 30).

Primary infection periods occurred in 2007 on 27-30 April, 10-11, 15-17, 19-21, 27-28 May, and 31 May – 2 June, and in 2008, on 28-29 April, 2-4, 15, 22-24, 26-27 May, and 31 May - 1 June (Figures 1, 2). The 2007 primary scab season had six infection periods, spanning 17 days; in 2008, there were six primary infection periods covering 13 days. So overall, 2007 had more wet days during the primary season, but 2008 had eight more wet days in the secondary scab season than 2007.

Insecticide and miticide applications followed a standard organic management program in 2007. Materials were applied to the whole orchard using a Rears Pak-Blast 100 sprayer. Horticultural oil (JMS Stylet oil) was applied at silver tip (22 April 2007 at 2.6 gal/A (24.3 L/ha)) and at ½ inch green tip (7 May 2007 at 1.7 gal/A (15.9 L/ha)) for management of mites (i.e., European red mites (*Panonychus ulmi* (Koch)) and two-spotted spider mites (*Tetranychus urticae* (Koch))). *Bacillus thuringiensis* (Dipel® DF) was applied twice in June (7 & 14 June 2007) and once in August (2 August 2007) for codling moth (*Cydia pomonella* (L.)) at 1 lb/A (1.1 kg/ha); spinosad (Entrust®) was used twice, once at the end of June (29 June 2007) for oblique banded leafroller (*Choristoneura rosaceana* (Harris)) and once in August (2 August 2007) for codling moth and apple maggot fly (*Rhagoletis pomonella* (Walsh)) at 1.5 fl. oz./A (0.1 L/ha). In addition, kaolin clay (Surround® WP) was applied three times throughout the season (29 May at 62.5 lb/A (70.1 kg/ha), 14 & 22 June 2007 at 41.7 lb/A (46.8 kg/ha)) targeting plum curculio (*Conotrachelus nenuphar* (Herbst)) and European apple sawfly

(*Hoplocampa testudinea* (Klug)). In 2008, horticultural oil (JMS Stylet oil) was applied at silver tip (18 April 2008 at 2.6 gal/A (24.3 L/ha)) for management of mites. No insecticides, except kaolin clay (Surround® WP), were applied in 2008, in order to assess any non-target affects of the fungicides on insect populations. Kaolin clay (Surround® WP) was applied two times in May (22 & 29 May 2008 at 62.5 lb/A (70.1 kg/ha)) for plum curculio and European apple sawfly and once more in June (5 June 2008 at 41.7 lb/A (46.8 kg/ha)) for plum curculio.

June Cluster Disease and Arthropod Assessment

The incidence of disease symptoms and the number of lesions of apple scab, cedar apple rust, and non-specific, unidentified necrotic leaf spots, which resembled frogeye leaf spot (*Botryosphaeria obtusa* (Schwein.) Shoemaker) were assessed on both sides of all leaves on ten fruit clusters per each single tree replicate for each of the five treatments: potassium bicarbonate; *Bacillus subtilis*; neem oil; lime sulfur/sulfur; and non-sprayed. Given the size of the canopy it was thought that this number of clusters would give a representative assessment of disease incidence and severity. Clusters were selected at random from the upper (within 8 feet (2.44 m) from the ground), lower, inner, and outer canopy; clusters were selected from around the whole area of the tree circumference. The clusters were removed from the tree, and stored in sealed plastic bags at 36°F (2.2°C) in the walk-in cooler at the Horticultural Research Center for one day until assessed for disease. Only leaves below the fruit were included in the assessment to avoid including leaves on bourse shoots. Since the trees had been sprayed with kaolin clay (Surround® WP), which left a white residue, the kaolin clay was gently rubbed off with a dry cloth or thumb in order to view the lesions or arthropod damage on the leaves after arthropod presence was noted. Most of the kaolin residue was washed off by rain; however, the trees in the neem oil treatment were covered with more kaolin clay. Head-piece magnifying glasses (10X magnification) aided the naked eye in the assessment.

In addition, the incidence of insect damage was assessed on each of the fruitlets on the ten fruit clusters per each single tree replicate that were collected. All the fruit on each cluster was assessed for European apple sawfly, plum curculio, and tarnished plant bug (*Lygus lineolaris* (Palisot de Beauvois)) damage. The cluster leaves and fruitlets were assessed on 20-21 June 2007 and on 16-19 June 2008.

June Terminal Disease Assessment

The incidence of disease symptoms and the number of lesions of apple scab, cedar apple rust, and necrotic leaf spots were assessed on all leaves on ten apical, vegetative terminals per each single tree replicate for each treatment. The same procedure for viewing the lesions on the cluster leaves was followed on the terminal leaves. Vegetative terminals were selected at random from around the whole area of the tree circumference. Where sufficient apical vegetative terminals were absent, bourse shoots were substituted and only the leaves above the fruit cluster were assessed. The selection of a bourse shoot was noted on the data sheets. The position of each leaf on the terminal was noted with the disease data to compare the location of disease symptoms on the terminals to when fungicide applications were made and when infection periods occurred using the leaf emergence data collected (Appendix D). Foliar disease incidence and severity (number of lesions per infected leaf) were assessed and leaves with no lesions were noted as clean of disease. The terminal leaves were assessed for lesions on 18-20 June 2007 and on 16-19 June 2008.

August Terminal Disease & Arthropod Assessment

Disease assessment in August followed the same procedures as the June terminal assessment in 2007. However, in 2008 the selected terminals from each tree were cut from the tree and stored in clear garbage bags at 36°F (2.2°C) in the walk-in cooler at the Horticultural Research Center for one day until assessed. The terminals were removed and stored on 11 August 2008. In 2007 and 2008, all leaves present on the terminals were assessed for lesions.   Total number of leaves per terminal was recorded and each leaf was examined (leaf position and missing leaves were not recorded). Foliar disease incidence and severity (number of lesions per infected leaf) were recorded in the assessment.

Arthropod pest data were also collected upon examination of each leaf on the ten terminals per tree. After the arthropod presence was noted, the kaolin clay (Surround® WP) residue was gently rubbed off to view disease lesions and/or arthropod damage on the leaves. Data that were collected included the incidence and/or damage of the following pests: spotted tentiform leafminer (*Phyllonorycter blancardella* (Fabr.)) or apple blotch leafminer (*Phyllonorycter crataegella* (Clemens)) (severity was also assessed for this insect); lyonetia leafminer (Lepidoptera: Lyonetiidae); green apple aphid (*Aphis pomi*); European red mite; two-spotted spider mite; white apple leafhopper (*Typhlocyba pomaria* (McAtee)); potato leafhopper (*Empoasca fabae* (Harris)); and Japanese beetle (*Popillia japonica* (Newman)). In addition, incidences were also recorded of beneficial insects such as: lady beetle adults and larvae (Coleoptera: Coccinellidae); cecidomyiid larvae (Diptera: Cecidomyiidae); syrphid fly larvae (Diptera: Syrphidae); and chrysopid eggs (Neuroptera: Chrysopidae). Leaves with no evidence of the pest or pest damage were recorded as clean of arthropod damage.

Terminals were assessed for disease and arthropods on 22-24 August 2007 and on 12-15August 2008.

Harvest Fruit Collection

On 10 September 2007 and on 3 September 2008, 64 fruit were collected from each of the 25 ‘Empire’ trees. A sample of eight apples was picked from each of four quadrants on both the east and west sides of the trees. The upper and lower canopies were divided into two quadrants each on the east and west sides, making a total of eight sections per tree. Eight apples were picked from each section in order to obtain a representative sample of fruit from each tree. The fruit were placed in labeled boxes and stored at 36°F (2.2°C) in the walk-in cooler at the Horticultural Research Center until disease and insect assessments were completed.

Harvest Fruit Disease & Insect Assessment

A target number of 50 fruit, chosen at random from the 64 collected per tree, were assessed for the following: apple scab; cedar apple rust; sooty blotch; fly speck; fruit rots (only counted rot when not associated with mechanical or other injury); and lenticel blackening, which may be the early symptoms of black rot (*Botryosphaeria obtusa* (Schwein) Shoemaker). Presence of physiological maladies such as phytotoxicity (i.e., purple and cracked apple skin) and russet were also recorded. A target number of 50 fruit was desired, but in some cases, because of low yield, fewer fruit were evaluated.

The 50 fruit were also evaluated for arthropod damage. The presence of damage from the following insects were assessed: plum curculio (i.e., crescent-shaped scarring); tarnished plant bug (i.e., dimpled scarring); apple maggot fly (i.e., small skin puncture with no frass, tunneling into the flesh); stink bug (Hemiptera: Pentatomidae) (i.e., sunken firm flesh dimple, slightly green in color); European apple sawfly (i.e., characteristic curved scar); internal Lepidoptera, which includes damage from codling moth, oriental fruit moth (*Grapholita molesta* (Busck), and lesser appleworm (*Grapholita prunivora* (Walsh) (i.e., circular hole, often with frass: inspection upon slicing revealed tunneling into the flesh generally toward the core); and, surface Lepidoptera (i.e., feeding on skin and flesh just below it, often with frass and 'squiggly trail' at the surface). The fruit was cut in half to determine if there was internal Lepidoptera damage and the skin was peeled off to see the presence of apple maggot fly larvae trails in the flesh below a possible entry pin-sized hole. Fruit assessment was completed on 1-2 October 2007 and on 9-10 & 15 September 2008.

Overall fruit quality was assessed in 2008 using the USDA fruit quality standards (40, Appendix E). Apples were placed in one of four grades: US-1 Count, in which fruit must weigh at least 140 g and have more than 25% red color, and have blemishes smaller than 0.5 cm; US-1 Bag, where fruit must weigh between 100 g and 140 g with greater than 25% red color, and blemishes no more than US-1 Count; U.S. Utility, where apples were less than 100 g and free from any rots or broken skin; and Cull, where the apples were not suitable for any of the other grades. Fruit quality was assessed at the same time the fruit were evaluated for disease and insect damage, on 1-2 October 2007 and on 9-10 & 15 September 2008.

Statistical Analysis

Data obtained were subjected to analysis of variance and significant differences between means were determined by Fisher's Protected LSD Test ($P \leq 0.05$) (32). When necessary, incidence data were transformed using the arcsine square root and severity data were transformed by taking the log (severity + 0.1). In treatments with very low or no disease or phytotoxicity incidence, data could not be normalized and significance was determined by the non-parametric Kruskal-Wallis Test ($P \leq 0.05$) (32).

RESULTS

Disease Management Evaluation

In 2007, the lime sulfur/sulfur treatment provided effective management of apple scab, with 1.1% of the leaves and 0.4% of the fruit with lesions at harvest time (Table 1). There were no significant differences among treatments in scab incidence on the cluster or terminal leaves in June. All of the alternative fungicides had significantly less foliar scab in August than the non-sprayed treatment; scab severity in August did not show any clear cut statistical differences. On the fruit, the potassium bicarbonate and neem oil treatments showed some activity against apple scab compared to the non-sprayed trees. The percent of fruit with scab at harvest were 11.2% and 11.6%, respectively, which was significantly less than the non-sprayed treatment and not statistically different than the lime sulfur/sulfur treatment.

Overall, the incidence of scab was much higher in 2008. The lime sulfur/sulfur treatment again provided better scab management of all the treatments, with 8.9% of the leaves and 2.9% of the fruit with lesions at harvest time (Table 1). The potassium bicarbonate and *Bacillus subtilis* treatments were significantly lower than the non-sprayed treatment, and were not significantly different than the lime sulfur/sulfur treatment on the cluster leaves in June. On the cluster leaves in June, the lime sulfur/sulfur treatment had the lowest incidence of scab, although it was not significantly different than the neem oil treatment. The lime sulfur/sulfur treatment also had the lowest scab severity on the terminal leaves in June and August; however, it was not significantly different than the neem oil treatment by August. The neem oil treatment provided significantly better management of apple scab than the non-sprayed treatment and the other alternatives on the leaves in August and on the fruit. The potassium bicarbonate treatment had significantly less incidence of scab than the non-sprayed treatment, but more than the neem oil treated trees in August and at harvest. However, scab management was not to commercially-acceptable levels. Foliar and fruit scab levels on the *Bacillus subtilis* treated trees were not significantly different than the scab levels on the non-sprayed treated trees.

There were no significant differences among the treatments in incidence of cedar apple rust on the leaves by August in 2007 or 2008 (Table 2). However, in each year, the neem oil and lime sulfur/sulfur treatments had numerically lower incidences of rust in

August than the other treatments. The potassium bicarbonate treatment had a significantly higher incidence of rust on the terminal leaves in June than all the other treatments in 2007. This treatment also had among the higher rust severities in June and August of 2007, although it was not significantly different than the *Bacillus subtilis* or non-sprayed treatment in June or any other treatment in August. No rust lesions were seen on the fruit at harvest in 2007 or 2008.

In 2007, the neem oil treatment had a significantly higher incidence of necrotic leaf spots than all treatments except the non-sprayed, and significantly higher severity than all other treatments, on the cluster leaves in June (Table 3). By August, the potassium bicarbonate and neem oil treatments had significantly higher incidences of necrotic leaf spots than the lime sulfur/sulfur and non-sprayed treatments. The potassium bicarbonate treatment was significantly different from the other treatments and had the highest number of lesions per infected leaf in August. In 2008, the neem oil treatment had a significantly higher percentage of leaves with necrotic leaf spots in August than all other treatments, including the non-sprayed (Table 3). The severity of lesions was significantly higher in the neem oil treatment on cluster leaves in June and on terminals in August as well. The necrotic leaf spot incidence in the potassium bicarbonate treatment was statistically lower than the neem oil treatment, and significantly higher than the lime sulfur/sulfur treatment by August.

In 2007, there were no significant differences among the treatments in incidence of summer diseases, including sooty blotch, flyspeck, fruit rots, and lenticel blackening (Table 4). Very little flyspeck and no sooty blotch were observed in the 2007 harvest. In

2008, again there was no sooty blotch observed, although flyspeck was present (Table 4). The lime sulfur/sulfur and neem oil treatments had flyspeck incidences significantly lower than all the other treatments. Both the potassium bicarbonate and *Bacillus subtilis* treatments had higher incidences of flyspeck than the non-sprayed treatment, although the difference was not significant on the *Bacillus subtilis* treated fruit. Like 2007, there were also no differences among the treatments in incidence of fruit rots in 2008 (Table 4). In 2008, there was significantly more lenticel blackening on the *Bacillus subtilis* treated apples than all other treatments.

Evaluation of Non-target Arthropod Impacts

The mite populations were much higher in 2007 than 2008 (Table 5). In 2007, there were no significant differences among the treatments for either European red mites or two-spotted spider mites. In 2008, no significant difference was detected for European red mites among the treatments; however, there was a significant difference in incidence of two-spotted spider mites with the lime sulfur/sulfur treatment having the highest incidence.

In 2007, there were no significant differences among treatments for incidence of spotted tentiform leafminer mines, which also could be apple blotch leafminer mines since the mines look similar, or lyonetia leafminer mines (Table 6). There were also no differences in incidence of the following: green apple aphids, white apple leafhoppers, white apple leafhopper damage, Japanese beetle damage, or potato leafhoppers. However, there were some significant differences in the incidence of potato leafhopper damage in 2007, with the *Bacillus subtilis* treated-trees having the highest percent of leaves with damage, even significantly higher than the non-sprayed, but not statistically different from the potassium bicarbonate treatment. The incidence of insect damage or the insect pest itself, except for potato leafhopper damage, on any of the treated trees was not statistically different from the non-sprayed trees.

In 2008, there were also no significant differences among treatments in the incidence of spotted tentiform/apple blotch leafminer mines or lyonetia leafminer mines; nor were there differences among the treatments in incidence of green apple aphids (Table 6). There was some separation among treatments in incidence of white apple leafhoppers. However, these are not clear-cut separations and there were no statistical differences in incidence of white apple leafhopper damage, although numerically there seemed to be a similar trend, with the *Bacillus subtilis* treatment resulting in the numerically highest pest and damage incidence. There were no significant differences in incidence of potato leafhoppers or their damage or damage from Japanese beetles in 2008. The percent of leaves clean of arthropod pests and their damage was measured in 2008 (Table 7). The highest percentage of clean foliage was in the neem oil treatment, but it was not significantly different than the non-sprayed trees. The lime sulfur/sulfur treatment had the significantly lowest percentage of leaves clean of insects and their damage, even lower than the non-sprayed trees.

There were no differences among the treatments in incidence of the beneficial syrphid fly larvae, chrysopid eggs, cecidomyiid larvae, or lady bug insect populations in either year of the study (Table 8). However, very few beneficials were observed with most incidences at zero and none more than 1%.

There was significantly more plum curculio damage in June 2007 on the fruitlets in the *Bacillus subtilis* treatment than all other treatments, including the non-sprayed (Table 9). There were no statistical differences among the treatments in fruitlets damaged by tarnished plant bug or European apple sawfly. In June 2008, there were no significant differences among treatments in the fruitlet assessment (Table 9). However, the same trend seen in 2007 was observed in 2008, where the *Bacillus subtilis* treatment had the highest incidence of plum curculio damage, but it did not separate out statistically from the other treatments.

By the 2007 harvest, there were no differences among treatments in damage from plum curculio, tarnished plant bug, European apple sawfly, apple maggot fly, or internal and surface Lepidoptera species (Table 10). In 2008, again there were no significant differences among treatments in incidence of tarnished plant bug, European apple sawfly, apple maggot fly, or internal Lepidoptera, but there were some differences in incidence of damage from plum curculio and surface Lepidoptera (Table 10). The treatment effects in 2008 seemed to follow a similar trend as 2007 for incidence of plum curculio damage at harvest, with lime sulfur/sulfur treated trees having the lower percentage of damage, followed by potassium bicarbonate treated trees, however, these were not significantly different from the non-sprayed trees. There were no clear-cut statistical separations in incidence of fruit with surface Lepidoptera damage in 2008. However, the neem oil treatment generally had the lowest incidence of damage, which was similar to what was observed in 2007. There were no significant differences among the treatments for incidence of stink bug damage in 2008 when data were collected, but the non-sprayed treatment had the numerically lowest incidence of damage.

Fruit Quality Evaluation

In 2007, the lime sulfur/sulfur treated fruit had phytotoxic burns observed on 8.8% of the fruit, significantly more than any of the other treatments (Table 11, Appendix E). There was also significantly more russetting on the fruit from the lime sulfur/sulfur treatment. These burns and russetting reduced fruit quality. No fruit had phytotoxic burns in 2008; however, there was significantly more russetting in the neem oil treatment than the other alternatives and the non-sprayed (Table 11). The amount of russetting on neem-treated apples was not significantly different than the lime sulfur/sulfur treated apples.

Overall, in the 2007 harvest, the percent of apples clean of all disease symptoms was numerically highest in the lime sulfur/sulfur treatment, followed by the potassium bicarbonate and neem oil treatments; the *Bacillus subtilis* treatment was not much higher than the non-sprayed treatment, although, there was no significant difference among the treatments (Table 12). In 2008, the lime sulfur/sulfur treatment had 92.1% fruit at harvest clean of disease symptoms, which was significantly more than any other treatments (Table 12). The neem oil treatment did not have as many fruit clean of disease as the lime sulfur/sulfur treatment, but it had significantly more clean than potassium bicarbonate and the other treatments; however, no treatments, except the lime sulfur/sulfur treatment, had percentages of fruit clean of disease symptoms within the commercially acceptable range of 85-90% of disease-free fruit harvested (17).

The neem oil treatment had significantly higher percentage of fruit clean of insect damage than the other alternatives and the non-sprayed treatment in 2007 (Table 13). This was also seen in 2008, where the neem oil treatment had the significantly highest incidence of fruit clean of insect damage.

Overall fruit quality was assessed in 2008 using the USDA fruit quality standards (40, Appendix F). There were no significant differences among the treatments in percent of fruit in the highest US-1 Count grade (Table 14). There were significantly more neem oil treated apples (18.4%) in the US-1 Bag grade than any other treatment, however, this amount is not commercially acceptable (17). There were significantly more lime sulfur/sulfur treated apples culled than the neem oil treatment, but neither treatment was significantly different than the non-sprayed treatment.

DISCUSSION

The incidence of scab was much higher in 2008, possibly because of two factors: (1) there was more overwintering inoculum, as indicated by a “high scab risk” rating in autumn 2007, and (2) there were more potential secondary infections due to the wet summer weather. In each year, whether there was a “high” or “low” risk of apple scab, the lime sulfur/sulfur treatment was the most effective against foliar scab and provided the best management of fruit scab, although levels of scab on the fruit in 2007 were not significantly different than that observed on the potassium bicarbonate and neem oil treatments. In both years, the neem oil and potassium bicarbonate alternatives showed some activity against apple scab, but did not provide acceptable control. Andrews *et.*

al.(2) found that potassium bicarbonate (0.5% w/v) was more effective than a water-only treatment against apple scab, but not as effective as Captan, the standard commercial fungicide treatment. Tamm *et. al.* (37) in a study in Switzerland, showed potassium bicarbonate controlled apple scab as well as a wettable sulfur treatment. Under the conditions of a study conducted in Pennsylvania, a potassium bicarbonate treatment was also comparable to a lime sulfur/sulfur treatment for the management of apple scab in an organic alternative fungicide trial (39). These past studies support that potassium bicarbonate has some fungicidal activity against apple scab, and potassium bicarbonate showed activity against apple scab under Vermont conditions, but was not as effective as the lime sulfur/sulfur treatment.

A literature search of studies examining the effects of neem oil against apple scab produced no results. Moline and Locke. (26) showed neem oil had some fungicidal activity towards select postharvest apple decay fungi such as *Botrytis cinera* (pers.) ex Fr. (gray mold) and *Glomerella cingulata* (Ston.) Spauld. & Schrenk. (bitter rot); but was not effective against *Penicillium expansum* Thom. (blue mold rot). In this Vermont study fruit rots were evaluated at harvest and no significant differences were detected in either year between the neem oil treatment and the other treatments, including the non-sprayed treatment.

The research reported from this Vermont study verifies past research evaluating the efficiency of *Bacillus subtilis* against apple fungal diseases. *Bacillus subtilis* did not provide suitable management of apple scab in a study conducted in Pennsylvania (39). A similar study in Pennsylvania showed a *Bacillus subtilis* treatment provided no acceptable control of flyspeck and sooty blotch in 'Golden Delicious' and 'Cortland' apples (38). However, the *Bacillus subtilis* treatment in a fungicide trial in Massachusetts showed some management of sooty blotch and flyspeck, but not to commercially acceptable levels (5). In addition, a study conducted in North Carolina showed a *Bacillus subtilis* treatment was not significantly different than the non-sprayed check for control of bitter rot and bot rot in apples (35).

The *Bacillus subtilis* treatment seemed to have some adverse, non-target disease and arthropod impacts in Vermont. The *Bacillus subtilis* treatment had significantly more lenticel blackening than all other treatments, including the non-sprayed, in 2008. The treatment also had significantly higher incidence of damage from plum curculio on the fruitlets in June 2007 than all other treatments including the non-sprayed treatment (the same trend was seen in June 2008, but with no statistical difference) and on the fruit at harvest in 2008. The incidence of damage from potato leafhoppers was also significantly higher in August 2007 in the *Bacillus subtilis* treatment. Further research is necessary to provide insight into the reasons for these results.

Apple scab is the main disease to manage in Vermont orchards, but effective management of other fungal diseases is also an important consideration when evaluating alternative fungicides. No alternative fungicide or the standard lime sulfur/sulfur treatment provided any significant activity against foliar rust when compared to the non-sprayed treatment. Lesions counted as cedar apple rust also may have included cedar hawthorn rust lesions, caused by *Gymnosporangium globosum* Farl., because symptoms are nearly identical and no determination between the rust diseases were made during the assessments (16). The fact that none of the treatments managed foliar rust is of concern since high levels of infection can cause premature defoliation. There were no significant differences among the treatments for incidence of summer diseases including flyspeck, sooty blotch, and fruit rots in 2007. In 2008, there were much higher percentages of flyspeck, possibly because of the eight more days of wetness occurring later in the 2008 growing season. The neem oil and lime sulfur/sulfur treatments had significantly lower incidences of flyspeck than all other treatments in 2008.

Overall, none of the alternatives managed disease, including apple scab, as well as the standard lime sulfur/sulfur fungicide program. In 2008, the neem oil treatment performed better than the other alternatives in management of fruit and foliar scab and against flyspeck. In addition, the neem oil treatment had a significantly higher percentage of fruit clean of all disease symptoms than the other alternatives in 2008. However, both the lime sulfur/sulfur and neem oil treatments had disadvantages such as phytotoxic burning and russetting of the fruit. The burns observed in 2007 on the lime sulfur/sulfur treated fruit may have been caused by the high rate (2%) of lime sulfur applied 7 June 2007 when the following day temperatures reached 89.7 F (32.1 C), possibly causing the chemical to burn the fruit in the unseasonably high temperatures. However, similar hot temperatures followed lime sulfur applications in 2008, and no phytotoxic effects resulted, which suggests it was a combination of conditions that may have caused the burning, such as poor drying conditions and high humidity. Past research in New York has found summer sprays of lime sulfur to cause injury to both fruit and foliage (11). A reduced rate of lime sulfur or a sulfur application could have potentially avoided the phytotoxicity. However, these options may not have resulted in similar disease management.

Another negative impact of the neem oil treatment was that the trees had significantly more necrotic leaf spots than all other treatments by August 2007 and 2008. This apparent phytotoxic effect is potentially due to the oil based formulation of neem oil. Agnello, Reissig, and Harris (1) found horticultural oils, applied for mite control under conditions of high temperature and moisture stress, caused foliar lesions mainly in the portions of the canopy where the spray had dried unevenly or had accumulated. The incidence and severity of the lesions increased when higher concentrations of oil were applied. It is recommended for tree fruit to avoid applying oil in high concentrations, to water-stressed plants, and to very young foliage to reduce phytotoxic twig injury and leaf burn (15). In addition, oil has been found to cause dark green to purplish discoloration on leaf margins, especially when drying conditions were poor and oil remained on the tissue for extended periods of time (42).

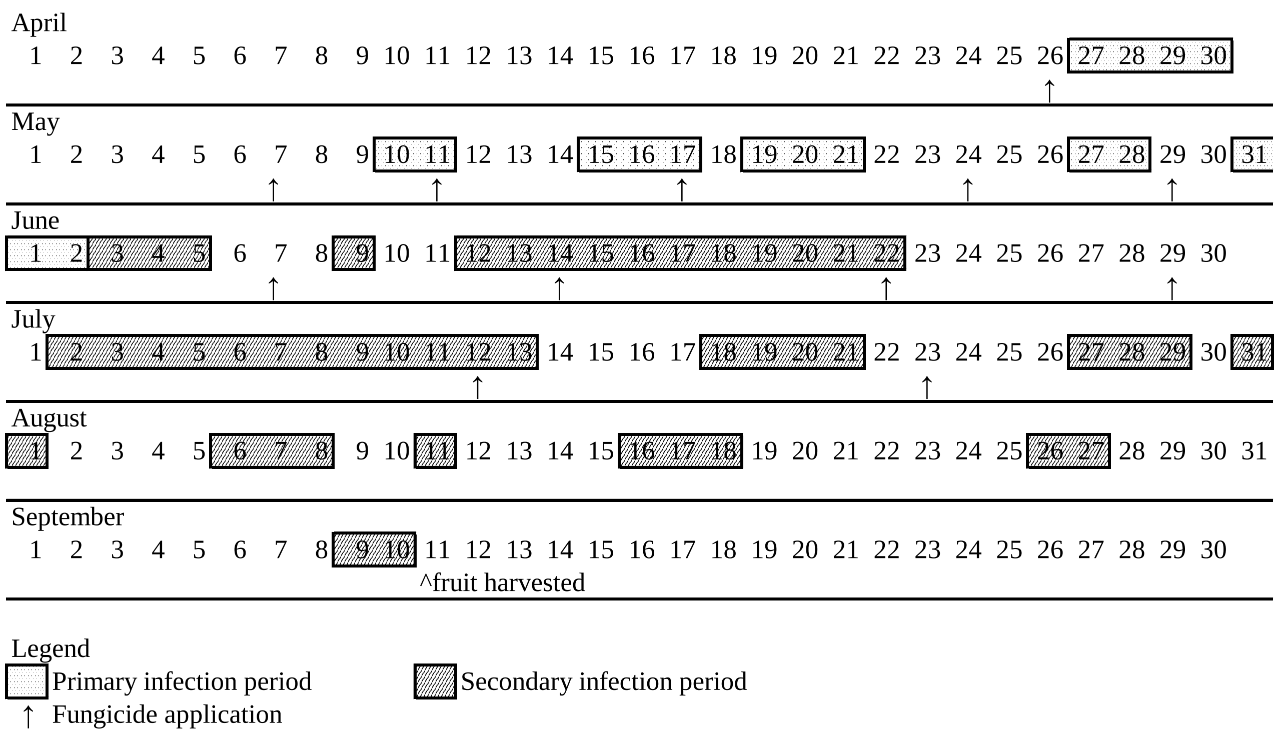
On the positive side of using neem oil, the neem oil treatment had significantly more fruit clean of insect damage than the other alternatives and the non-sprayed treatment in 2007, and more than all treatments in 2008. This can be attributed to the insecticidal properties that neem oil has. Neem oil (Trilogy®) is marketed as a fungicide/insecticide/miticide so it was expected to suppress insects. Overall, it is assumed the percentages of clean fruit were higher in 2007 because additional insecticide applications of *Bacillus thuringiensis* (Dipel® DF) and spinosad (Entrust®) were used, whereas in 2008, only kaolin clay (Surround® WP) was applied. However, with no other insecticides used in 2008, the insect management from the neem oil treatment was not at a commercially-acceptable level.

The assessment of mites in this study supported the evidence that lime sulfur- and sulfur-based fungicides can have adverse affects on mite management. Although no significant differences were detected in the European red mite population among the treatments, the two-spotted spider mites were numerically higher in the lime sulfur/sulfur treatment than all the other treatments in 2007, and significantly highest in 2008. However, predatory mite populations were not assessed in this experiment and therefore, no assumptions can be made as to why there were differences in two-spotted spider mite population incidences. Because of low levels of other beneficial organisms (i.e., lady bug beetles, cecidomyiid larvae, syrphid fly larvae, and chrysopid eggs), no assumptions can be made on the potential impacts of lime sulfur/sulfur or the alternative fungicides on these beneficial populations.

The overall quality of the fruit, assessed with the USDA fruit grades, was not at levels that would be accepted in standard non-organic commercial orchards, although organic orchardists may tolerate a lesser fruit quality in a niche market (17). The majority (59-77%) of the fruit harvested from all the treatments in this Vermont study was of no value and placed in the cull grade, indicating the need for improvement in disease and arthropod management to produce acceptable quality apples.

In summary, this research shows that potassium bicarbonate, *Bacillus subtilis*, and neem oil do not offer substantial advantages over the standard lime sulfur/sulfur fungicide program in organic apple production in Vermont. Other alternative fungicides waiting for EPA registration and organic approval may provide more possibilities in the future.

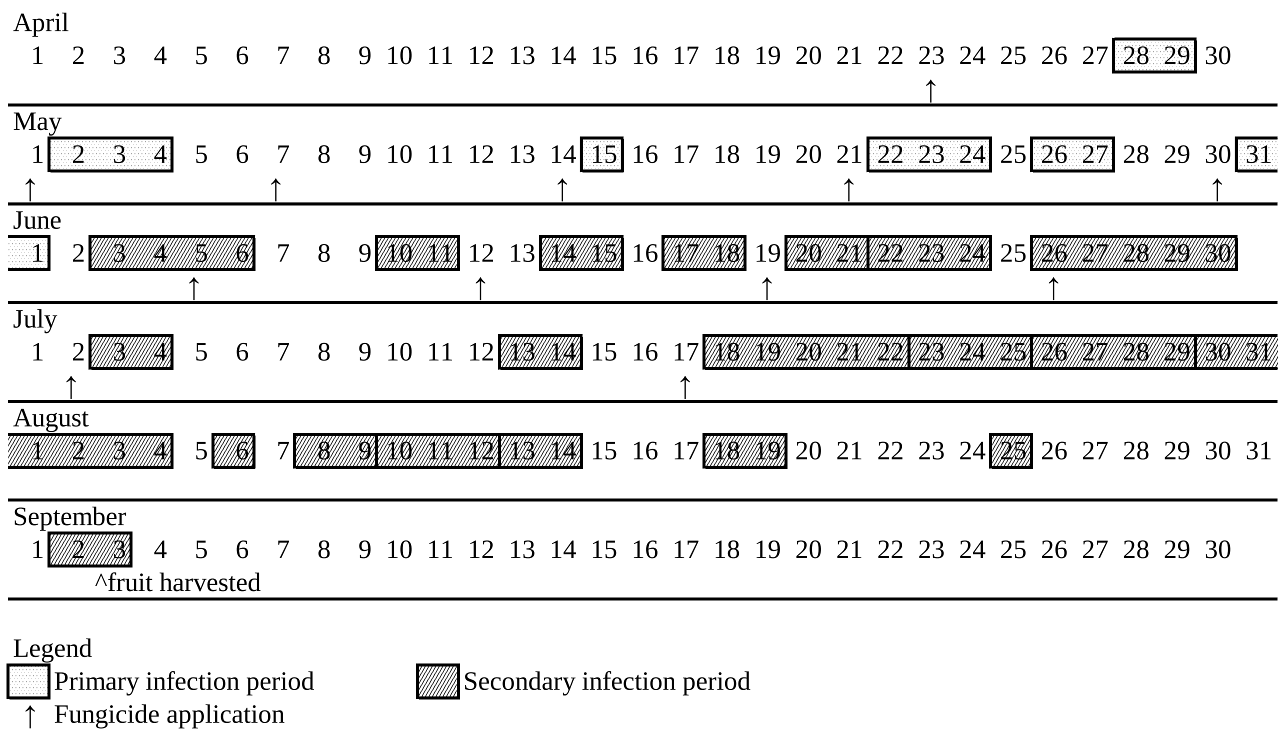
Figure 1. Apple scab infection periods,
1. Apple scab infection periods, 2007.[z]
scab infection periods, 2007.[z] UVM



[z]Infection periods were calculated using formulas from Reardon, J.E., Berkett, L.P., Garcia, M.E., Gotlieb, A., Ashikaga, T., and Badger, G. 2005. Field evaluation of the new sequential sampling technique for determining apple scab "risk". Plant Disease 89(3):228-236, which used the revised Mills table [MacHardy, W.E. and Gadoury, D.M. 1989. A revision of Mill's criteria for predicting apple scab infection periods. Phytopathology 79:304-310], as amended by Stensvand, A., Gardoury, D.M., Amundsen, T., Semb, L., and Seem, R.C. 1997. Ascospore release and infection of apple leaves by conidia and ascospores of *Venturia inaequalis* at low temperatures. Phytopathology 87:1046-1053. Since a portion of mature ascospores are released during night time hours, rain events that started at night were not discounted.

Figure 2. Apple scab infection periods, 2008.[z] UVM

2. Apple scab infection periods, 2008.[z] UVM



[z]Infection periods were calculated using formulas from Reardon, J.E., Berkett, L.P., Garcia, M.E., Gotlieb, A., Ashikaga, T., and Badger, G. 2005. Field evaluation of the new sequential sampling technique for determining apple scab "risk". Plant Disease 89(3):228-236, which used the revised Mills table [MacHardy, W.E. and Gadoury, D.M. 1989. A revision of Mill's criteria for predicting apple scab infection periods. Phytopathology 79:304-310], as amended by Stensvand, A., Gardoury, D.M., Amundsen, T., Semb, L., and Seem, R.C. 1997. Ascospore release and infection of apple leaves by conidia and ascospores of *Venturia inaequalis* at low temperatures. Phytopathology 87:1046-1053. Since a portion of mature ascospores are released during night time hours, rain events that started at night were not discounted.

Table 1. Apple scab on

1. Apple scab on 'Empire' trees,

Apple scab on 'Empire' trees

2007

Treatment and rate/A (rate/ha)	Application timing[z]	Percent scab incidence: Cluster leaves[x] 18-20 Jun	Percent scab incidence: Terminal leaves[w] 18-20 Jun	Percent scab incidence: Terminal leaves[w] 22-24 Aug	Percent scab incidence: Fruit[v] 10 Sep	Scab severity[t]: Cluster leaves 18-20 Jun	Scab severity[t]: Terminal leaves 18-20 Jun	Scab severity[t]: Terminal leaves 22-24 Aug
potassium bicarbonate 3.75 lb (4.2 kg)	1-12………..	0.1[u]	0.4	12.3 b	11.2 bc	0.0	0.1	3.4 ab
Bacillus subtilis 3 lb (3.4 kg)………	1-12………..	0.3	1.5	17.0 b	22.4 ab	0.0	0.2	3.0 ab
neem oil 2 gal (18.7 L)………..……	1-12………..	0.0	1.2	9.9 b	11.6 bc	0.0	0.2	2.0 bc
sulfur 15 lb (16.8 kg)	1, 5, 8, 10-12							
lime sulfur 2 gal (18.7 L)………..	2-4, 6-7, 9….	0.0	0.7	1.1 c	0.4 c	0.0	0.1	0.3 c
non-sprayed…………………………	1-12………..	0.3	2.4	29.2 a	25.2 a	0.0	0.4	4.9 a

2008

Treatment and rate/A (rate/ha)	Application timing[y]	Percent scab incidence: Cluster leaves[x] 16-18 Jun	Percent scab incidence: Terminal leaves[w] 16-18 Jun	Percent scab incidence: Terminal leaves[w] 12-15 Aug	Percent scab incidence: Fruit[v] 3 Sep	Scab severity[t]: Cluster leaves 16-18 Jun	Scab severity[t]: Terminal leaves 16-18 Jun	Scab severity[t]: Terminal leaves 12-15 Aug
potassium bicarbonate 3.75 lb (4.2 kg)	1-12………..	2.1 c[u]	13.6 b	41.5 b	45.8 b	0.4 cd	1.2 a	4.4 b
Bacillus subtilis 3 lb (3.4 kg)………	1-12………..	5.2 bc	16.9 ab	54.5 a	62.4 a	0.5 bc	1.5 a	7.9 a
neem oil 2 gal (18.7 L)………..……	1-12………..	7.6 ab	9.9 bc	28.7 c	32.4 c	1.0 a	1.1 a	3.3 bc
sulfur 15 lb (16.8 kg)	8-12………..							
lime sulfur 2 gal (18.7 L)………..	1-7………….	1.1 c	4.3 c	8.9 d	2.9 d	0.1 d	0.6 b	0.7 c
non-sprayed…………………………	1-12………..	10.9 a	21.9 a	55.7 a	64.0 a	0.8 ab	1.4 a	7.7 a

[z]Application timings: 1 = (Green-tip) 26 Apr; 2 = (TC) 7 May; 3 = (Pink) 11 May; 4 = (Pink) 17 May; 5 = (Pink-Bloom) 24 May; 6 = (Petal fall) 29 May; 7 = 7 Jun; 8 = 14 Jun; 9 = 22 Jun; 10 = 29 Jun; 11 = 12 Jul; 12 = 23 Jul.

[y]Application timings: 1 = (Green-tip) 23 Apr; 2 = (TC) 1 May; 3 = (Pink) 7 May; 4 = (Bloom) 14 May; 5 = (Petal fall) 21 May; 6 = 30 May; 7 = 5 Jun; 8 = 12 Jun; 9 = 19 Jun; 10 = 26 Jun; 11 = 2 Jul; 12 = 17 Jul.

[x]Assessment of 10 clusters per tree on 5 single-tree replicates per treatment

[w]Assessment of 10 terminals per tree on 5 single-tree replicates per treatment

[v]Assessment of 50 fruit per tree on 5 single-tree replicates per treatment

[u]Numbers within columns followed by the same letter do not differ significantly, Fisher's Protected LSD, $P \leq 0.05$; columns with no letters following the numbers do not have a significant F-value, Analysis of Variance, $P \leq 0.05$ or Kruskal-Wallis, $P \leq 0.05$, when data normality could not be rescued with data transformation because of zeros in data.

[t]Mean number of lesions per infected leaf

Table 2. Cedar apple
2. Cedar apple rust on
apple rust on 'Empire'

2007

Treatment and rate/A (rate/ha)	Application timing[z]	Percent cedar apple rust incidence: Cluster leaves[x] 18-20 Jun	Terminal leaves[w] 18-20 Jun	Terminal leaves[w] 22-24 Aug	Fruit[v] 10 Sep	Cedar apple rust severity[t]: Cluster leaves 18-20 Jun	Terminal leaves 18-20 Jun	Terminal leaves 22-24 Aug
potassium bicarbonate 3.75 lb (4.2 kg)	1-12………..	0.0[u]	8.8 a	16.5	0.0	0.0	0.8 a	1.4
Bacillus subtilis 3 lb (3.4 kg)………	1-12………..	0.0	3.5 bc	13.8	0.0	0.0	0.6 ab	1.3
neem oil 2 gal (18.7 L)………..……	1-12………..	0.0	1.5 c	10.8	0.0	0.0	0.2 c	1.1
sulfur 15 lb (16.8 kg)	1, 5, 8, 10-12							
lime sulfur 2 gal (18.7 L)………..	2-4, 6-7, 9….	0.1	4.0 bc	12.6	0.0	0.0	0.4 bc	1.3
non-sprayed…………………………	1-12………..	0.0	4.8 b	17.3	0.0	0.0	0.6 ab	1.4

2008

Treatment and rate/A (rate/ha)	Application timing[y]	Percent cedar apple rust incidence: Cluster leaves[x] 16-18 Jun	Terminal leaves[w] 16-18 Jun	Terminal leaves[w] 12-15 Aug	Fruit[v] 3 Sep	Cedar apple rust severity[t]: Cluster leaves 16-18 Jun	Terminal leaves 16-18 Jun	Terminal leaves 12-15 Aug
potassium bicarbonate 3.75 lb (4.2 kg)	1-12………..	0.0[u]	3.3	6.8	0.0	0.0	0.4	0.7
Bacillus subtilis 3 lb (3.4 kg)………	1-12………..	0.0	4.0	7.8	0.0	0.0	0.7	1.1
neem oil 2 gal (18.7 L)………..……	1-12………..	0.0	2.0	3.8	0.0	0.0	0.3	0.7
sulfur 15 lb (16.8 kg)	8-12………..							
lime sulfur 2 gal (18.7 L)………..	1-7………….	0.0	3.1	2.4	0.0	0.2	0.5	0.5
non-sprayed…………………………	1-12………..	0.0	2.9	5.7	0.0	0.0	0.3	0.8

[z]Application timings: 1 = (Green-tip) 26 Apr; 2 = (TC) 7 May; 3 = (Pink) 11 May; 4 = (Pink) 17 May; 5 = (Pink-Bloom) 24 May; 6 = (Petal fall) 29 May; 7 = 7 Jun; 8 = 14 Jun; 9 = 22 Jun; 10 = 29 Jun; 11 = 12 Jul; 12 = 23 Jul.

[y]Application timings: 1 = (Green-tip) 23 Apr; 2 = (TC) 1 May; 3 = (Pink) 7 May; 4 = (Bloom) 14 May; 5 = (Petal fall) 21 May; 6 = 30 May; 7 = 5 Jun; 8 = 12 Jun; 9 = 19 Jun; 10 = 26 Jun; 11 = 2 Jul; 12 = 17 Jul.

[x]Assessment of 10 clusters per tree on 5 single-tree replicates per treatment

[w]Assessment of 10 terminals per tree on 5 single-tree replicates per treatment

[v]Assessment of 50 fruit per tree on 5 single-tree replicates per treatment

[u]Numbers within columns followed by the same letter do not differ significantly, Fisher's Protected LSD, $P \leq 0.05$; columns with no letters following the numbers do not have a significant F-value, Analysis of Variance, $P \leq 0.05$ or Kruskal-Wallis, $P \leq 0.05$, when data normality could not be rescued with data transformation because of zeros in data.

[t]Mean number of lesions per infected leaf

Table 3. Necrotic leaf spots
3. Necrotic leaf spots on
Necrotic leaf spots on

2007

Treatment and rate/A (rate/ha)	Application timing[z]	Percent necrotic leaf spot incidence: Cluster leaves[x] 18-20 Jun	Percent necrotic leaf spot incidence: Terminal leaves[w] 18-20 Jun	Percent necrotic leaf spot incidence: Terminal leaves[w] 22-24 Aug	Necrotic leaf spot severity[u]: Cluster leaves 18-20 Jun	Necrotic leaf spot severity[u]: Terminal leaves 18-20 Jun	Necrotic leaf spot severity[u]: Terminal leaves 22-24 Aug
potassium bicarbonate 3.75 lb (4.2 kg)	1-12………..	0.7 b[v]	8.4	35.3 a	0.1 b	1.1 a	5.8 a
Bacillus subtilis 3 lb (3.4 kg)………	1-12………..	0.5 b	9.3	22.4 b	0.1 b	1.0 a	1.3 c
neem oil 2 gal (18.7 L)………..……	1-12………..	6.1 a	10.1	36.7 a	0.9 a	1.0 a	2.9 b
sulfur 15 lb (16.8 kg)	1, 5, 8, 10-12						
lime sulfur 2 gal (18.7 L)………..	2-4, 6-7, 9….	0.9 b	5.6	19.5 b	0.1 b	0.5 b	2.7 bc
non-sprayed…………………………	1-12………..	1.2 b	10.9	16.9 b	0.2 b	1.2 a	1.3 c

2008

Treatment and rate/A (rate/ha)	Application timing[y]	Percent necrotic leaf spot incidence: Cluster leaves[x] 16-18 Jun	Percent necrotic leaf spot incidence: Terminal leaves[w] 16-18 Jun	Percent necrotic leaf spot incidence: Terminal leaves[w] 12-15 Aug	Necrotic leaf spot severity[u]: Cluster leaves 16-18 Jun	Necrotic leaf spot severity[u]: Terminal leaves 16-18 Jun	Necrotic leaf spot severity[u]: Terminal leaves 12-15 Aug
potassium bicarbonate 3.75 lb (4.2 kg)	1-12………..	0.3 b[v]	1.6 bc	19.6 b	0.0 b	0.3 b	2.0 b
Bacillus subtilis 3 lb (3.4 kg)………	1-12………..	0.4 b	2.4 bc	15.8 bc	0.1 b	0.4 ab	1.4 c
neem oil 2 gal (18.7 L)………..……	1-12………..	2.1 a	6.3 a	32.6 a	0.4 a	0.7 a	2.7 a
sulfur 15 lb (16.8 kg)	8-12………..						
lime sulfur 2 gal (18.7 L)………..	1-7………….	0.5 b	0.8 c	11.9 c	0.1 b	0.2 b	1.6 bc
non-sprayed…………………………	1-12………..	1.2 ab	3.6 ab	18.1 b	0.1 b	0.7 a	1.4 c

[z]Application timings: 1 = (Green-tip) 26 Apr; 2 = (TC) 7 May; 3 = (Pink) 11 May; 4 = (Pink) 17 May; 5 = (Pink-Bloom) 24 May; 6 = (Petal fall) 29 May; 7 = 7 Jun; 8 = 14 Jun; 9 = 22 Jun; 10 = 29 Jun; 11 = 12 Jul; 12 = 23 Jul.

[y]Application timings: 1 = (Green-tip) 23 Apr; 2 = (TC) 1 May; 3 = (Pink) 7 May; 4 = (Bloom) 14 May; 5 = (Petal fall) 21 May; 6 = 30 May; 7 = 5 Jun; 8 = 12 Jun; 9 = 19 Jun; 10 = 26 Jun; 11 = 2 Jul; 12 = 17 Jul.

[x]Assessment of 10 clusters per tree on 5 single-tree replicates per treatment

[w]Assessment of 10 terminals per tree on 5 single-tree replicates per treatment

[v]Numbers within columns followed by the same letter do not differ significantly, Fisher's Protected LSD, $P \leq 0.05$; columns with no letters following the numbers do not have a significant F-value, Analysis of Variance, $P \leq 0.05$.

[u]Mean number of lesions per infected leaf

Table 4. Disease incidence on

4. Disease incidence on

Disease incidence on 'Empire'

2007

Treatment and rate/A (rate/ha)	Application timing[z]	Percent disease incidence on fruit[x] 10 Sep 2007: Sooty blotch	Flyspeck	Fruit rots	Lenticel blackening
potassium bicarbonate 3.75 lb (4.2 kg)	1-12………..	0.0[w]	1.6	6.4	0.0
Bacillus subtilis 3 lb (3.4 kg)………	1-12………..	0.0	2.8	4.4	1.6
neem oil 2 gal (18.7 L)……….…….	1-12………..	0.0	0.0	6.5	1.2
sulfur 15 lb (16.8 kg)	1, 5, 8, 10-12				
lime sulfur 2 gal (18.7 L)………..	2-4, 6-7, 9….	0.0	0.0	11.2	4.8
non-sprayed…………………………	1-12………..	0.0	1.2	9.2	0.0

2008

Treatment and rate/A (rate/ha)	Application timing[y]	Percent incidence on fruit[x] 3 Sep 2008: Sooty blotch	Flyspeck	Fruit rots	Lenticel blackening
potassium bicarbonate 3.75 lb (4.2 kg)	1-12………..	0.0[w]	39.4 a	7.7	6.1 b
Bacillus subtilis 3 lb (3.4 kg)………	1-12………..	0.0	34.8 ab	6.4	12.4 a
neem oil 2 gal (18.7 L)……….…….	1-12………..	0.0	5.2 c	4.4	5.2 bc
sulfur 15 lb (16.8 kg)	8-12………..				
lime sulfur 2 gal (18.7 L)………..	1-7…………	0.0	0.5 c	4.5	0.0 c
non-sprayed…………………………	1-12………..	0.0	24.8 b	6.8	3.6 bc

[z]Application timings: 1 = (Green-tip) 26 Apr; 2 = (TC) 7 May; 3 = (Pink) 11 May; 4 = (Pink) 17 May; 5 = (Pink-Bloom) 24 May; 6 = (Petal fall) 29 May; 7 = 7 Jun; 8 = 14 Jun; 9 = 22 Jun; 10 = 29 Jun; 11 = 12 Jul; 12 = 23 Jul.

[y]Application timings: 1 = (Green-tip) 23 Apr; 2 = (TC) 1 May; 3 = (Pink) 7 May; 4 = (Bloom) 14 May; 5 = (Petal fall) 21 May; 6 = 30 May; 7 = 5 Jun; 8 = 12 Jun; 9 = 19 Jun; 10 = 26 Jun; 11 = 2 Jul; 12 = 17 Jul.

[x]Assessment of 50 fruit per tree on 5 single-tree replicates per treatment

[w]Numbers within columns followed by the same letter do not differ significantly, Fisher's Protected LSD, $P \leq 0.05$; columns with no letters following the numbers do not have a significant F-value, Analysis of Variance, $P \leq 0.05$ or Kruskal-Wallis, $P \leq 0.05$, when data normality could not be rescued with data transformation because of zeros in data.

Table 5. Incidence of mites on 'Empire'

5. Incidence of mites on 'Empire'

Incidence of mites on 'Empire' terminal

2007

Treatment and rate/A (rate/ha)	Application timing[z]	Percent mite incidence, Terminal leaves, 22-24 Aug[x]: European red mites	Two-spotted spider mites
potassium bicarbonate 3.75 lb (4.2 kg)	1-12………..	45.3[w]	36.7
Bacillus subtilis 3 lb (3.4 kg)………	1-12………..	70.5	33.3
neem oil 2 gal (18.7 L)………...……	1-12………..	60.9	31.1
sulfur 15 lb (16.8 kg)	1, 5, 8, 10-12		
lime sulfur 2 gal (18.7 L)………..	2-4, 6-7, 9….	48.2	63.4
non-sprayed…………………………	1-12………..	65.9	34.3

2008

Treatment and rate/A (rate/ha)	Application timing[y]	Percent mite incidence, Terminal leaves, 12-15 Aug[x]: European red mites	Two-spotted spider mites
potassium bicarbonate 3.75 lb (4.2 kg)	1-12………..	4.8[v]	3.6 b
Bacillus subtilis 3 lb (3.4 kg)………	1-12………..	2.9	1.0 bc
neem oil 2 gal (18.7 L)………...……	1-12………..	3.2	0.0 c
sulfur 15 lb (16.8 kg)	8-12………..		
lime sulfur 2 gal (18.7 L)………..	1-7………….	3.9	8.7 a
non-sprayed…………………………	1-12………..	7.1	0.8 b

[z]Application timings: 1 = (Green-tip) 26 Apr; 2 = (TC) 7 May; 3 = (Pink) 11 May; 4 = (Pink) 17 May; 5 = (Pink-Bloom) 24 May; 6 = (Petal fall) 29 May; 7 = 7 Jun; 8 = 14 Jun; 9 = 22 Jun; 10 = 29 Jun; 11 = 12 Jul; 12 = 23 Jul.

[y]Application timings: 1 = (Green-tip) 23 Apr; 2 = (TC) 1 May; 3 = (Pink) 7 May; 4 = (Bloom) 14 May; 5 = (Petal fall) 21 May; 6 = 30 May; 7 = 5 Jun; 8 = 12 Jun; 9 = 19 Jun; 10 = 26 Jun; 11 = 2 Jul; 12 = 17 Jul.

[x]Assessment of 10 terminals per tree on 5 single-tree replicates per treatment

[w]Columns with no letters following the numbers do not have a significant F-value, Analysis of Variance, $P \leq 0.05$ or Kruskal-Wallis, $P \leq 0.05$, when data normality could not be rescued with data transformation because of zeros in data.

[v]Numbers within columns followed by the same letter do not differ significantly, Kruskal-Wallis pairwise comparison, $P \leq 0.05$; columns with no letters following the numbers do not have a significant F-value, Analysis of Variance, $P \leq 0.05$ or Kruskal-Wallis, $P \leq 0.05$, when data normality could not be rescued with data transformation because of zeros in data.

Table 6. Insect pest incidence on
6. Insect pest incidence on 'Empire'
Insect pest incidence on 'Empire'

2007

Treatment and rate/A (rate/ha)	Application timing[z]	ST/AB[w] leafminer mines	Lyonetia mines	Green apple aphids	White apple leafhopper	White apple leafhopper damage	Potato leafhopper	Potato leafhopper damage	Japanese beetle damage
		Percent insect pest incidence – Terminal leaves, 22-24 Aug 2007[x]							
potassium bicarbonate 3.75 lb (4.2 kg)	1-12………..	24.6[v]	0.0	0.4	0.9	0.0	2.8	1.8 ab	0.1
Bacillus subtilis 3 lb (3.4 kg)………	1-12………..	32.3	0.1	0.9	0.7	0.0	3.4	3.0 a	0.3
neem oil 2 gal (18.7 L)………..……	1-12………..	20.9	0.2	1.7	0.6	0.0	1.6	1.1 b	0.0
sulfur 15 lb (16.8 kg)	1, 5, 8, 10-12								
lime sulfur 2 gal (18.7 L)………..	2-4, 6-7, 9….	32.8	0.0	0.3	0.3	0.0	0.9	0.6 b	0.2
non-sprayed…………………………	1-12………..	32.6	0.0	0.5	0.9	0.0	3.3	1.2 b	0.0

2008

Treatment and rate/A (rate/ha)	Application timing[y]	ST/AB leafminer mines	Lyonetia mines	Green apple aphids	White apple leafhopper	White apple leafhopper damage	Potato leafhopper	Potato leafhopper damage	Japanese beetle damage
		Percent insect pest incidence – Terminal leaves, 12-15 Aug 2008[x]							
potassium bicarbonate 3.75 lb (4.2 kg)	1-12………..	6.0[u]	1.5	0.1	1.8 ab	5.6	2.8	7.8	0.1
Bacillus subtilis 3 lb (3.4 kg)………	1-12………..	5.7	0.5	0.1	2.7 a	8.0	1.3	6.4	0.1
neem oil 2 gal (18.7 L)………..……	1-12………..	4.5	1.4	0.0	1.3 abc	3.1	2.0	10.0	0.3
sulfur 15 lb (16.8 kg)	8-12………..								
lime sulfur 2 gal (18.7 L)………..	1-7………….	4.3	0.8	0.8	0.6 bc	1.6	3.4	4.7	0.5
non-sprayed…………………………	1-12………..	6.5	0.7	0.2	0.3 c	3.0	2.4	9.2	0.0

[z]Application timings: 1 = (Green-tip) 26 Apr; 2 = (TC) 7 May; 3 = (Pink) 11 May; 4 = (Pink) 17 May; 5 = (Pink-Bloom) 24 May; 6 = (Petal fall) 29 May; 7 = 7 Jun; 8 = 14 Jun; 9 = 22 Jun; 10 = 29 Jun; 11 = 12 Jul; 12 = 23 Jul.

[y]Application timings: 1 = (Green-tip) 23 Apr; 2 = (TC) 1 May; 3 = (Pink) 7 May; 4 = (Bloom) 14 May; 5 = (Petal fall) 21 May; 6 = 30 May; 7 = 5 Jun; 8 = 12 Jun; 9 = 19 Jun; 10 = 26 Jun; 11 = 2 Jul; 12 = 17 Jul.

[x]Assessment of 10 terminals per tree on 5 single-tree replicates per treatment

[w]ST/AB = spotted tentiform or apple blotch leafminer (mines appear similar and were not distinguished)

[v]Numbers within columns followed by the same letter do not differ significantly, Fisher's Protected LSD, $P \leq 0.05$; columns with no letters following the numbers do not have a significant F-value, Analysis of Variance, $P \leq 0.05$ or Kruskal-Wallis, $P \leq 0.05$, when data normality could not be rescued with data transformation because of zeros in data.

[u]Numbers within columns followed by the same letter do not differ significantly, Kruskal-Wallis pairwise comparison, $P \leq 0.05$; columns with no letters following the numbers do not have a significant F-value, Analysis of Variance, $P \leq 0.05$ or Kruskal-Wallis, $P \leq 0.05$, when data normality could not be rescued with data transformation because of zeros in data.

Table 7. Incidence of foliage clean of arthropod

7. Incidence of foliage clean of arthropod pests and

Incidence of foliage clean of arthropod pests and

		Percent insect pest incidence
		Terminal leaves, 12-15 Aug[y]
Treatment and rate/A (rate/ha)	Application timing[z]	Clean of pest and damage
potassium bicarbonate 3.75 lb (4.2 kg)	1-12………..	50.7 b[x]
Bacillus subtilis 3 lb (3.4 kg)………	1-12………..	51.1 ab
neem oil 2 gal (18.7 L)………..……	1-12………..	60.3 a
sulfur 15 lb (16.8 kg)	8-12………..	
lime sulfur 2 gal (18.7 L)………..	1-7………….	35.1 c
non-sprayed…………………………	1-12………..	55.8 ab

[z]Application timings: 1 = (Green-tip) 23 Apr; 2 = (TC) 1 May; 3 = (Pink) 7 May; 4 = (Bloom) 14 May; 5 = (Petal fall) 21 May; 6 = 30 May; 7 = 5 Jun; 8 = 12 Jun; 9 = 19 Jun; 10 = 26 Jun; 11 = 2 Jul; 12 = 17 Jul.

[y]Assessment of 10 terminals per tree on 5 single-tree replicates per treatment

[x]Numbers within columns followed by the same letter do not differ significantly, Fisher's Protected LSD, $P \leq 0.05$.

Table 8. Beneficial insect incidence on

8. Beneficial insect incidence on 'Empire'

Beneficial insect incidence on 'Empire'

2007

Treatment and rate/A (rate/ha)	Application timing[z]	Percent beneficial insect incidence, Terminal leaves, 22-24 Aug[x]: Lady beetle adult	Lady beetle larvae	Cecidomyiid larvae	Syrphid fly larvae	Chrysopid egg
potassium bicarbonate 3.75 lb (4.2 kg)	1-12………..	0.0[w]	0.0	0.0	0.0	0.0
Bacillus subtilis 3 lb (3.4 kg)………	1-12………..	0.0	0.2	0.0	0.0	0.1
neem oil 2 gal (18.7 L)………..……	1-12………..	0.0	0.0	0.0	0.0	0.0
sulfur 15 lb (16.8 kg)	1, 5, 8, 10-12					
lime sulfur 2 gal (18.7 L)………..	2-4, 6-7, 9….	0.0	0.0	0.0	0.0	0.0
non-sprayed…………………………	1-12………..	0.1	0.1	0.0	0.0	0.0

2008

Treatment and rate/A (rate/ha)	Application timing[y]	Percent beneficial insect incidence, Terminal leaves, 12-15 Aug[x]: Lady beetle adult	Lady beetle larvae	Cecidomyiid larvae	Syrphid fly larvae	Chrysopid egg
potassium bicarbonate 3.75 lb (4.2 kg)	1-12………..	0.0[w]	0.0	0.2	0.0	0.0
Bacillus subtilis 3 lb (3.4 kg)………	1-12………..	0.0	0.0	0.0	0.0	0.0
neem oil 2 gal (18.7 L)………..……	1-12………..	0.0	0.0	0.0	0.0	0.0
sulfur 15 lb (16.8 kg)	8-12………..					
lime sulfur 2 gal (18.7 L)………..	1-7………….	0.0	0.0	0.6	0.0	0.2
non-sprayed…………………………	1-12………..	0.0	0.0	0.1	0.0	0.1

[z]Application timings: 1 = (Green-tip) 26 Apr; 2 = (TC) 7 May; 3 = (Pink) 11 May; 4 = (Pink) 17 May; 5 = (Pink-Bloom) 24 May; 6 = (Petal fall) 29 May; 7 = 7 Jun; 8 = 14 Jun; 9 = 22 Jun; 10 = 29 Jun; 11 = 12 Jul; 12 = 23 Jul.

[y]Application timings: 1 = (Green-tip) 23 Apr; 2 = (TC) 1 May; 3 = (Pink) 7 May; 4 = (Bloom) 14 May; 5 = (Petal fall) 21 May; 6 = 30 May; 7 = 5 Jun; 8 = 12 Jun; 9 = 19 Jun; 10 = 26 Jun; 11 = 2 Jul; 12 = 17 Jul.

[x]Assessment of 10 terminals per tree on 5 single-tree replicates per treatment

[w]Numbers within columns followed by the same letter do not differ significantly, Fisher's Protected LSD, $P \leq 0.05$; columns with no letters following the numbers do not have a significant F-value, Analysis of Variance, $P \leq 0.05$ or Kruskal-Wallis, $P \leq 0.05$, when data normality could not be rescued with data transformation because of zeros in data.

Table 9. Incidence of insect damage on

e 9. Incidence of insect damage on 'Empire'

2007

Treatment and rate/A (rate/ha)	Application timing[z]	Percent insect pest incidence, Fruit, 18-20 Jun[x]: Plum curculio	Tarnished plant bug	European Apple Sawfly
potassium bicarbonate 3.75 lb (4.2 kg)	1-12………..	2.0 b[w]	11.5	1.5
Bacillus subtilis 3 lb (3.4 kg)………	1-12………..	9.2 a	12.7	4.3
neem oil 2 gal (18.7 L)………..……	1-12………..	1.0 b	8.0	1.7
sulfur 15 lb (16.8 kg)	1, 5, 8, 10-12			
lime sulfur 2 gal (18.7 L)………..	2-4, 6-7, 9….	0.0 b	2.2	3.3
non-sprayed…………………………	1-12………..	2.0 b	11.2	9.2

2008

Treatment and rate/A (rate/ha)	Application timing[y]	Percent insect pest incidence, Fruit, 16-18 Jun[x]: Plum curculio	Tarnished plant bug	European Apple Sawfly
potassium bicarbonate 3.75 lb (4.2 kg)	1-12………..	6.0[w]	15.2	12.5
Bacillus subtilis 3 lb (3.4 kg)………	1-12………..	23.3	8.0	16.0
neem oil 2 gal (18.7 L)………..……	1-12………..	10.0	3.0	4.7
sulfur 15 lb (16.8 kg)	8-12………..			
lime sulfur 2 gal (18.7 L)………..	1-7…………	4.7	2.7	6.7
non-sprayed…………………………	1-12………..	13.0	15.7	8.2

[z]Application timings: 1 = (Green-tip) 26 Apr; 2 = (TC) 7 May; 3 = (Pink) 11 May; 4 = (Pink) 17 May; 5 = (Pink-Bloom) 24 May; 6 = (Petal fall) 29 May; 7 = 7 Jun; 8 = 14 Jun; 9 = 22 Jun; 10 = 29 Jun; 11 = 12 Jul; 12 = 23 Jul.

[y]Application timings: 1 = (Green-tip) 23 Apr; 2 = (TC) 1 May; 3 = (Pink) 7 May; 4 = (Bloom) 14 May; 5 = (Petal fall) 21 May; 6 = 30 May; 7 = 5 Jun; 8 = 12 Jun; 9 = 19 Jun; 10 = 26 Jun; 11 = 2 Jul; 12 = 17 Jul.

[x]Assessment of individual fruit on 10 fruit clusters per tree on 5 single-tree replicates per treatment

[w]Numbers within columns followed by the same letter do not differ significantly, Fisher's Protected LSD, $P \leq 0.05$; columns with no letters following the numbers do not have a significant F-value, Analysis of Variance, $P \leq 0.05$ or Kruskal-Wallis, $P \leq 0.05$, when data normality could not be rescued with data transformation because of zeros in data.

Table 10. Incidence of insect damage

10. Incidence of insect damage on

Incidence of insect damage on 'Empire'

2007

Treatment and rate/A (rate/ha)	Application timing[z]	Plum curculio	Tarnished plant bug	European apple sawfly	Apple maggot fly	Internal Lepidoptera	Surface Lepidoptera
		Percent insect pest damage incidence — Fruit, 10 Sep 2007[x]					
potassium bicarbonate 3.75 lb (4.2 kg)	1-12………..	5.2[w]	22.0	2.8	6.4	4.8	22.0
Bacillus subtilis 3 lb (3.4 kg)………	1-12………..	8.4	18.4	3.6	7.6	4.8	26.4
neem oil 2 gal (18.7 L)………..……	1-12………..	5.6	4.0	0.0	4.4	2.0	10.0
sulfur 15 lb (16.8 kg)	1, 5, 8, 10-12						
lime sulfur 2 gal (18.7 L)………..	2-4, 6-7, 9….	1.6	14.4	1.6	13.2	1.6	16.4
non-sprayed…………………………	1-12………..	8.4	18.4	1.6	13.6	3.2	21.6

2008

Treatment and rate/A (rate/ha)	Application timing[y]	Plum curculio	Tarnished plant bug	European apple sawfly	Apple maggot fly	Internal Lepidoptera	Surface Lepidoptera	Stink bug
		Percent insect pest damage incidence — Fruit, 3 Sep 2008[x]						
potassium bicarbonate 3.75 lb (4.2 kg)	1-12………..	16.1 bc[w]	14.1	3.6	4.2	33.2	55.0 a	15.3
Bacillus subtilis 3 lb (3.4 kg)………	1-12………..	39.2 a	14.8	6.0	4.0	25.2	44.0 ab	15.2
neem oil 2 gal (18.7 L)………..……	1-12………..	30.0 ab	7.2	1.2	0.8	18.4	28.0 c	11.6
sulfur 15 lb (16.8 kg)	8-12………..							
lime sulfur 2 gal (18.7 L)………..	1-7…………	13.8 c	3.7	0.8	7.4	39.2	57.7 a	15.3
non-sprayed…………………………	1-12………..	23.6 bc	16.0	2.8	4.0	31.6	40.0 bc	9.6

[z]Application timings: 1 = (Green-tip) 26 Apr; 2 = (TC) 7 May; 3 = (Pink) 11 May; 4 = (Pink) 17 May; 5 = (Pink-Bloom) 24 May; 6 = (Petal fall) 29 May; 7 = 7 Jun; 8 = 14 Jun; 9 = 22 Jun; 10 = 29 Jun; 11 = 12 Jul; 12 = 23 Jul.

[y]Application timings: 1 = (Green-tip) 23 Apr; 2 = (TC) 1 May; 3 = (Pink) 7 May; 4 = (Bloom) 14 May; 5 = (Petal fall) 21 May; 6 = 30 May; 7 = 5 Jun; 8 = 12 Jun; 9 = 19 Jun; 10 = 26 Jun; 11 = 2 Jul; 12 = 17 Jul.

[x]Assessment of 50 fruit per tree on 5 single-tree replicates per treatment

[w]Numbers within columns followed by the same letter do not differ significantly, Fisher's Protected LSD, $P \leq 0.05$; columns with no letters following the numbers do not have a significant F-value, Analysis of Variance, $P \leq 0.05$ or Kruskal-Wallis, $P \leq 0.05$, when data normality could not be rescued with data transformation because of zeros in data.

Table 11. Phytotoxic effects of
11. Phytotoxic effects of treatments on
Phytotoxic effects of treatments on

2007

Treatment and rate/A (rate/ha)	Application timing[z]	Percent phytotoxic burn incidence Fruit[x] 10 Sep	Percent russet incidence Fruit[x] 10 Sep
potassium bicarbonate 3.75 lb (4.2 kg)	1-12………..	0.0[w]	0.4 [w]
Bacillus subtilis 3 lb (3.4 kg)………	1-12………..	0.0	0.0
neem oil 2 gal (18.7 L)………..……	1-12………..	0.0	0.4
sulfur 15 lb (16.8 kg)	1, 5, 8, 10-12		
lime sulfur 2 gal (18.7 L)………..	2-4, 6-7, 9….	8.8	5.2
non-sprayed…………………………	1-12………..	0.0	0.4

2008

Treatment and rate/A (rate/ha)	Application timing[y]	Percent phytotoxic burn incidence Fruit[x] 3 Sep	Percent russet incidence Fruit[x] 3 Sep
potassium bicarbonate 3.75 lb (4.2 kg)	1-12………..	0.0	3.5 b[v]
Bacillus subtilis 3 lb (3.4 kg)………	1-12………..	0.0	2.0 b
neem oil 2 gal (18.7 L)………..……	1-12………..	0.0	8.8 a
sulfur 15 lb (16.8 kg)	8-12………..		
lime sulfur 2 gal (18.7 L)………..	1-7………….	0.0	5.0 ab
non-sprayed…………………………	1-12………..	0.0	1.2 b

[z]Application timings: 1 = (Green-tip) 26 Apr; 2 = (TC) 7 May; 3 = (Pink) 11 May; 4 = (Pink) 17 May; 5 = (Pink-Bloom) 24 May; 6 = (Petal fall) 29 May; 7 = 7 Jun; 8 = 14 Jun; 9 = 22 Jun; 10 = 29 Jun; 11 = 12 Jul; 12 = 23 Jul.

[y]Application timings: 1 = (Green-tip) 23 Apr; 2 = (TC) 1 May; 3 = (Pink) 7 May; 4 = (Bloom) 14 May; 5 = (Petal fall) 21 May; 6 = 30 May; 7 = 5 Jun; 8 = 12 Jun; 9 = 19 Jun; 10 = 26 Jun; 11 = 2 Jul; 12 = 17 Jul.

[x]Assessment of 50 fruit per tree on 5 single-tree replicates per treatment

[w]Numbers within columns are significantly different, Kruskal-Wallis, $P \leq 0.05$.

[v]Numbers within columns followed by the same letter do not differ significantly, Fisher's Protected LSD, $P \leq 0.05$.

Table 12. Incidence of 'Empire'
12. Incidence of 'Empire' fruit
Incidence of 'Empire' fruit clean

	Percent clean of disease incidence	
	Fruit[z]	Fruit[z]
Treatment and rate/A (rate/ha)	10 Sep 2007	3 Sep 2008
potassium bicarbonate 3.75 lb (4.2 kg)	81.6[y]	31.4 c
Bacillus subtilis 3 lb (3.4 kg)………	69.2	25.6 c
neem oil 2 gal (18.7 L)………..……	81.1	60.0 b
sulfur 15 lb (16.8 kg)		
lime sulfur 2 gal (18.7 L)………..	82.8	92.1 a
non-sprayed…………………………	65.2	29.6 c

[z]Assessment of 50 fruit per tree on 5 single-tree replicates per treatment

[y]Numbers within columns followed by the same letter do not differ significantly, Fisher's Protected LSD, $P \leq 0.05$; columns with no letters following the numbers do not have a significant F-value, Analysis of Variance, $P \leq 0.05$ or Kruskal-Wallis, $P \leq 0.05$, when data normality could not be rescued with data transformation because of zeros in data.

Table 13. Incidence of 'Empire' fruit
13. Incidence of 'Empire' fruit clean
Incidence of 'Empire' fruit clean of

	Percent clean of insect damage incidence	
	Fruit[z]	Fruit[z]
Treatment and rate/A (rate/ha)	10 Sep 2007	3 Sep 2008
potassium bicarbonate 3.75 lb (4.2 kg)	52.8 b[y]	19.6 b
Bacillus subtilis 3 lb (3.4 kg)………	45.6 b	20.0 b
neem oil 2 gal (18.7 L)………..……	77.1 a	37.6 a
sulfur 15 lb (16.8 kg)		
lime sulfur 2 gal (18.7 L)………..	59.6 ab	17.5 b
non-sprayed…………………………	50.8 b	26.0 b

[z]Assessment of 50 fruit per tree on 5 single-tree replicates per treatment

[y]Numbers within columns followed by the same letter do not differ significantly, Fisher's Protected LSD, $P \leq 0.05$.

Table 14. USDA fruit grade of
14. USDA fruit grade of
USDA fruit grade of 'Empire'

Treatment and rate/A (rate/ha)	Percent USDA fruit grade incidence			
	US-1 Count	US-1 Bag	U.S. Utility	Cull
	3 Sep	3 Sep	3 Sep	3 Sep
potassium bicarbonate 3.75 lb (4.2 kg)	2.4[z]	8.3 b[y]	13.4 bc[y]	75.9 a[y]
Bacillus subtilis 3 lb (3.4 kg)………	0.4	4.8 b	24.0 a	70.8 ab
neem oil 2 gal (18.7 L)………..……	4.4	18.4 a	17.6 ab	59.6 b
sulfur 15 lb (16.8 kg)				
lime sulfur 2 gal (18.7 L)………..	5.6	10.7 b	5.9 c	77.4 a
non-sprayed…………………………	4.0	5.2 b	22.0 ab	68.8 ab

[z]columns with no letters following the numbers do not have a significant F-value, Analysis of Variance, $P \leq 0.05$ (or Kruskal-Wallis, $P \leq 0.05$, when data normality could not be rescued with data transformation because of zeros in data).

[y]Numbers within columns followed by the same letter do not differ significantly, Fisher's Protected LSD, $P \leq 0.05$

ACKNOWLEDGEMENTS

We thank Terence Bradshaw for his endless help in the field and Sarah Kingsley-Richards for all those long tedious days of data collection.

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CHAPTER 3. JOURNAL ARTICLE

PRELIMINARY EVALUATION OF RAW MILK AS A FUNGICIDE IN ORGANIC APPLE PRODUCTION IN VERMONT

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Abstract

The fungicides containing sulfur and lime sulfur active ingredients are the most commonly used against apple scab, a major disease limitation in organic apple production systems; however, there are drawbacks to their use. Lime sulfur-based fungicides are highly caustic to the applicator. Sulfur is less caustic, but is not as effective against apple scab and has detrimental effects on beneficial mites. In addition, lime sulfur is injurious to the tree and can cause lower fruit yields. Because of these potential non-target impacts on the apple trees and surrounding ecosystem, it is important to evaluate alternative fungicides for apple disease management. The objective of this trial was to compare the efficiency of a 30% v/v raw milk dilution to a non-sprayed treatment for the control of apple scab and other fungal diseases. The study was conducted at the University of Vermont Horticultural Research Center on 'McIntosh' trees in a completely randomized design with three single-tree replications. Milk applications were made on approximately a weekly schedule from 26 Apr 2007 to the end of June and every two weeks through 23 Jul 2007. Disease incidence and severity on terminal leaves were recorded on 20-21 Jun 2007 and 22-24 Aug 2007 and on fruit on 10 Sep 2007. Overall, milk did not provide management of disease and caused premature leaf yellowing and defoliation of the apple trees.

INTRODUCTION

A major limitation to organic apple production in Vermont is the available fungicide options for the management of apple scab (*Venturia inaequalis* (Cooke) Wint.), a major disease of apples in New England. There are integrated pest management (IPM) methods to reduce inoculum; however, disease management on scab susceptible cultivars requires fungicide use. Apple disease management programs also must consider cedar apple rust (*Gymnosporangium juniperi-virginianae* (Schwein)), sooty blotch (a complex of *Peltaster fructicola* (Johnson, Sutton, Hodges), *Geastrumia polystigmatus* (Batista & M.L. Farr), *Leptodontium elatus* (G. Mangenot) De Hoog, and *Gloedes Pomigena* (Schwein) Colby), and fly speck (*Zygophiala jamaicensis* (E. Mason)) since management of these diseases may require fungicide use on susceptible cultivars under favorable environmental conditions.

There are a number of fungicides which are organically approved by the Northeast Organic Farming Association (NOFA) of Vermont. The fungicides containing sulfur and lime sulfur active ingredients are the most commonly used against *Venturia inaequalis* in organic apple production systems (3). However, lime sulfur-based fungicides are highly caustic (7). Sulfur-based materials are less caustic to the applicator, but are less effective, with only weak protective activity against apple scab (6, 17, 3). Liquid lime sulfur was a highly recommended fungicide in the early twentieth century and was effective as a protectant fungicide, and could also be used to eradicate established infections (12). However, it can be injurious to the tree, lowers photosynthesis rates, and reduces fruit set and pollen germination (25, 27, 4, 20, 21). Lime sulfur applications can also result in lower fruit yields and premature fruit drop, and causes russetting and phytotoxic burns on the fruit, thus lowering fruit quality (21, 4, 28, 13). Consequently, wettable sulfur fungicides were incorporated into management programs with lime sulfur even though they were less effective and lacked the eradicative capability of lime sulfur (20). However, management programs of sulfur- and/or lime sulfur-based fungicides have additional impacts on the orchard ecosystem; their use in apple orchards have adverse, non-target effects on beneficial predatory mites (15, 32, 22, 21).

Because of the potential non-target impacts on the apple trees and surrounding ecosystem of current organically-approved fungicides, it is important to evaluate alternative fungicides for apple disease management. One possible fungicidal alternative is milk. The lactoperoxidase system in milk has antimicrobial properties. The peroxidase oxidizes available halides or thiocyanate to reactive oxidizing compounds, which attach sulfhydryl groups in essential proteins in microbes such as fungi (27, 11). A study of the mode of action of milk in the control of grapevine powdery mildew, Crisp *et al.* (5) showed that the milk produced oxygen radicals when exposed to natural light and this in conjunction with the action of lactoferrin (an antimicrobial component of milk) collapsed the hyphae and damaged the conidia of *Erysiphe (Uncinula) necator* (Schwein) Burrill. Exposure of milk to the ultraviolet radiation in sunlight resulted in the reduction of oxygen to superoxide anion, which is highly reactive (16). Milk and whey have been found to effectively treat grapevine powdery mildew, *Erysiphe (Uncinula) necator*

(Schwein) Burrill, (26, 4, 13). Pscheidt and Kenyon (26) found whey powder applied 12.5 to 19 lb per acre (14-21.3 kg per ha) significantly reduced the severity of powdery mildew on leaves and clusters compared to non-treated and water treatments. Crisp *et al*. (4) tested the efficacy of milk, whey, and sulfur against grapevine powdery mildew in Australia. All test materials significantly reduced the severity of powdery mildew on leaves and bunches compared to non-treated vines. There was no significant difference in severity of the disease on vine leaves sprayed with milk, whey, or sulfur. Hed and Travis (13) found whole milk (20%) provided control of powdery mildew on Concord grapes that was statistically superior to the water check and equivalent to the conventional fungicide program.

In addition, Bettiol (1) found milk to be an effective alternative for control of powdery mildew on zucchini squash, *Podosphaera xanthii* (formerly known as *Sphaerotheca fuliginea* Schlech ex Fr. Poll.), in greenhouse conditions. Milk applied twice a week at concentrations of 10% and higher controlled powdery mildew at least as effectively as the conventional fungicides, fenarimol and benomyl. Mold grew on the upper surfaces of leaves treated with 30% and higher, but the plants did not appear to be injured. The main toxicity risk associated with milk and other dairy products is the potential that they are allergens to some humans (8).

With Vermont's large dairy industry, the antifungal properties of milk, and the readily available milk from the University of Vermont dairy farm, milk was examined as an alternative fungicide in a Vermont apple orchard in this preliminary study.

MATERIALS AND METHODS

This preliminary study evaluating the efficiency of raw milk as a fungicide was conducted in 2007 at the University of Vermont Horticultural Research Center (UVM HRC) in South Burlington on six 'McIntosh' trees planted in 1982 on M.26 rootstock. The 'McIntosh' trees are approximately 3.0 m (height) x 3.0 m (width) and planted at a spacing of 4.9 m x 7.3 m (Figure 1.). Most of the other trees in the planting are scab-resistant cultivars and therefore, were not included in this research study. The study was conducted using a completely randomized design on six 'McIntosh' trees, with three single-tree replicates of the two treatments: raw milk (30% dilution v/v) [milk was obtained from the UVM dairy farm holding tank the morning of each application]; and non-sprayed.

Environmental and weather conditions at UVM HRC were recorded with a Davis Vantage Pro Wireless Weather Station (Davis Instruments Corp., 3465 Diablo Ave., Hayward, California 94545 USA). Data collected were used to determine primary and secondary infection periods (Figure 2). Infection periods were calculated, according to formulas used by Reardon (28), which were based on the "revised" Mills table (19, 31, 29), with the exception that wetting periods starting with nightfall rains were included in the calculations because a portion of ascospores are released at night (10) (Appendix B). Ascospore maturity was calculated, following formulas used by Reardon (28) who used the New Hampshire model developed by Gadoury and MacHardy (9) (Appendix C). The potential release of mature ascospores was determined according to criteria established by Gadoury *et. al.* and used by Reardon *et. al* (10, 29).

Milk applications began on 26 Apr 2007 and continued on approximately a weekly schedule through the end of June and then every two weeks to the last application on 23 Jul. Milk was applied with a 189-liter 3-point hitch PTO sprayer (Nifty Fifty, Rears Mfg Co., Eugene, OR) with an attached Green Guard handgun (model JD9-C) having an L tip, at a pressure of 100 lb/sq. in. (689.48 kpa). Milk, in a 30% v/v solution with water, was applied to drip, approximately 0.5 gallon (1.89 L) per tree. No other materials were applied to the trees throughout the season. Actual primary infection periods occurred on April 27-30, May 10-11, 15-17, 19-21, 27-28, May 31 – June 2. Secondary infection periods occurred on June 2-5, 9, 12-13, 14-22, July 2-3, 4-6, 7-13, 18-21, 27-29, July 31 – August 1, August 6-8, 11, 16-18, 26-27, and September 9-10 (Figure 2).

June Foliar Disease Assessment

The incidence of disease symptoms and the number of lesions of apple scab, cedar apple rust, necrotic leaf spots, which resembled frogeye leaf spot (*Botryosphaeria obtusa* (Schwein.) Shoemaker), as well as pinpoint purple lesions, which appeared to be aborted rust lesions, were assessed on all leaves on ten apical, vegetative terminals per each single tree replicate for each treatment on 18-20 Jun 2007. Both sides of each terminal leaf were examined. Vegetative terminals were selected at random from around the whole area of the tree circumference.

Timed Assessment of the Presence of Yellow Leaves

As a way to assess the poor condition and defoliation of the trees, a timed assessment of the number of yellow leaves on each tree was conducted on June 18, 2007.

In order to capture if there was a treatment effect, a visual assessment was made by slowly walking around each of the six trees two times: first scanning the lower 8 ft (2.44 m) section of the tree, then the remaining upper section of the canopy, and counting the number of yellow leaves observed over a five minute period. Data collected were the number of yellowing leaves observed per tree in both the raw milk and non-sprayed treatments.

August Foliar Disease & Arthropod Assessment

Foliar disease incidence and severity (number of lesions per infected leaf), as well as incidence of arthropod pests and their damage were recorded in August. Disease assessment in August followed the same procedures as the June terminal assessment. In addition, the following arthropod data were collected upon examination of each leaf on the ten terminals per tree: spotted tentiform leafminer mines (*Phyllonorycter blancardella* (Fabr.)) or apple blotch leafminer mines (*Phyllonorycter crataegella* (Clemens)) (mines from both of these pests appear similar and were not distinguished) (severity was also assessed for this insect); lyonetia leafminer mines (Lepidoptera: Lyonetiidae); green apple aphids (*Aphis pomi*); European red mites (*Panonychus ulmi* (Koch)); two-spotted spider mites (*Tetranychus urticae* (Koch)); white apple leafhoppers (*Typhlocyba pomaria* (McAtee)) and their damage; potato leafhoppers (*Empoasca fabae* (Harris)) and their damage; and Japanese beetles (*Popillia japonica* (Newman)) and their damage. In addition, incidences were also recorded of beneficial insects such as: lady beetle adults and larvae (Coleoptera: Coccinellidae); cecidomyiid larvae (Diptera: Cecidomyiidae); syrphid fly larvae (Diptera: Syrphidae); and chrysopid eggs

(Neuroptera: Chrysopidae). Leaves with no evidence of the pest or pest damage were recorded as clean of arthropod damage. Terminals were assessed for disease and arthropods on 22-24 Aug 2007.

Harvest Fruit Collection

On September 10, 2007, 64 fruit were collected from each of the 6 'McIntosh' trees. A sample of eight apples was picked from each of four quadrants on both the east and west sides of the trees. The upper and lower canopies were divided into two quadrants each on the east side as well as the west, making a total of eight sections per tree. Eight apples were picked from each section in order to obtain a representative sample of fruit from each tree. When the tree bore less than 64 fruit, all available fruit was collected from the tree. The fruit were placed in labeled boxes and stored at 36°F (2.2°C). After a week, the samples were transferred to paper bags until assessment was completed.

Harvest Fruit Disease & Insect Assessment

A target number of 50 fruit, chosen at random from the 64 collected per tree, were assessed for the following: apple scab; cedar apple rust; sooty blotch; fly speck; fruit rots (only counted rots when not associated with mechanical or other injury); and lenticel blackening, which may be the early symptoms of black rot (*Botryosphaeria obtusa* (Schwein) Shoemaker). Presence of physiological maladies such as phytotoxicity (i.e. purple and cracked apple skin) and russet were also recorded.

The 50 fruit was also evaluated for arthropod damage. The presence of damage from the following insects were assessed: plum curculio (*Conotrachelus nenuphar*

(Herbst)) (i.e., crescent shaped scarring); tarnished plant bug (*Lygus lineolaris* (Palisot de Beauvois)) (i.e., dimpled scarring); apple maggot fly (*Rhagoletis pomonella* (Walsh)) (i.e., small skin puncture with no frass, tunneling into the flesh); European apple sawfly (*Hoplocampa testudinea* (Klug)) (i.e., characteristic curved scar); internal Lepidoptera, which includes damage from codling moth (*Cydia pomonella* (L.)), oriental fruit moth (*Grapholita molesta* (Busck)), and lesser appleworm (*Grapholita prunivora* (Walsh)) (i.e., circular hole, often with frass, inspection upon slicing revealed tunneling into the flesh generally toward the core); and surface Lepidoptera (i.e., feeding on skin and flesh just below it, often with frass and 'squiggly trail' at the surface). The fruit was cut in half to determine if there was internal Lepidoptera damage and the skin was peeled off to see the presence of apple maggot fly larvae trails in the flesh below a possible entry pin-sized hole. Fruit assessment was completed on 1-2 October 2007.

Statistical Analysis

Data obtained were subjected to analysis of variance and significant differences between means were determined by Fisher's protected Least Significant Difference (LSD) Test ($P \leq 0.05$) (30).

RESULTS

Disease Assessment

The preliminary evaluation of raw milk as a fungicide resulted in virtually no disease management (Tables 1-6) (Appendix H). The only significant differences between the milk treatment and the non-sprayed treatment were found with pin-point purple lesion incidence on the terminal leaves in June (Table 3) and necrotic leaf spot incidence in June and August, where the milk treatment had significantly *more* necrotic leaf spots than the non-sprayed treatment (Table 4).

For flyspeck, fruit rots, and lenticel blackening, no significant differences were found between the treatments (Table 5). No sooty blotch symptoms were observed on fruit in either treatment. No russetting of the non-treated fruit was observed; some fruit on milk-treated trees had russetting but this was not statistically different. No other phytotoxicity or sunburn was observed on the fruit. Only 1-2% of the fruit was clean of disease symptoms (Table 6).

Arthropod Assessment

The foliar and fruit arthropod assessment showed no significant differences between the treatments (Tables 7 and 8). Overall, the same percent (26%) of fruit was clean of insect damage from both treatments. There were no beneficial insects observed in any of the trees regardless of the treatment.

Yellow Leaf Assessment

The trees in the study were defoliating prematurely. A timed assessment of the number of yellow leaves per tree revealed that trees treated with milk had significantly more yellow leaves per tree than the non-sprayed trees, i.e., 288.3 yellow leaves compared to 166.7 leaves, respectively (Table 9).

DISCUSSION

The disease pressure was high in the experimental plot because the study was conducted in a non-managed planting at the UVM Horticultural Research Center, which explains some of the very high incidence of disease, but there can be no conclusions in support of raw milk as a fungicide from this study.

This preliminary study of the efficiency of raw milk as a fungicide showed the material provided little, if any, disease control. In most cases, the incidences of disease in the milk treatment were comparable to the non-sprayed treatment, and in some cases were higher in the milk treatment. The milk treatment did have a percentage of clean fruit two times higher than the non-sprayed, but at 2.7% clean, there was still no management of diseases sufficient for a quality crop.

This study is preliminary because there were very few replications and because there was no standard fungicide treatment for comparison. The objective of the study was to see if there was any indication of management of certain apple diseases with milk applications. However, despite its preliminary nature, this study does not support milk for the management of the diseases that were assessed.

This study also does not indicate any non-target impacts on arthropod pests. However, the study does indicate a significant adverse effect, i.e., premature defoliation, as shown in the extent of yellowing (dying) leaves. In addition, the black growth observed on the leaves in the milk treatment may have contributed to the premature defoliation (Figure 3). This result was also seen in past research, Bettiol (1) found mold grew on the leaf surfaces of zucchini squash when milk was applied for powdery mildew at a 30% concentration.

Overall, milk did not provide management of diseases and caused premature leaf yellowing and defoliation of the apple trees.

Figure 1. Orchard Map, 2007. UVM Horticultural Research Center. Experimental trees were 'McIntosh' on Malling 26 rootstocks. Other trees in the orchard were various scab-resistant cultivars.

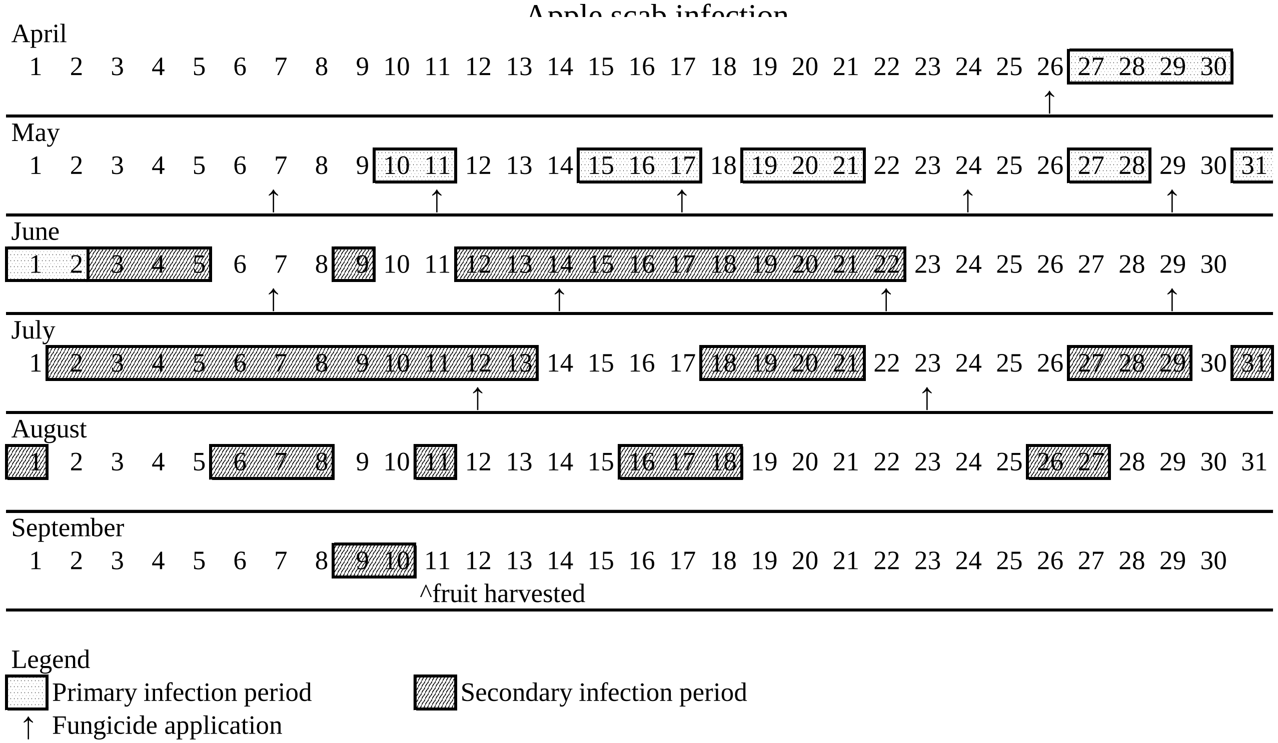
SOUTH

Tree	Row 5	Row 4	Row 3	Row 2	Row 1
1	-	-	-	-	-
2	-	-	-	-	Mac-26
3	Mac-26	Mac-26	-	-	Mac-26
4	-	-	-	-	Mac-26
5	-	-	-	-	Mac-26
6	-	-	-	-	
7	-	-	-	-	
8	-	-	-	-	
9	-	-	-	-	
10	-	-	-	-	
11	-	-	-	-	
12	-	-	-	-	
13	-	-	-	-	
14	-	-	-	-	
15	-	-	-	-	
16	-	-	-	-	
17	-	-	-	-	
18	-	-	-	-	
19	-	-	-	-	
20	-	-	-	-	
21	-	-	-	-	

NORTH

TREATMENTS	
	Non-sprayed
	Raw milk dilution (30% v/v)

Figure 2. Apple scab
2. Apple scab infection
Apple scab infection



[z]Infection periods were calculated using formulas from Reardon, J.E., Berkett, L.P., Garcia, M.E., Gotlieb, A., Ashikaga, T., and Badger, G. 2005. Field evaluation of the new sequential sampling technique for determining apple scab "risk". Plant Disease 89(3):228-236, which used the revised Mills table [MacHardy, W.E. and Gadoury, D.M. 1989. A revision of Mill's criteria for predicting apple scab infection periods. Phytopathology 79:304-310], as amended by Stensvand, A., Gardoury, D.M., Amundsen, T., Semb, L., and Seem, R.C. 1997. Ascospore release and infection of apple leaves by conidia and ascospores of *Venturia inaequalis* at low temperatures. Phytopathology 87:1046-1053. Since a portion of mature ascospores are released during night time hours, rain events that started at night were not discounted.

Figure 3. Black mold observed on milk-treated trees.

Table 1. Apple scab on

e 1. Apple scab on 'McIntosh'

	Application	Scab Incidence %			Scab Severity[v]	
		Terminal leaves[y]		Fruit[x]	Terminal leaves	
Treatment and rate/A (rate/ha)	timing[z]	18-20 Jun	22-24 Aug	10 Sep	18-20 Jun	22-24 Aug
non-sprayed…......................	1-12………..	28.7[w]	76.0	97.3	3.3	12.0
raw milk 34 gal (0.32 kl)….	1-12………..	23.8	74.2	96.0	3.5	10.6

[z]Application timings: 1 = (Green-tip) 26 Apr; 2 = (TC) 7 May; 3 = (Pink) 11 May; 4 = (Pink) 17 May; 5 = (Pink-Bloom) 24 May; 6 = (Petal fall) 29 May; 7 = 7 Jun; 8 = 14 Jun; 9 = 22 Jun; 10 = 29 Jun; 11 = 12 Jul; 12 = 23 Jul.

[y]Assessment of 10 terminals per tree on 3 single-tree replicates per treatment

[x]Assessment of 50 fruit per tree on 3 single-tree replicates per treatment

[w]Numbers within columns followed by the same letter do not differ significantly, Fisher's Protected LSD, $P \leq 0.05$; columns with no letters following the numbers do not have a significant F-value, Analysis of Variance, $P \leq 0.05$.

[v]Mean number of lesions per infected leaf

Table 2. Cedar apple rust

2. Cedar apple rust (CAR) on

Treatment and rate/A (rate/ha)	Application timing[z]	CAR Incidence % Terminal leaves[y] 18-20 Jun	CAR Incidence % Terminal leaves[y] 22-24 Aug	CAR Incidence % Fruit[x] 10 Sep	CAR Severity[v] Terminal leaves 18-20 Jun	CAR Severity[v] Terminal leaves 22-24 Aug
non-sprayed…......................	1-12………..	5.8[w]	22.7	0.0	0.6	1.8
raw milk 34 gal (0.32 kl)….	1-12………..	3.6	26.1	0.0	0.4	1.4

[z]Application timings: 1 = (Green-tip) 26 Apr; 2 = (TC) 7 May; 3 = (Pink) 11 May; 4 = (Pink) 17 May; 5 = (Pink-Bloom) 24 May; 6 = (Petal fall) 29 May; 7 = 7 Jun; 8 = 14 Jun; 9 = 22 Jun; 10 = 29 Jun; 11 = 12 Jul; 12 = 23 Jul.

[y]Assessment of 10 terminals per tree on 3 single-tree replicates per treatment

[x]Assessment of 50 fruit per tree on 3 single-tree replicates per treatment

[w]Numbers within columns followed by the same letter do not differ significantly, Fisher's Protected LSD, $P \le 0.05$; columns with no letters following the numbers do not have a significant F-value, Analysis of Variance, $P \le 0.05$.

[v]Mean number of lesions per infected leaf

Table 3. Pin-point purple lesions (PPP) on

e 3. Pin-point purple lesions (PPP) on

Treatment and rate/A (rate/ha)	Application timing[z]	PPP Incidence % Terminal leaves[y]		PPP Severity[w] Terminal leaves	
		18-20 Jun	22-24 Aug	18-20 Jun	22-24 Aug
non-sprayed…......................	1-12………..	35.8 a[x]	21.5	7.2	4.0
raw milk 34 gal (0.32 kl)….	1-12………..	28.7 b	25.0	5.0	4.1

[z] Application timings: 1 = (Green-tip) 26 Apr; 2 = (TC) 7 May; 3 = (Pink) 11 May; 4 = (Pink) 17 May; 5 = (Pink-Bloom) 24 May; 6 = (Petal fall) 29 May; 7 = 7 Jun; 8 = 14 Jun; 9 = 22 Jun; 10 = 29 Jun; 11 = 12 Jul; 12 = 23 Jul.

[y] Assessment of 10 terminals per tree on 3 single-tree replicates per treatment

[x] Numbers within columns followed by the same letter do not differ significantly, Fisher's Protected LSD, $P \leq 0.05$; columns with no letters following the numbers do not have a significant F-value, Analysis of Variance, $P \leq 0.05$.

[w] Mean number of lesions per infected leaf

Table 4. Necrotic leaf spots on

e 4. Necrotic leaf spots on

Treatment and rate/A (rate/ha)	Application timing[z]	Necrotic leaf spot Incidence % Terminal leaves[y] 18-20 Jun	Necrotic leaf spot Incidence % Terminal leaves[y] 22-24 Aug	Necrotic leaf spot Severity[w] Terminal leaves 18-20 Jun	Necrotic leaf spot Severity[w] Terminal leaves 22-24 Aug
non-sprayed…......................	1-12………..	10.7 b[x]	24.4 b	1.2	4.4
raw milk 34 gal (0.32 kl)….	1-12………..	28.9 a	53.9 a	6.9	10.9

[z]Application timings: 1 = (Green-tip) 26 Apr; 2 = (TC) 7 May; 3 = (Pink) 11 May; 4 = (Pink) 17 May; 5 = (Pink-Bloom) 24 May; 6 = (Petal fall) 29 May; 7 = 7 Jun; 8 = 14 Jun; 9 = 22 Jun; 10 = 29 Jun; 11 = 12 Jul; 12 = 23 Jul.

[y]Assessment of 10 terminals per tree on 3 single-tree replicates per treatment

[x]Numbers within columns followed by the same letter do not differ significantly, Fisher's Protected LSD, $P \leq 0.05$; columns with no letters following the numbers do not have a significant F-value, Analysis of Variance, $P \leq 0.05$.

[w]Mean number of lesions per infected leaf

Table 5. Incidence of disease and phytotoxicity

e 5. Incidence of disease and phytotoxicity on

		Fruit[y]					
		10 Sep					
Treatment and rate/A (rate/ha)	Application timing[z]	Flyspeck	Sooty blotch	Soft rots	Lenticel blackening	Phytotoxic burn	Russet
non-sprayed…......................	1-12………..	1.3[x]	0.0	19.4	1.4	0.0	0.0
raw milk 34 gal (0.32 kl)….	1-12………..	2.7	0.0	11.3	4.7	0.0	10.0

[z]Application timings: 1 = (Green-tip) 26 Apr; 2 = (TC) 7 May; 3 = (Pink) 11 May; 4 = (Pink) 17 May; 5 = (Pink-Bloom) 24 May; 6 = (Petal fall) 29 May; 7 = 7 Jun; 8 = 14 Jun; 9 = 22 Jun; 10 = 29 Jun; 11 = 12 Jul; 12 = 23 Jul.

[y]Assessment of 50 fruit per tree on 3 single-tree replicates per treatment

[x]Numbers within columns followed by the same letter do not differ significantly, Fisher's Protected LSD, $P \leq 0.05$; columns with no letters following the numbers do not have a significant F-value, Analysis of Variance, $P \leq 0.05$.

Table 6. Incidence of foliage and fruit clean of disease

e 6. Incidence of foliage and fruit clean of disease symptoms

Treatment and rate/A (rate/ha)	Application timing[z]	Clean Incidence %: Terminal leaves[y] 18-20 Jun	Clean Incidence %: Fruit[x] 10 Sep
non-sprayed….....................	1-12………..	37.6[w]	1.4
raw milk 34 gal (0.32 kl)….	1-12………..	34.7	2.7

[z]Application timings: 1 = (Green-tip) 26 Apr; 2 = (TC) 7 May; 3 = (Pink) 11 May; 4 = (Pink) 17 May; 5 = (Pink-Bloom) 24 May; 6 = (Petal fall) 29 May; 7 = 7 Jun; 8 = 14 Jun; 9 = 22 Jun; 10 = 29 Jun; 11 = 12 Jul; 12 = 23 Jul.

[y]Assessment of 10 terminals per tree on 3 single-tree replicates per treatment

[x]Assessment of 50 fruit per tree on 3 single-tree replicates per treatment

[w]Numbers within columns followed by the same letter do not differ significantly, Fisher's Protected LSD, $P \leq 0.05$; columns with no letters following the numbers do not have a significant F-value, Analysis of Variance, $P \leq 0.05$.

Table 7. Arthropod pest and damage

e 7. Arthropod pest and damage incidence on

		Percent incidence of arthropod pest and damage — 22-24 Aug, Terminal leaves[x]									
Treatment and rate/A (rate/ha)	Application timing[z]	ST/AB leafminer mines	Lyonetia mines	Green apple aphids	European red mites	Two-spotted spider mites	White apple leafhoppers	White apple leafhopper damage	Potato leafhoppers	Potato leafhopper damage	Japanese beetle damage
non-sprayed….....................	1-12………..	14.8[w]	0.0	0.0	4.5	0.0	0.9	0.0	2.1	0.0	0.0
raw milk 34 gal (0.32 kl)….	1-12………..	19.7	0.0	0.7	4.5	0.0	1.0	0.0	4.2	0.0	0.0

[z]Application timings: 1 = (Green-tip) 26 Apr; 2 = (TC) 7 May; 3 = (Pink) 11 May; 4 = (Pink) 17 May; 5 = (Pink-Bloom) 24 May; 6 = (Petal fall) 29 May; 7 = 7 Jun; 8 = 14 Jun; 9 = 22 Jun; 10 = 29 Jun; 11 = 12 Jul; 12 = 23 Jul.

[y]ST/AB = Spotted tentiform/Apple blotch leafminers

[x]Assessment of 10 terminals per tree on 3 single-tree replicates per treatment

[w]Numbers within columns followed by the same letter do not differ significantly, Fisher's Protected LSD, $P \leq 0.05$; columns with no letters following the numbers do not have a significant F-value, Analysis of Variance, $P \leq 0.05$.

Table 8. Incidence of insect damage on

e 8. Incidence of insect damage on

		Percent incidence of insect damage						
		10 Sep, Fruit[y]						
Treatment and rate/A (rate/ha)	Application timing[z]	Clean of insect damage	Plum curculio	European Apple Sawfly	Tarnished plant bug	Apple maggot fly	Surface lepidoptera	Internal lepidoptera
non-sprayed…......................	1-12………..	26.1[x]	48.2	2.0	16.9	6.2	21.7	6.7
raw milk 34 gal (0.32 kl)….	1-12………..	26.0	60.7	1.3	15.3	2.0	14.0	7.3

[z]Application timings: 1 = (Green-tip) 26 Apr; 2 = (TC) 7 May; 3 = (Pink) 11 May; 4 = (Pink) 17 May; 5 = (Pink-Bloom) 24 May; 6 = (Petal fall) 29 May; 7 = 7 Jun; 8 = 14 Jun; 9 = 22 Jun; 10 = 29 Jun; 11 = 12 Jul; 12 = 23 Jul.

[y]Assessment of 50 fruit per tree on 3 single-tree replicates per treatment

[x]Numbers within columns followed by the same letter do not differ significantly, Fisher's Protected LSD, $P \leq 0.05$; columns with no letters following the numbers do not have a significant F-value, Analysis of Variance, $P \leq 0.05$.

Table 9. Yellow leaf analysis on

e 9. Yellow leaf analysis on

Treatment and rate/A (rate/ha)	Application timing[z]	Average number of yellow leaves[y] 18-20 Jun
non-sprayed….....................	1-12………..	166.7 b[x]
raw milk 34 gal (0.32 kl)….	1-12………..	288.3 a

[z]Application timings: 1 = (Green-tip) 26 Apr; 2 = (TC) 7 May; 3 = (Pink) 11 May; 4 = (Pink) 17 May; 5 = (Pink-Bloom) 24 May; 6 = (Petal fall) 29 May; 7 = 7 Jun; 8 = 14 Jun; 9 = 22 Jun; 10 = 29 Jun; 11 = 12 Jul; 12 = 23 Jul.

[y]Each tree was assessed for 5 minutes, counting the number of yellow leaves first in the lower 3m of the canopy, then the remaining upper canopy while circling the tree.

[x]Numbers within columns followed by the same letter do not differ significantly, Fisher's Protected LSD, $P \leq 0.05$; columns with no letters following the numbers do not have a significant F-value, Analysis of Variance, $P \leq 0.05$.

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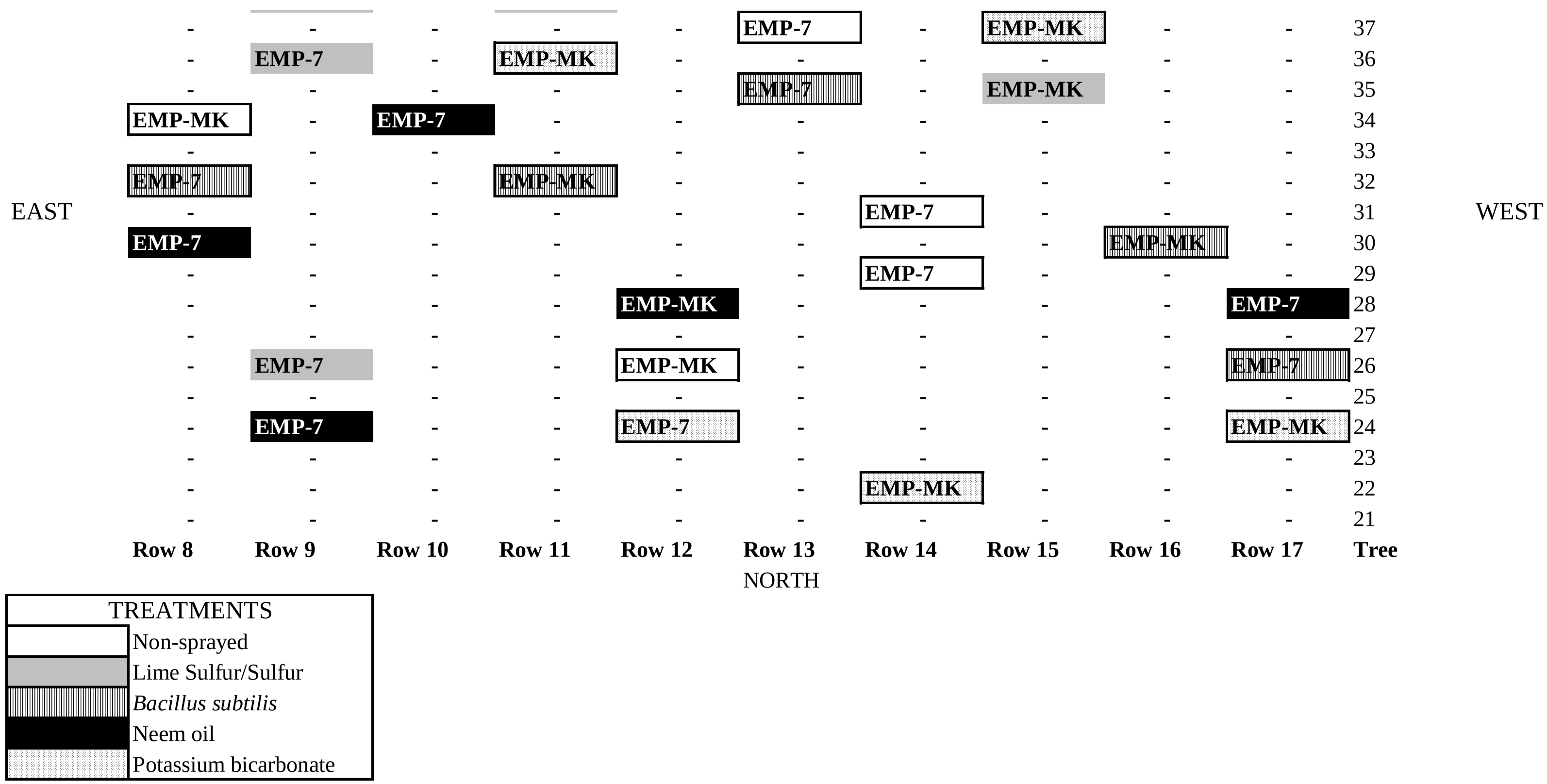
APPENDICES

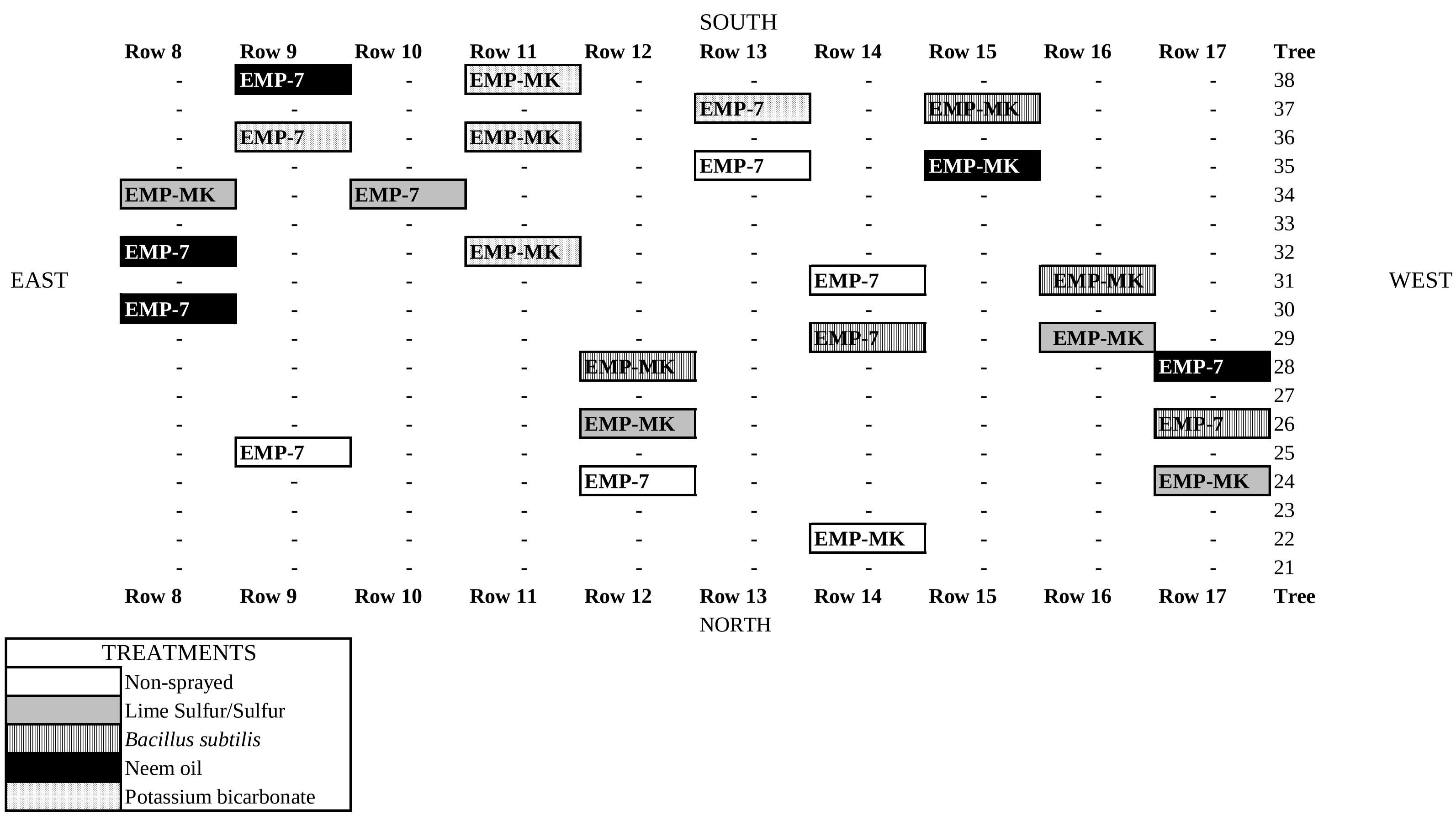
The following section includes supplementary data and information for this research, such as maps of the research orchard and weather data collected. This information is incorporated here to provide additional information for future readers.

APPENDIX A.
DIX A.

Appendix A-1a. 2007 Map of Orchard 11, University of Vermont Horticultural Research Center, South Burlington, Vermont. Experiment trees were 'Empire' cultivar on Mark and Malling 7 rootstocks. Other trees in the orchard were various scab resistant cultivars



Appendix A-1b. 2008 Map of Orchard 11, University of Vermont Horticultural Research Center, South Burlington, Vermont. Experiment trees were 'Empire' cultivar on Mark and Malling 7 rootstocks. Other trees in the orchard were various scab resistant cultivars.



Appendix B-1a. Primary infection periods with rain and leaf wetness events, April 2007[a]

Time rain started[b]	Time LW[c] started	Time LW ended	from start of rain	from start of LW	end of LW (°F)	end of LW (°F)	IP[d]?	between LW	LW when combined	when combined	Combined IP[e]?	IP number
4/23/07 23:00	4/23/07 22:00	4/23/07 23:00	0.0	1.0	63.4	64.3	n	n/a	n/a	n/a	n/a	
4/24/07 2:00	4/24/07 2:00	4/24/07 4:00	3.0	3.0	56.6	56.6	n	3	4	58.3	n/a	
4/27/07 0:00	4/27/07 0:00	4/27/07 2:00	3.0	3.0	49.1	49.1	n	>24	n/a	n/a	y	1
4/27/07 8:00	4/27/07 8:00	4/27/07 9:00	1.0	1.0	50.7	50.7	n	5	4	49.5	y	1
4/28/07 3:00	4/28/07 1:00	4/28/07 10:00	8.0	10.0	53.5	53.5	y	16	14	52.4	y	1
4/28/07 19:00	4/28/07 18:00	4/29/07 16:00	22.0	23.0	49.5	49.7	y	7	37	50.7	y	1
4/30/07 1:00	4/29/07 18:00	4/30/07 7:00	7.0	14.0	47.9	47.1	y	1	51	49.7	y	1

[a]Table format courtesy of Reardon, J.E., Berkett, L.P., Garcia, M.E., Gotlieb, A., Ashikaga, T., and Badger, G. 2005. Field evaluation of the new sequential sampling technique for determining apple scab "risk". Plant Disease 89(3):228-236

[b]None=no rain, only leaf wetness.

[c]LW=leaf wetness.

[d]IP=infection period, N=no, Y=yes. Infection periods were calculated using formulas from Reardon, J.E., Berkett, L.P., Garcia, M.E., Gotlieb, A., Ashikaga, T., and Badger, G. 2005. Field evaluation of the new sequential sampling technique for determining apple scab "risk". Plant Disease 89(3):228-236, using the revised Mills table of MacHardy, W.E. and Gadoury, D.M. 1989. A revision of Mill's criteria for predicting apple scab infection periods. Phytopathology 79:304-310, as amended by Stensvand, A., Gardoury, D.M., Amundsen, T., Semb, L., and Seem, R.C. 1997. Ascospore release and infection of apple leaves by conidia and ascospores of Venturia inaequalis at low temperatures. Phytpathology 87:1046-1053. Since a portion of mature ascospores are released during nighttime hours, rain events that started at night were not discounted.

[e]When a rain period is followed by leaf wetness coused by dew, the first dew period is added to the rain period and they are considered a single consecutive wetting even if separated by <24hr. When two consecutive rain events occur, they are considered a single wetting event if separated by <24hr. N/a=not applicable.

Appendix B-1b. Primary infection periods with rain and leaf wetness events, May 2007[a]

Time rain started[b]	Time LW[c] started	Time LW ended	Hr LW from start of rain	Hr LW from start of LW	Avg. temp. from start of rain to end of LW (°F)	Avg. temp. from start of LW to end of LW (°F)	IP[d]?	Hr between LW	Total hr LW when combined	Avg. temp. when combined	Combined IP[e]?	IP number
none	5/10/07 0:00	5/10/07 7:00		8.0		59.9	y	>24	n/a	n/a	n/a	2
5/10/07 18:00	5/10/07 18:00	5/10/07 19:00	1.0	1.0	71.1	71.1	n	>24	n/a	n/a	y	2
5/10/07 23:00	5/10/07 23:00	5/11/07 6:00	8.0	8.0	61.7	61.7	y	4	9	62.7	y	2
5/15/07 3:00	5/15/07 3:00	5/15/07 4:00	2.0	2.0	54.7	54.7	n	>24	n/a	n/a	n/a	
5/15/07 7:00	5/15/07 6:00	5/15/07 8:00	2.0	3.0	52.3	53.2	n	1	5	53.8	y	3
5/15/07 11:00	5/15/07 11:00	5/15/07 12:00	1.0	1.0	53.6	53.6	n	2	6	53.7	y	3
5/15/07 15:00	5/15/07 15:00	5/17/07 3:00	37.0	37.0	49.1	49.1	y	3	43	49.7	y	3
none	5/18/07 22:00	5/19/07 7:00	10.0	10.0		41.9	n	>24	n/a	n/a	y	4
5/19/07 16:00	5/19/07 14:00	5/19/07 18:00	3.0	5.0	56.2	56.4	n	6	15	46.7	y	4
5/19/07 20:00	5/19/07 20:00	5/20/07 7:00	12.0	12.0	51.8	51.8	y	1	27	49.0	y	4
5/20/07 19:00	5/20/07 18:00	5/21/07 8:00	14.0	15.0	46.4	47.1	y	10	42	48.3	y	4
5/27/07 12:00	5/27/07 12:00	5/27/07 14:00	3.0	3.0	60.4	60.4	n	>24	n/a	n/a	n/a	
5/27/07 21:00	5/27/07 21:00	5/28/07 1:00	5.0	5.0	65.2	65.2	n	6	8	63.4	y	5
5/31/07 4:00	5/31/07 0:00	5/31/07 11:00	8.0	12.0	61.2	61.2	y	>24	n/a	n/a	n/a	6
none	5/31/07 22:00	6/1/07 3:00		6.0	62.6	62.6	y	10	18	61.6	y	6

[a]Table format courtesy of Reardon, J.E., Berkett, L.P., Garcia, M.E., Gotlieb, A., Ashikaga, T., and Badger, G. 2005. Field evaluation of the new sequential sampling technique for determining apple scab "risk". Plant Disease 89(3):228-236

[b]None=no rain, only leaf wetness.

[c]LW=leaf wetness.

[d]IP=infection period, N=no, Y=yes. Infection periods were calculated using formulas from Reardon, J.E., Berkett, L.P., Garcia, M.E., Gotlieb, A., Ashikaga, T., and Badger, G. 2005. Field evaluation of the new sequential sampling technique for determining apple scab "risk". Plant Disease 89(3):228-236, using the revised Mills table of MacHardy, W.E. and Gadoury, D.M. 1989. A revision of Mill's criteria for predicting apple scab infection periods. Phytopathology 79:304-310, as amended by Stensvand, A., Gardoury, D.M., Amundsen, T., Semb, L., and Seem, R.C. 1997. Ascospore release and infection of apple leaves by conidia and ascospores of Venturia inaequalis at low temperatures. Phytpathology 87:1046-1053. Since a portion of mature ascospores are released during nighttime hours, rain events that started at night were not discounted.

[e]When a rain period is followed by leaf wetness coused by dew, the first dew period is added to the rain period and they are considered a single consecutive wetting even if separated by <24hr. When two consecutive rain events occur, they are considered a single wetting event if separated by <24hr. N/a=not applicable.

Appendix B-1c. Primary infection periods with rain and leaf wetness events, June 2007[a]

Time rain started[b]	Time LW[c] started	Time LW ended	Hr LW from start of rain	Hr LW from start of LW	Avg. temp. from start of rain to end of LW (°F)	Avg. temp. from start of LW to end of LW (°F)	IP[d]?	Hr between LW	Total hr LW when combined	Avg. temp. when combined	Combined IP[e]?	IP number
6/2/07 5:00	6/2/07 2:00	6/2/07 6:00	2.0	5.0	65.2	65.6	n	22	23	62.5	y	6
6/2/07 8:00	6/2/07 8:00	6/2/07 12:00	5.0	5.0	69.5	69.5	n	1	28	68.3	y	6
6/2/07 14:00	6/2/07 14:00	6/2/07 15:00	1.0	1.0	74.7	74.7	n	1	29	71.5	y	6
6/2/07 17:00	6/2/07 17:00	6/3/07 7:00	15.0	15.0	64.2	64.2	y	2	44	64.7	y	6
6/4/07 4:00	6/4/07 3:00	6/4/07 11:00	8.0	9.0	60.8	60.8	y	19	53	61.9	y	6
6/4/07 17:00	6/4/07 17:00	6/5/07 9:00	17.0	17.0	61.7	61.7	y	5	70	61.7	y	6
6/5/07 20:00	6/5/07 19:00	6/5/07 20:00	0.0	1.0	62.0	64.4	n	9	71	63.5	y	6

[a]Table format courtesy of Reardon, J.E., Berkett, L.P., Garcia, M.E., Gotlieb, A., Ashikaga, T., and Badger, G. 2005. Field evaluation of the new sequential sampling technique for determining apple scab “risk”. Plant Disease 89(3):228-236

[b]None=no rain, only leaf wetness.

[c]LW=leaf wetness.

[d]IP=infection period, N=no, Y=yes. Infection periods were calculated using formulas from Reardon, J.E., Berkett, L.P., Garcia, M.E., Gotlieb, A., Ashikaga, T., and Badger, G. 2005. Field evaluation of the new sequential sampling technique for determining apple scab “risk”. Plant Disease 89(3):228-236, using the revised Mills table of MacHardy, W.E. and Gadoury, D.M. 1989. A revision of Mill’s criteria for predicting apple scab infection periods. Phytopathology 79:304-310, as amended by Stensvand, A., Gardoury, D.M., Amundsen, T., Semb, L., and Seem, R.C. 1997. Ascospore release and infection of apple leaves by conidia and ascospores of Venturia inaequalis at low temperatures. Phytpathology 87:1046-1053. Since a portion of mature ascospores are released during nighttime hours, rain events that started at night were not discounted.

[e]When a rain period is followed by leaf wetness coused by dew, the first dew period is added to the rain period and they are considered a single consecutive wetting even if separated by <24hr. When two consecutive rain events occur, they are considered a single wetting event if separated by <24hr. N/a=not applicable.

Appendix B-2a. Primary infection periods with rain and leaf wetness events, April 2008[a]

Time rain started[b]	Time LW[c] started	Time LW ended	Hr LW from start of rain	Hr LW from start of LW	Avg. temp. from start of rain to end of LW (°F)	Avg. temp. from start of LW to end of LW (°F)	IP[d]?	Hr between LW	Total hr LW when combined	Avg. temp. when combined	Combined IP[e]?	IP number
4/11/08 12:00	4/11/08 11:00	4/12/08 9:00	22	23	37.1	37.1	n	n/a	n/a	n/a	n/a	
4/23/08 23:00	4/23/08 23:00	4/23/08 0:00	2	2	56.8	56.8	n	>24	n/a	n/a	n/a	
4/27/08 4:00	4/27/08 2:00	4/27/08 5:00	2	4	50.1	53.3	n	>24	n/a	n/a	n/a	
4/28/08 11:00	4/28/08 10:00	4/29/08 12:00	26.0	27.0	46.5	46.7	y	>24	n/a	n/a	n/a	1

[a]Table format courtesy of Reardon, J.E., Berkett, L.P., Garcia, M.E., Gotlieb, A., Ashikaga, T., and Badger, G. 2005. Field evaluation of the new sequential sampling technique for determining apple scab “risk”. Plant Disease 89(3):228-236

[b]None=no rain, only leaf wetness.

[c]LW=leaf wetness.

[d]IP=infection period, N=no, Y=yes. Infection periods were calculated using formulas from Reardon, J.E., Berkett, L.P., Garcia, M.E., Gotlieb, A., Ashikaga, T., and Badger, G. 2005. Field evaluation of the new sequential sampling technique for determining apple scab “risk”. Plant Disease 89(3):228-236, using the revised Mills table of MacHardy, W.E. and Gadoury, D.M. 1989. A revision of Mill’s criteria for predicting apple scab infection periods. Phytopathology 79:304-310, as amended by Stensvand, A., Gardoury, D.M., Amundsen, T., Semb, L., and Seem, R.C. 1997. Ascospore release and infection of apple leaves by conidia and ascospores of Venturia inaequalis at low temperatures. Phytpathology 87:1046-1053. Since a portion of mature ascospores are released during nighttime hours, rain events that started at night were not discounted.

[e]When a rain period is followed by leaf wetness coused by dew, the first dew period is added to the rain period and they are considered a single consecutive wetting even if separated by <24hr. When two consecutive rain events occur, they are considered a single wetting event if separated by <24hr. N/a=not applicable.

Appendix B-2b. Primary infection periods with rain and leaf wetness events, May 2008[a]

Time rain started[b]	Time LW[c] started	Time LW ended	Hr LW from start of rain	Hr LW from start of LW	Avg. temp. from start of rain to end of LW (°F)	Avg. temp. from start of LW to end of LW (°F)	IP[d]?	Hr between LW	Total hr LW when combined	Avg. temp. when combined	Combined IP[e]?	IP number
5/2/08 20:00	5/2/08 18:00	5/3/08 1:00	6.0	8.0	46.6	47.6	n	>24	n/a	n/a	n/a	2
5/3/08 3:00	5/3/08 3:00	5/3/08 11:00	9.0	9.0	47.7	47.7	n	1	17	47.7	y	2
5/4/08 4:00	5/4/08 4:00	5/4/08 10:00	7.0	7.0	45.4	45.4	n	16	24	45.7	y	2
5/15/08 6:00	5/15/08 6:00	5/15/08 13:00	8.0	8.0	54.5	54.5	y	>24	n/a	n/a	n/a	3
5/22/08 20:00	5/22/08 20:00	5/23/08 8:00	13.0	13.0	47.6	47.6	y	>24	n/a	n/a	n/a	4
5/23/08 16:00	5/23/08 15:00	5/23/08 17:00	2.0	3.0	54.9	55.6	n	6	16	49.1	y	4
5/23/08 21:00	5/23/08 21:00	5/24/08 6:00	10.0	10.0	49.4	49.4	n	3	26	49.2	y	4
5/26/08 18:00	5/26/08 18:00	5/27/08 10:00	17.0	17.0	62.0	62.0	y	>24	n/a	n/a	n/a	5
5/31/08 3:00	5/31/08 3:00	5/31/08 12:00	10.0	10.0	57.6	57.6	y	>24	n/a	n/a	n/a	6
5/31/08 14:00	5/31/08 14:00	5/31/08 15:00	2.0	2.0	66.8	66.8	n	1	12	63.7	y	6
5/31/08 21:00	5/31/08 21:00	6/1/08 7:00	11.0	11.0	60.2	60.2	y	5	23	60.5	y	6

[a]Table format courtesy of Reardon, J.E., Berkett, L.P., Garcia, M.E., Gotlieb, A., Ashikaga, T., and Badger, G. 2005. Field evaluation of the new sequential sampling technique for determining apple scab "risk". Plant Disease 89(3):228-236

[b]None=no rain, only leaf wetness.

[c]LW=leaf wetness.

[d]IP=infection period, N=no, Y=yes. Infection periods were calculated using formulas from Reardon, J.E., Berkett, L.P., Garcia, M.E., Gotlieb, A., Ashikaga, T., and Badger, G. 2005. Field evaluation of the new sequential sampling technique for determining apple scab "risk". Plant Disease 89(3):228-236, using the revised Mills table of MacHardy, W.E. and Gadoury, D.M. 1989. A revision of Mill's criteria for predicting apple scab infection periods. Phytopathology 79:304-310, as amended by Stensvand, A., Gardoury, D.M., Amundsen, T., Semb, L., and Seem, R.C. 1997. Ascospore release and infection of apple leaves by conidia and ascospores of Venturia inaequalis at low temperatures. Phytpathology 87:1046-1053. Since a portion of mature ascospores are released during nighttime hours, rain events that started at night were not discounted.

[e]When a rain period is followed by leaf wetness coused by dew, the first dew period is added to the rain period and they are considered a single consecutive wetting even if separated by <24hr. When two consecutive rain events occur, they are considered a single wetting event if separated by <24hr. N/a=not applicable.

Appendix C-1a. Ascospore maturity as determined by ascospore maturity model of Gadoury and MacHardy (1982)[a], April, 2007[b]

	Temperature °F			DD °F		Temperature °C			DD °C		Proportion	Confidence Interval	
Date	Mean	High	Low	Daily DD	Accum. DD[c]	Mean	High	Low	Daily DD	Accum. DD	of Spores Mature	Lower Bound	Upper Bound
23-Apr	69.7	82.0	58.3	38.2	38.2	20.9	27.8	14.6	21.2	21.2	0.02077	0.00093	0.06890
24-Apr	51.0	63.5	42.6	21.1	59.2	10.6	17.5	5.9	11.7	32.9	0.02736	0.00137	0.08580
25-Apr	44.0	52.8	37.5	13.2	72.4	6.7	11.6	3.1	7.3	40.2	0.03230	0.00174	0.09782
26-Apr	50.1	60.2	36.5	16.4	88.7	10.1	15.7	2.5	9.1	49.3	0.03944	0.00232	0.11445
27-Apr	52.9	56.9	47.1	20.0	108.7	11.6	13.8	8.4	11.1	60.4	0.04987	0.00326	0.13739
28-Apr	53.7	60.7	45.8	21.3	130.0	12.1	15.9	7.7	11.8	72.2	0.06325	0.00463	0.16501
29-Apr	48.9	53.2	42.6	15.9	145.9	9.4	11.8	5.9	8.8	81.0	0.07497	0.00597	0.18788
30-Apr	50.8	59.3	44.8	20.1	165.9	10.4	15.2	7.1	11.1	92.2	0.09203	0.00815	0.21937

[a]Gadoury, D.M. and MacHardy, W.E. 1982. A model to estimate the maturity of ascospores of Venturia inaequalis. Phytopathology 72:901-904.
[b]Table format courtesy of Reardon, J.E., Berkett, L.P., Garcia, M.E., Gotlieb, A., Ashikaga, T., and Badger, G. 2005. Field evaluation of the new sequential sampling technique for determining apple scab "risk". Plant Disease 89(3):228-236
[c]Gadoury and MacHardy (1982) found ascospores to be in the lag phase of development at 1-300 DD Base 32°F, the accelerated phase at 300-700 DD Base 32°F, and the final phase at 700-800 Base 32°F.

Appendix C-1b. Ascospore maturity as determined by ascospore maturity model of Gadoury and MacHardy (1982)[a], May, 2007[b]

	Temperature ºF			DD ºF		Temperature ºC			DD ºC		Proportion	Confidence Interval	
				Daily	Accum.				Daily	Accum.	of Spores	Lower	Upper
Date	Mean	High	Low	DD	DD[b]	Mean	High	Low	DD	DD	Mature	Bound	Bound
1-May	48.0	55.9	37.6	14.8	180.7	8.9	13.3	3.1	8.2	100.4	0.10631	0.01016	0.24435
2-May	48.9	57.6	40.5	17.1	197.7	9.4	14.2	4.7	9.5	109.8	0.12473	0.01302	0.27503
3-May	48.7	59.9	33.8	14.9	212.6	9.3	15.5	1.0	8.3	118.1	0.14250	0.01605	0.30322
4-May	48.5	62.3	31.3	14.8	227.4	9.2	16.8	-0.4	8.2	126.3	0.16183	0.01965	0.33253
5-May	47.1	58.9	34.0	14.5	241.8	8.4	14.9	1.1	8.0	134.3	0.18229	0.02381	0.36217
6-May	47.3	58.3	36.5	15.4	257.2	8.5	14.6	2.5	8.6	142.9	0.20579	0.02904	0.39469
7-May	49.7	72.1	32.1	20.1	277.3	9.8	22.3	0.1	11.2	154.1	0.23902	0.03726	0.43824
8-May	67.9	83.0	54.7	36.9	314.2	19.9	28.3	12.6	20.5	174.5	0.30688	0.05720	0.51965
9-May	69.0	83.4	58.6	39.0	353.2	20.5	28.6	14.8	21.7	196.2	0.38665	0.08659	0.60486
10-May	68.8	87.2	55.4	39.3	392.5	20.4	30.7	13.0	21.8	218.0	0.47221	0.12637	0.68591
11-May	66.9	78.1	60.1	37.1	429.6	19.4	25.6	15.6	20.6	238.6	0.55424	0.17422	0.75503
12-May	49.6	59.9	41.6	18.8	448.3	9.8	15.5	5.3	10.4	249.1	0.59505	0.20230	0.78656
13-May	48.9	59.8	36.3	16.1	464.4	9.4	15.4	2.4	8.9	258.0	0.62920	0.22835	0.81158
14-May	59.1	73.9	39.8	24.9	489.2	15.1	23.3	4.3	13.8	271.8	0.68003	0.27218	0.84656
15-May	57.9	71.6	51.6	29.6	518.8	14.4	22.0	10.9	16.4	288.2	0.73638	0.32933	0.88223
16-May	47.2	52.5	40.9	14.7	533.5	8.5	11.4	4.9	8.2	296.4	0.76235	0.35938	0.89758
17-May	43.2	48.3	39.1	11.7	545.2	6.2	9.1	3.9	6.5	302.9	0.78198	0.38395	0.90872
18-May	46.3	55.3	36.8	14.1	559.3	7.9	12.9	2.7	7.8	310.7	0.80426	0.41408	0.92087
19-May	49.7	57.3	39.9	16.6	575.9	9.8	14.1	4.4	9.2	319.9	0.82873	0.45033	0.93360
20-May	54.3	62.3	47.7	23.0	598.9	12.4	16.8	8.7	12.8	332.7	0.85925	0.50117	0.94855

[a]Gadoury, D.M. and MacHardy, W.E. 1982. A model to estimate the maturity of ascospores of Venturia inaequalis. Phytopathology 72:901-904.
[b]Table format courtesy of Reardon, J.E., Berkett, L.P., Garcia, M.E., Gotlieb, A., Ashikaga, T., and Badger, G. 2005. Field evaluation of the new sequential sampling technique for determining apple scab “risk”. Plant Disease 89(3):228-236
[c]Gadoury and MacHardy (1982) found ascospores to be in the lag phase of development at 1-300 DD Base 32°F, the accelerated phase at 300-700 DD Base 32°F, and the final phase at 700-800 Base 32°F.

Appendix C-1c. Ascospore maturity as determined by ascospore maturity model of Gadoury and MacHardy (1982)[a], May and June, 2007[b]

	Temperature °F			DD °F		Temperature °C			DD °C		Proportion	Confidence Interval	
Date	Mean	High	Low	Daily DD	Accum. DD[b]	Mean	High	Low	Daily DD	Accum. DD	of Spores Mature	Lower Bound	Upper Bound
21-May	51.3	63.2	43.3	21.3	620.1	10.7	17.3	6.3	11.8	344.5	0.88396	0.54815	0.95985
22-May	52.7	67.8	36.0	19.9	640.0	11.5	19.9	2.2	11.1	355.6	0.90415	0.59156	0.96853
23-May	61.7	79.0	44.5	29.8	669.8	16.5	26.1	6.9	16.5	372.1	0.92933	0.65425	0.97856
24-May	72.3	87.8	58.4	41.1	710.9	22.4	31.0	14.7	22.8	394.9	0.95536	0.73407	0.98788
25-May	75.6	89.0	62.0	43.5	754.4	24.2	31.7	16.7	24.2	419.1	0.97386	0.80698	0.99370
26-May	68.4	76.3	55.4	33.9	788.2	20.2	24.6	13.0	18.8	437.9	0.98337	0.85426	0.99635
27-May	59.6	67.1	47.4	25.3	813.5	15.3	19.5	8.6	14.0	451.9	0.98837	0.88399	0.99762
28-May	65.0	71.8	59.8	33.8	847.3	18.3	22.1	15.4	18.8	470.7	0.99299	0.91666	0.99870
29-May	62.0	72.8	48.6	28.7	876.0	16.7	22.7	9.2	15.9	486.6	0.99556	0.93851	0.99924
30-May	63.7	80.7	48.9	32.8	908.8	17.6	27.1	9.4	18.2	504.9	0.99743	0.95770	0.99960
31-May	64.1	72.7	59.0	33.9	942.6	17.8	22.6	15.0	18.8	523.7	0.99859	0.97210	0.99980
1-Jun	71.0	81.1	61.2	39.2	981.8	21.7	27.3	16.2	21.8	545.4	0.99932	0.98342	0.99991

[a]Gadoury, D.M. and MacHardy, W.E. 1982. A model to estimate the maturity of ascospores of Venturia inaequalis. Phytopathology 72:901-904.
[b]Table format courtesy of Reardon, J.E., Berkett, L.P., Garcia, M.E., Gotlieb, A., Ashikaga, T., and Badger, G. 2005. Field evaluation of the new sequential sampling technique for determining apple scab "risk". Plant Disease 89(3):228-236
[c]Gadoury and MacHardy (1982) found ascospores to be in the lag phase of development at 1-300 DD Base 32°F, the accelerated phase at 300-700 DD Base 32°F, and the final phase at 700-800 Base 32°F.

Appendix C-2a. Ascospore maturity as determined by ascospore maturity model of Gadoury and MacHardy (1982)[a], April, 2008[b]

	Temperature °F			DD °F		Temperature °C			DD °C		Proportion	Confidence Interval	
Date	Mean	High	Low	Daily DD	Accum. DD[c]	Mean	High	Low	Daily DD	Accum. DD	of Spores Mature	Lower Bound	Upper Bound
19-Apr	54.8	76.8	40.3	26.6	26.6	12.7	24.9	4.6	14.8	14.8	0.01775	0.00075	0.06075
20-Apr	66.1	77.4	48.2	30.8	57.4	18.9	25.2	9.0	17.1	31.9	0.02672	0.00133	0.08420
21-Apr	63.0	76.3	49.9	31.1	88.5	17.2	24.6	9.9	17.3	49.1	0.03932	0.00231	0.11418
22-Apr	62.9	77.4	48.2	30.8	119.3	17.1	25.2	9.0	17.1	66.3	0.05620	0.00389	0.15068
23-Apr	66.3	78.1	54.7	34.4	153.7	19.1	25.6	12.6	19.1	85.4	0.08130	0.00675	0.19979
24-Apr	56.6	66.3	45.4	23.9	177.5	13.7	19.1	7.4	13.3	98.6	0.10313	0.00970	0.23889
25-Apr	53.3	67.9	40.2	22.1	199.6	11.8	19.9	4.6	12.3	110.9	0.12685	0.01337	0.27847
26-Apr	60.6	70.8	48.0	27.4	227.0	15.9	21.6	8.9	15.2	126.1	0.16129	0.01955	0.33172
27-Apr	58.5	68.4	48.3	26.4	253.3	14.7	20.2	9.1	14.6	140.7	0.19968	0.02763	0.38638
28-Apr	50.7	56.6	46.4	19.5	272.8	10.4	13.7	8.0	10.8	151.6	0.23134	0.03527	0.42840
29-Apr	43.5	46.8	39.5	11.2	284.0	6.4	8.2	4.2	6.2	157.8	0.25063	0.04036	0.45284
30-Apr	40.3	48.5	33.1	8.8	292.8	4.6	9.2	0.6	4.9	162.6	0.26644	0.04479	0.47225

[a]Gadoury, D.M. and MacHardy, W.E. 1982. A model to estimate the maturity of ascospores of Venturia inaequalis. Phytopathology 72:901-904.
[b]Table format courtesy of Reardon, J.E., Berkett, L.P., Garcia, M.E., Gotlieb, A., Ashikaga, T., and Badger, G. 2005. Field evaluation of the new sequential sampling technique for determining apple scab “risk”. Plant Disease 89(3):228-236
[c]Gadoury and MacHardy (1982) found ascospores to be in the lag phase of development at 1-300 DD Base 32°F, the accelerated phase at 300-700 DD Base 32°F, and the final phase at 700-800 Base 32°F.

Appendix C-2b. Ascospore maturity as determined by ascospore maturity model of Gadoury and MacHardy (1982)[a], May, 2008[b]

	Temperature ºF			DD ºF		Temperature ºC			DD ºC		Proportion	Confidence Interval	
Date	Mean	High	Low	Daily DD	Accum. DD[b]	Mean	High	Low	Daily DD	Accum. DD	of Spores Mature	Lower Bound	Upper Bound
1-May	41.9	54.1	30.3	10.2	303.0	5.5	12.3	-0.9	5.7	168.3	0.28538	0.05040	0.49484
2-May	45.1	53.2	35.6	12.4	315.4	7.3	11.8	2.0	6.9	175.2	0.30922	0.05797	0.52231
3-May	49.3	53.9	45.8	17.9	333.2	9.6	12.2	7.7	9.9	185.1	0.34499	0.07039	0.56163
4-May	49.9	59.8	44.5	20.2	353.4	9.9	15.4	6.9	11.2	196.3	0.38708	0.08677	0.60529
5-May	48.9	65.5	35.6	18.6	371.9	9.4	18.6	2.0	10.3	206.6	0.42705	0.10422	0.64435
6-May	56.2	73.3	40.2	24.8	396.7	13.5	22.9	4.6	13.8	220.4	0.48150	0.13127	0.69414
7-May	53.7	65.8	37.6	19.7	416.4	12.0	18.8	3.1	10.9	231.3	0.52514	0.15602	0.73140
8-May	60.1	68.6	49.1	26.9	443.2	15.6	20.3	9.5	14.9	246.2	0.58403	0.19440	0.77823
9-May	49.8	59.3	39.2	17.3	460.5	9.9	15.2	4.0	9.6	255.8	0.62098	0.22185	0.80567
10-May	52.7	67.4	38.0	20.7	481.2	11.5	19.7	3.3	11.5	267.3	0.66387	0.25754	0.83573
11-May	53.9	68.4	40.8	22.6	503.8	12.2	20.2	4.9	12.6	279.9	0.70836	0.29966	0.86490
12-May	56.4	64.2	47.3	23.8	527.5	13.6	17.9	8.5	13.2	293.1	0.75192	0.34700	0.89150
13-May	55.7	70.4	41.3	23.9	551.4	13.2	21.3	5.2	13.3	306.3	0.79191	0.39707	0.91420
14-May	61.3	78.8	41.6	28.2	579.6	16.3	26.0	5.3	15.7	322.0	0.83391	0.45847	0.93621
15-May	59.8	68.1	48.8	26.5	606.0	15.4	20.1	9.3	14.7	336.7	0.86793	0.51702	0.95261
16-May	50.5	59.8	40.3	18.1	624.1	10.3	15.4	4.6	10.0	346.7	0.88819	0.55683	0.96172
17-May	56.3	72.1	39.3	23.7	647.8	13.5	22.3	4.1	13.2	359.9	0.91127	0.60819	0.97145
18-May	55.9	67.1	49.2	26.2	673.9	13.3	19.5	9.6	14.5	374.4	0.93240	0.66272	0.97971
19-May	46.9	49.8	45.1	15.5	689.4	8.3	9.9	7.3	8.6	383.0	0.94291	0.69347	0.98357
20-May	53.0	62.9	43.5	21.2	710.6	11.7	17.2	6.4	11.8	394.8	0.95520	0.73352	0.98782

[a]Gadoury, D.M. and MacHardy, W.E. 1982. A model to estimate the maturity of ascospores of Venturia inaequalis. Phytopathology 72:901-904.
[b]Table format courtesy of Reardon, J.E., Berkett, L.P., Garcia, M.E., Gotlieb, A., Ashikaga, T., and Badger, G. 2005. Field evaluation of the new sequential sampling technique for determining apple scab "risk". Plant Disease 89(3):228-236
[c]Gadoury and MacHardy (1982) found ascospores to be in the lag phase of development at 1-300 DD Base 32°F, the accelerated phase at 300-700 DD Base 32°F, and the final phase at 700-800 Base 32°F.

Appendix C-2c. Ascospore maturity as determined by ascospore maturity model of Gadoury and MacHardy (1982)[a], May and June, 2008[b]

	Temperature °F			DD °F		Temperature °C			DD °C		Proportion	Confidence Interval	
				Daily	Accum.				Daily	Accum.	of Spores	Lower	Upper
Date	Mean	High	Low	DD	DD[b]	Mean	High	Low	DD	DD	Mature	Bound	Bound
21-May	51.6	61.3	42.3	19.8	730.4	10.9	16.3	5.7	11.0	405.8	0.96466	0.76837	0.99090
22-May	49.5	56.6	42.6	17.6	748.0	9.7	13.7	5.9	9.8	415.5	0.97163	0.79709	0.99304
23-May	52.4	61.2	42.9	20.1	768.0	11.3	16.2	6.1	11.1	426.7	0.97813	0.82707	0.99492
24-May	57.3	67.9	46.5	25.2	793.2	14.0	19.9	8.1	14.0	440.7	0.98448	0.86052	0.99664
25-May	59.2	76.0	42.2	27.1	820.3	15.1	24.4	5.7	15.1	455.7	0.98948	0.89125	0.99789
26-May	63.7	74.0	53.8	31.9	852.2	17.6	23.3	12.1	17.7	473.4	0.99351	0.92080	0.99881
27-May	56.8	66.9	49.9	26.4	878.6	13.8	19.4	9.9	14.7	488.1	0.99574	0.94028	0.99928
28-May	51.9	64.3	39.9	20.1	898.7	11.1	17.9	4.4	11.2	499.3	0.99695	0.95242	0.99951
29-May	60.4	76.7	44.2	28.5	927.2	15.8	24.8	6.8	15.8	515.1	0.99814	0.96614	0.99972
30-May	56.8	69.8	40.8	23.3	950.5	13.8	21.0	4.9	12.9	528.0	0.99878	0.97478	0.99983
31-May	62.7	75.6	54.1	32.9	983.3	17.0	24.2	12.3	18.3	546.3	0.99934	0.98377	0.99992
1-Jun	60.1	66.4	56.2	29.3	1012.6	15.6	19.1	13.4	16.3	562.6	0.99963	0.98932	0.99996

[a]Gadoury, D.M. and MacHardy, W.E. 1982. A model to estimate the maturity of ascospores of Venturia inaequalis. Phytopathology 72:901-904.
[b]Table format courtesy of Reardon, J.E., Berkett, L.P., Garcia, M.E., Gotlieb, A., Ashikaga, T., and Badger, G. 2005. Field evaluation of the new sequential sampling technique for determining apple scab "risk". Plant Disease 89(3):228-236
[c]Gadoury and MacHardy (1982) found ascospores to be in the lag phase of development at 1-300 DD Base 32°F, the accelerated phase at 300-700 DD Base 32°F, and the final phase at 700-800 Base 32°F.

APPENDIX D. Leaf Emergence

Appendix D-1. Leaf Emergence Assessment Methods, UVM Horticultural Research Center, South Burlington, VT.

Leaf emergence was assessed throughout the 2007 and 2008 growing seasons to potentially allow infection periods and spray applications to be compared to location of disease symptoms on the terminals. To obtain an average of leaf emergence, terminals were selected and flagged on five non-sprayed and five lime sulfur/sulfur treated 'Empire' trees in the research orchard of this alternative fungicide study. The position of the last unfurled leaf on ten vegetative terminals per tree was assessed and recorded every 7-10 days. The terminals were selected from within the upper (within eight feet from the ground), lower, inner, and outer canopy; terminals were selected from around the whole area of the tree circumference.

In 2007 and 2008, leaf emergence was not monitored throughout the entire season on some of the selected terminals because the tip was broken due to mechanical injury or the entire terminal was mistakenly pruned during summer pruning in the orchard. Therefore, there was missing data for these terminals after certain dates. Leaf emergence was measured from 10 May – 23 July 2007 and 19 May – 4 August 2008.

Appendix D-2a. 2007 Leaf Emergence Assessment, 'Empire' trees in research study, UVM Horticultural Research Center, South Burlington, VT.

Date	Tree[z]	# leaves/Terminal (range)	# leaves/Terminal (avg)
5/10/2007	non	3-12	6
	LS/S	3-8	6
5/19/2007	non	4-12	8
	LS/S	5-10	8
5/23/2007	non	4-12	9
	LS/S	6-11	9
6/4/2007	non	8-16	13
	LS/S	6-17	12
6/11/2007	non	8-18	14
	LS/S	6-18	14
6/18/2007	non	8-20	14
	LS/S	6-22	15
6/25/2007	non	9-23	15
	LS/S	5-25	15
7/3/2007	non	8-25	16
	LS/S	6-25	18
7/9/2007	non	8-28	19
	LS/S	6-32	20
7/17/2007	non	9-31	20
	LS/S	6-35	20
7/23/2007	non	9-33	21
	LS/S	6-37	21

[z]non=non-sprayed treatment LS/S=lime sulfur/sulfur treatment. Ten terminals on all five trees in each of these treatments were assessed for leaf emergence so to gauge what leaf positions were present at times of infection periods.

Appendix D-2b. 2008 Leaf Emergence Assessment, 'Empire' trees in research study, UVM Horticultural Research Center, South Burlington, VT.

Date	Tree[z]	# leaves/Terminal (range)	# leaves/Terminal (avg)
5/19/2008	non	8-12	11
	LS/S	9-13	11
5/27/2008	non	8-14	12
	LS/S	9-14	12
6/2/2008	non	9-16	13
	LS/S	10-16	13
6/9/2008	non	9-19	16
	LS/S	10-18	14
6/16/2008	non	11-22	17
	LS/S	10-20	14
6/23/2008	non	11-23	18
	LS/S	10-22	15
6/30/2008	non	11-27	19
	LS/S	10-24	16
7/7/2008	non	11-30	21
	LS/S	10-27	17
7/14/2008	non	11-33	22
	LS/S	10-30	19
7/21/2008	non	11-37	24
	LS/S	10-33	20
8/4/2008	non	11-42	25
	LS/S	10-37	21

[z]non=non-sprayed treatment LS/S=lime sulfur/sulfur treatment. Ten terminals on all five trees in each of these treatments were assessed for leaf emergence so to gauge what leaf positions were present at times of infection periods.

Appendix E. Phytotoxic burns and russetting observed on fruit.

Figure 1. Phytotoxic burns on 'Empire' fruit, Jul 2007.

Figure 2. Phytotoxic burns on 'Empire' fruit, Sept 2007.

Figure 3. Russetting observed on 'Empire' fruit, Sept 2008.

Appendix F. United States Department of Agriculture, Standards for Grades of Apples**.**

United States Department of Agriculture. 2002. United States Standards for Grades of Apples. USDA Agricultural Marketing Service, Fruit and Vegetable Programs, Fresh Products Branch.

§51.316 Injury.

"Injury" means any specific defect defined in this Section or an equally objectionable variation of any one of these defects, any other defect, or any combination of defects, which more than slightly detract from the appearance or the edible or shipping quality of the apple. In addition, specific defect measurements are based on an apple three inches in diameter. Corresponding smaller or larger areas would be allowed on smaller or larger fruit. Any reference to *"inch"* or *"inches in diameter"* refers to that of a circle of the specified diameter. Any reference to *"aggregate area," "total area,"* or *"aggregate affected area"* means the gathering together of separate areas into one mass for the purpose of comparison to determine the extent affected. The following specific defects shall be considered as injury:

(a) Russetting in the stem cavity or calyx basin which cannot be seen when the apple is placed stem end or calyx end down on a flat surface shall not be considered in determining whether an apple is injured by russetting. Smooth net-like russetting outside of the stem cavity or calyx basin shall be considered as injury when an aggregate area of more than 10 percent of the surface is covered, and the color of the russetting shows no very pronounced contrast with the background color of the apple, or lesser amounts of more conspicuous net-like russetting when the appearance is affected to a greater extent than the amount permitted above.

(b) Sunburn or sprayburn, when the discolored area does not blend into the normal color of the fruit.

(c) Dark brown or black limb rubs which affect a total area of more than one-fourth inch in diameter, except that light brown limb rubs of a russet character shall be considered under the definition of injury by russetting.

(d) Hail marks, drought spots, other similar depressions or scars:

(1) When the skin is broken, whether healed or unhealed;

(2) When there is appreciable discoloration of the surface;

(3) When any surface indentation exceeds one-sixteenth inch in depth;

(4) When any surface indentation exceeds one-eighth inch in diameter; or

(5) When the aggregate affected area of such spots exceeds one-half inch in diameter.

(e) Bruises which are not slight and incident to proper handling and packing, and which are greater than:

(1) 1/8 inch in depth;

(2) 5/8 inch in diameter;

(3) any combination of lesser bruises which detract from the appearance or edible quality of the apple to an extent greater than any one bruise described in paragraphs (1) or (2) of this section.

(f) Brown surface discoloration when caused by delayed sunburn, surface scald, or any other means and affects an area greater than 1/4 inch in diameter.
(g) Disease: (1) Cedar rust infection which affects a total area of more than three-sixteenths inch in diameter.
(2) Sooty blotch or fly speck which is thinly scattered over more than 5 percent of the surface, or dark, heavily concentrated spots which affect an area of more than one-fourth inch in diameter.
(3) Red skin spots which are thinly scattered over more than one-tenth of the surface, or dark, heavily concentrated spots which affect an area of more than one-fourth inch in diameter.
(h) Insects: (1) Any healed sting or healed stings which affect a total area of more than one-eighth inch in diameter including any encircling discolored rings.
(2) Worm holes.

§51.317 Damage.

"Damage" means any specific defect defined in this section or an equally objectionable variation of any one of these defects, any other defect, or any combination of defects, which materially detract from the appearance, or the edible or shipping quality of the apple. In addition, specific defect measurements are based on an apple three inches in diameter. Corresponding smaller or larger areas would be allowed on smaller or larger fruit. Any reference to *"inch"* or *"inches in diameter"* refers to that of a circle of the specified diameter. Any reference to *"aggregate area," "total area,"* or *"aggregate affected area"* means the gathering together of separate areas into one mass for the purpose of comparison to determine the extent affected. The following specific defects shall be considered as damage:
(a) Russetting in the stem cavity or calyx basin which cannot be seen when the apple is placed stem end or calyx end down on a flat surface shall not be considered in determining whether an apple is damaged by russetting, except that excessively rough or bark-like russetting in the stem cavity or calyx basin shall be considered as damage when the appearance of the apple is materially affected. The following types and amounts of russetting outside of the stem cavity or calyx basin shall be considered as damage:
(1) Russetting which is excessively rough on Roxbury Russet and other similar varieties.
(2) Smooth net-like russetting, when an aggregate area of more than 15 percent of the surface is covered, and the color of the russetting shows no very pronounced contrast with the background color of the apple, or lesser amounts of more conspicuous net-like russetting when the appearance is affected to a greater extent than the amount permitted above.
(3) Smooth solid russetting, when an aggregate area of more than 5 percent of the surface is covered, and the pattern and color of the russetting shows no very pronounced contrast with the background color of the apple, or lesser amounts of more conspicuous solid russetting when the appearance is affected to a greater extent than the above amount permitted.
(4) Slightly rough russetting which covers an aggregate area of more than one-half inch in diameter.

(5) Rough russetting which covers an aggregate area of more than one-fourth inch in diameter.
(b) Sunburn or sprayburn which has caused blistering or cracking of the skin, or when the discolored area does not blend into the normal color of the fruit unless the injury can be classed as russetting.
(c) Limb rubs which affect a total area of more than one-half inch in diameter, except that light brown limb rubs of a russet character shall be considered under the definition of damage by russetting.
(d) Hail marks, drought spots, other similar depressions, or scars:
(1) When any unhealed mark is present;
(2) When any surface indentation exceeds one-eighth inch in depth;
(3) When the skin has not been broken and the aggregate affected area exceeds one-half inch in diameter; or
(4) When the skin has been broken and well healed, and the aggregate affected area exceeds one-fourth inch in diameter.
(e) Stem or calyx cracks which are not well healed, or well healed stem or calyx cracks which exceed an aggregate length of one-fourth inch.
(f) Invisible water core existing around the core and extending to water core in the vascular bundles, or surrounding the vascular bundles when the affected areas surrounding three or more vascular bundles meet or coalesce, or existing in more than a slight degree outside the circular area formed by the vascular bundles. *Provided*, That invisible water core shall not be scored as damage against the Fuji variety of apples under any circumstances.
(g) Bruises which are not slight and incident to proper handling and packing, and which are greater than:
(1) 3/16 inch in depth;
(2) 7/8 inch in diameter;
(3) any combination of lesser bruises which detract from the appearance or edible quality of the apple to an extent greater than any one bruise described in paragraphs (1) or (2) of this section.
(h) Brown surface discoloration when caused by delayed sunburn, surface scald, or any other means and affects an area greater than 1/2 inch in diameter.
(i) Disease: (1) Scab spots which affect a total area of more than one-fourth inch in diameter.
(2) Cedar rust infection which affects a total area of more than one-fourth inch in diameter.
(3) Sooty blotch or fly speck which is thinly scattered over more than one-tenth of the surface, or dark, heavily concentrated spots which affect an area of more than one-half inch in diameter.
(4) Red skin spots which are thinly scattered over more than one-tenth of the surface, or dark, heavily concentrated spots which affect an area of more than one-half inch in diameter.
(5) Bitter pit or Jonathan spot when one or more spots affects the surface of the apple.

(j) Insects: (1) Any healed sting or healed stings which affect a total area of more than three-sixteenths inch in diameter including any encircling discolored rings.
(2) Worm holes.

§51.318 Serious damage.

"Serious damage" means any specific defect defined in this section; or an equally objectionable variation of any one of these defects, any other defect, or any combination of defects which seriously detract from the appearance, or the edible or shipping quality of the apple. In addition, specific defect measurements are based on an apple three inches in diameter. Corresponding smaller or larger areas would be allowed on smaller or larger fruit. Any reference to *"inch"* or *"inches in diameter"* refers to that of a circle of the specified diameter. Any reference to *"aggregate area," "total area,"* or *"aggregate affected area"* means the gathering together of separate areas into one mass for the purpose of comparison to determine the extent affected. The following specific defects shall be considered as serious damage:
(a) The following types and amounts of russetting shall be considered as serious damage:
(1) Smooth solid russetting, when more than one-half of the surface in the aggregate is covered, including any russetting in the stem cavity or calyx basin, or slightly rough, or excessively rough or bark-like russetting, which detracts from the appearance of the fruit to a greater extent than the amount of smooth solid russetting permitted: *Provided,* That any amount of russetting shall be permitted on Roxbury Russet and other similar varieties.
(2) [Reserved]
(b) Sunburn or sprayburn which seriously detracts from the appearance of the fruit.
(c) Limb rubs which affect more than one-tenth of the surface in the aggregate.
(d) Hail marks, drought spots, or scars, if they materially deform or disfigure the fruit, or if such defects affect more than one-tenth of the surface in the aggregate: *Provided,* That no hail marks which are unhealed shall be permitted and not more than an aggregate area of one-half inch shall be allowed for well healed hail marks where the skin has been broken.
(e) Stem or calyx cracks which are not well healed, or well healed stem or calyx cracks which exceed an aggregate length of one-half inch.
(f) Visible water core which affects an area of more than one-half inch in diameter.
(g) Disease: (1) Scab spots which affect a total area of more than three-fourths inch in diameter.
(2) Cedar rust infection which affects a total area of more than three-fourths inch in diameter.
(3) Sooty blotch or fly speck which affects more than one-third of the surface.
(4) Red skin spots which affect more than one-third of the surface.
(5) Bitter pit or Jonathan spot which is thinly scattered over more than one-tenth of the surface.
(h) Insects: (1) Healed stings which affect a total area of more than one-fourth inch in diameter including any encircling discolored rings.
(2) Worm holes.

(i) Bruises which are not slight and incident to proper handling and packing, and which are greater than:
(1) 3/8 inch in depth;
(2) 1 1/8 inches in diameter;
(3) any combination of lesser bruises which detract from the appearance or edible quality of the apple to an extent greater than any one bruise described in paragraph (i)(1) or (2) of this section.
(j) Brown surface discoloration when caused by delayed sunburn, surface scald, or any other means and affects an area greater than 3/4 inch in diameter.

Table 1. Apple scab on 'Empire' trees, 2007 & 2008.

2007

		Percent scab incidence				Scab severity[t]		
	Application timing[z]	Cluster leaves[x]	Terminal leaves[w]		Fruit[v]	Cluster leaves	Terminal leaves	
Treatment and rate/A (rate/ha)		18-20 Jun	18-20 Jun	22-24 Aug	10 Sep	18-20 Jun	18-20 Jun	22-24 Aug
potassium bicarbonate 3.75 lb (4.2 kg)	1-12………..	0.1(±0.3)[u]	0.4(±0.6)	12.3(±6.2) b	11.2(±8.2) bc	0.0(±0.0)	0.1(±0.1)	3.4(±2.4) ab
Bacillus subtilis 3 lb (3.4 kg)………	1-12………..	0.3(±0.6)	1.5(±0.7)	17.0(±8.3) b	22.4(±8.6) ab	0.0(±0.1)	0.2(±0.1)	3.0(±2.6) ab
neem oil 2 gal (18.7 L)………..……	1-12………..	0.0(±0.0)	1.2(±1.2)	9.9(±6.1) b	11.6(±12.4) bc	0.0(±0.0)	0.2(±0.2)	2.0(±0.6) bc
sulfur 15 lb (16.8 kg)	1, 5, 8, 10-12							
lime sulfur 2 gal (18.7 L)………..	2-4, 6-7, 9….	0.0(±0.0)	0.7(±0.8)	1.1(±1.1) c	0.4(±0.9) c	0.0(±0.0)	0.1(±0.2)	0.3(±0.2) c
non-sprayed…………………………	1-12………..	0.3(±0.6)	2.4(±2.0)	29.2(±2.1) a	25.2(±12.7) a	0.0(±0.1)	0.4(±0.3)	4.9(±0.9) a

2008

		Percent scab incidence				Scab severity[t]		
	Application	Cluster leaves[x]	Terminal leaves[w]		Fruit[v]	Cluster leaves	Terminal leaves	
Treatment and rate/A (rate/ha)	timing[y]	16-18 Jun	16-18 Jun	12-15 Aug	3 Sep	16-18 Jun	16-18 Jun	12-15 Aug
potassium bicarbonate 3.75 lb (4.2 kg)	1-12………..	2.1(±1.6) c[u]	13.6(±2.9) b	41.5(±4.6) b	45.8(±11.5) b	0.4(±0.3) cd	1.2(±0.2) a	4.4(±0.9) b
Bacillus subtilis 3 lb (3.4 kg)………	1-12………..	5.2(±3.9) bc	16.9(±4.9) ab	54.5(±8.6) a	62.4(±6.7) a	0.5(±0.4) bc	1.5(±0.4) a	7.9(±3.4) a
neem oil 2 gal (18.7 L)………..……	1-12………..	7.6(±2.7) ab	9.9(±5.2) bc	28.7(±8.9) c	32.4(±12.1) c	1.0(±0.3) a	1.1(±0.6) a	3.3(±1.8) bc
sulfur 15 lb (16.8 kg)	8-12………..							
lime sulfur 2 gal (18.7 L)………..	1-7………….	1.1(±1.7) c	4.3(±1.5) c	8.9(±5.7) d	2.9(±4.1) d	0.1(±0.1) d	0.6(±0.3) b	0.7(±0.4) c
non-sprayed…………………………	1-12………..	10.9(±4.7) a	21.9(±11.1) a	55.7(±3.9) a	64.0(±10.3) a	0.8(±0.3) ab	1.4(±0.3) a	7.7(±2.4) a

[z]Application timings: 1 = (Green-tip) 26 Apr; 2 = (TC) 7 May; 3 = (Pink) 11 May; 4 = (Pink) 17 May; 5 = (Pink-Bloom) 24 May; 6 = (Petal fall) 29 May; 7 = 7 Jun; 8 = 14 Jun; 9 = 22 Jun; 10 = 29 Jun; 11 = 12 Jul; 12 = 23 Jul.

[y]Application timings: 1 = (Green-tip) 23 Apr; 2 = (TC) 1 May; 3 = (Pink) 7 May; 4 = (Bloom) 14 May; 5 = (Petal fall) 21 May; 6 = 30 May; 7 = 5 Jun; 8 = 12 Jun; 9 = 19 Jun; 10 = 26 Jun; 11 = 2 Jul; 12 = 17 Jul.

[x]Assessment of 10 clusters per tree on 5 single-tree replicates per treatment

[w]Assessment of 10 terminals per tree on 5 single-tree replicates per treatment

[v]Assessment of 50 fruit per tree on 5 single-tree replicates per treatment

[u]Numbers within columns followed by the same letter do not differ significantly, Fisher's Protected LSD, $P \leq 0.05$; columns with no letters following the numbers do not have a significant F-value, Analysis of Variance, $P \leq 0.05$ or Kruskal-Wallis, $P \leq 0.05$, when data normality could not be rescued with data transformation because of zeros in data.

[t]Mean number of lesions per infected leaf

Table 2. Cedar apple rust on 'Empire' trees, 2007 & 2008.

2007

Treatment and rate/A (rate/ha)	Application timing[z]	Percent cedar apple rust incidence: Cluster leaves[x] 18-20 Jun	Terminal leaves[w] 18-20 Jun	Terminal leaves[w] 22-24 Aug	Fruit[v] 10 Sep	Cedar apple rust severity[t]: Cluster leaves 18-20 Jun	Terminal leaves 18-20 Jun	Terminal leaves 22-24 Aug
potassium bicarbonate 3.75 lb (4.2 kg)	1-12………..	0.0(±0.0)[u]	8.8(±3.2) a	16.5(±9.2)	0.0(±0.0)	0.0(±0.0)	0.8(±0.4) a	1.4(±0.4)
Bacillus subtilis 3 lb (3.4 kg)………	1-12………..	0.0(±0.0)	3.5(±0.9) bc	13.8(±3.4)	0.0(±0.0)	0.0(±0.0)	0.6(±0.4) ab	1.3(±0.2)
neem oil 2 gal (18.7 L)………..……	1-12………..	0.0(±0.0)	1.5(±1.8) c	10.8(±4.0)	0.0(±0.0)	0.0(±0.0)	0.2(±0.2) c	1.1(±0.1)
sulfur 15 lb (16.8 kg)	1, 5, 8, 10-12							
lime sulfur 2 gal (18.7 L)………..	2-4, 6-7, 9….	0.1(±0.3)	4.0(±1.4) bc	12.6(±4.7)	0.0(±0.0)	0.0(±0.0)	0.4(±0.1) bc	1.3(±0.2)
non-sprayed…………………………	1-12………..	0.0(±0.0)	4.8(±2.1) b	17.3(±4.1)	0.0(±0.0)	0.0(±0.0)	0.6(±0.2) ab	1.4(±0.3)

2008

Treatment and rate/A (rate/ha)	Application timing[y]	Percent cedar apple rust incidence: Cluster leaves[x] 16-18 Jun	Terminal leaves[w] 16-18 Jun	Terminal leaves[w] 12-15 Aug	Fruit[v] 3 Sep	Cedar apple rust severity[t]: Cluster leaves 16-18 Jun	Terminal leaves 16-18 Jun	Terminal leaves 12-15 Aug
potassium bicarbonate 3.75 lb (4.2 kg)	1-12………..	0.0(±0.0)[u]	3.3(±1.2)	6.8(±4.4)	0.0(±0.0)	0.0(±0.0)	0.4(±0.2)	0.7(±0.4)
Bacillus subtilis 3 lb (3.4 kg)………	1-12………..	0.0(±0.0)	4.0(±0.8)	7.8(±4.5)	0.0(±0.0)	0.0(±0.0)	0.7(±0.3)	1.1(±0.4)
neem oil 2 gal (18.7 L)………..……	1-12………..	0.0(±0.0)	2.0(±1.9)	3.8(±2.4)	0.0(±0.0)	0.0(±0.0)	0.3(±0.3)	0.7(±0.4)
sulfur 15 lb (16.8 kg)	8-12………..							
lime sulfur 2 gal (18.7 L)………..	1-7………….	0.7(±0.7)	3.1(±1.1)	2.4(±1.5)	0.0(±0.0)	0.2(±0.2)	0.5(±0.2)	0.5(±0.4)
non-sprayed…………………………	1-12………..	0.0(±0.0)	2.9(±1.0)	5.7(±2.0)	0.0(±0.0)	0.0(±0.0)	0.3(±0.1)	0.8(±0.2)

[z]Application timings: 1 = (Green-tip) 26 Apr; 2 = (TC) 7 May; 3 = (Pink) 11 May; 4 = (Pink) 17 May; 5 = (Pink-Bloom) 24 May; 6 = (Petal fall) 29 May; 7 = 7 Jun; 8 = 14 Jun; 9 = 22 Jun; 10 = 29 Jun; 11 = 12 Jul; 12 = 23 Jul.

[y]Application timings: 1 = (Green-tip) 23 Apr; 2 = (TC) 1 May; 3 = (Pink) 7 May; 4 = (Bloom) 14 May; 5 = (Petal fall) 21 May; 6 = 30 May; 7 = 5 Jun; 8 = 12 Jun; 9 = 19 Jun; 10 = 26 Jun; 11 = 2 Jul; 12 = 17 Jul.

[x]Assessment of 10 clusters per tree on 5 single-tree replicates per treatment

[w]Assessment of 10 terminals per tree on 5 single-tree replicates per treatment

[v]Assessment of 50 fruit per tree on 5 single-tree replicates per treatment

[u]Numbers within columns followed by the same letter do not differ significantly, Fisher's Protected LSD, $P \leq 0.05$; columns with no letters following the numbers do not have a significant F-value, Analysis of Variance, $P \leq 0.05$ or Kruskal-Wallis, $P \leq 0.05$, when data normality could not be rescued with data transformation because of zeros in data.

[t]Mean number of lesions per infected leaf

Table 3. Necrotic leaf spots on 'Empire' trees, 2007 & 2008.

2007

Treatment and rate/A (rate/ha)	Application timing[z]	Percent necrotic leaf spot incidence: Cluster leaves[x] 18-20 Jun	Terminal leaves[w] 18-20 Jun	Terminal leaves[w] 22-24 Aug	Necrotic leaf spot severity[u]: Cluster leaves 18-20 Jun	Terminal leaves 18-20 Jun	Terminal leaves 22-24 Aug
potassium bicarbonate 3.75 lb (4.2 kg)	1-12………..	0.7(±1.2) b[v]	8.4(±2.0)	35.3(±5.2) a	0.1(±0.2) b	1.1(±0.2) a	5.8(±0.7) a
Bacillus subtilis 3 lb (3.4 kg)………	1-12………..	0.5(±0.9) b	9.3(±5.6)	22.4(±5.2) b	0.1(±0.1) b	1.0(±0.2) a	1.3(±0.1) c
neem oil 2 gal (18.7 L)………..……	1-12………..	6.1(±4.7) a	10.1(±8.0)	36.7(±9.4) a	0.9(±0.7) a	1.0(±0.5) a	2.9(±1.6) b
sulfur 15 lb (16.8 kg)	1, 5, 8, 10-12						
lime sulfur 2 gal (18.7 L)………..	2-4, 6-7, 9….	0.9(±0.6) b	5.6(±3.2)	19.5(±6.5) b	0.1(±0.1) b	0.5(±0.2) b	2.7(±0.7) bc
non-sprayed…………………………	1-12………..	1.2(±1.7) b	10.9(±1.8)	16.9(±3.0) b	0.2(±0.2) b	1.2(±0.4) a	1.3(±0.2) c

2008

Treatment and rate/A (rate/ha)	Application timing[y]	Percent necrotic leaf spot incidence: Cluster leaves[x] 16-18 Jun	Terminal leaves[w] 16-18 Jun	Terminal leaves[w] 12-15 Aug	Necrotic leaf spot severity[u]: Cluster leaves 16-18 Jun	Terminal leaves 16-18 Jun	Terminal leaves 12-15 Aug
potassium bicarbonate 3.75 lb (4.2 kg)	1-12………..	0.3(±0.4) b[v]	1.6(±0.6) bc	19.6(±4.5) b	0.0(±0.1) b	0.3(±0.1) b	2.0(±0.4) b
Bacillus subtilis 3 lb (3.4 kg)………	1-12………..	0.4(±0.4) b	2.4(±1.2) bc	15.8(±6.1) bc	0.1(±0.1) b	0.4(±0.1) ab	1.4(±0.3) c
neem oil 2 gal (18.7 L)………..……	1-12………..	2.1(±0.6) a	6.3(±4.0) a	32.6(±3.0) a	0.4(±0.1) a	0.7(±0.3) a	2.7(±0.4) a
sulfur 15 lb (16.8 kg)	8-12………..						
lime sulfur 2 gal (18.7 L)………..	1-7…………	0.5(±0.6) b	0.8(±0.9) c	11.9(±4.1) c	0.1(±0.1) b	0.2(±0.2) b	1.6(±0.5) bc
non-sprayed…………………………	1-12………..	1.2(±1.4) ab	3.6(±1.0) ab	18.1(±2.8) b	0.1(±0.1) b	0.7(±0.5) a	1.4(±0.3) c

[z]Application timings: 1 = (Green-tip) 26 Apr; 2 = (TC) 7 May; 3 = (Pink) 11 May; 4 = (Pink) 17 May; 5 = (Pink-Bloom) 24 May; 6 = (Petal fall) 29 May; 7 = 7 Jun; 8 = 14 Jun; 9 = 22 Jun; 10 = 29 Jun; 11 = 12 Jul; 12 = 23 Jul.

[y]Application timings: 1 = (Green-tip) 23 Apr; 2 = (TC) 1 May; 3 = (Pink) 7 May; 4 = (Bloom) 14 May; 5 = (Petal fall) 21 May; 6 = 30 May; 7 = 5 Jun; 8 = 12 Jun; 9 = 19 Jun; 10 = 26 Jun; 11 = 2 Jul; 12 = 17 Jul.

[x]Assessment of 10 clusters per tree on 5 single-tree replicates per treatment

[w]Assessment of 10 terminals per tree on 5 single-tree replicates per treatment

[v]Numbers within columns followed by the same letter do not differ significantly, Fisher's Protected LSD, $P \leq 0.05$; columns with no letters following the numbers do not have a significant F-value, Analysis of Variance, $P \leq 0.05$.

[u]Mean number of lesions per infected leaf

Table 4. Disease incidence on 'Empire' fruit at harvest, 2007 & 2008.

2007

		Percent disease incidence on fruit[x]			
		10 Sep 2007			
Treatment and rate/A (rate/ha)	Application timing[z]	Sooty blotch	Flyspeck	Fruit rots	Lenticel blackening
potassium bicarbonate 3.75 lb (4.2 kg)	1-12………..	0.0(±0.0)[w]	1.6(±3.6)	6.4(±5.2)	0.0(±0.0)
Bacillus subtilis 3 lb (3.4 kg)………	1-12………..	0.0(±0.0)	2.8(±3.3)	4.4(±4.3)	1.6(±1.7)
neem oil 2 gal (18.7 L)………..……	1-12………..	0.0(±0.0)	0.0(±0.0)	6.5(±9.1)	1.2(±1.8)
sulfur 15 lb (16.8 kg)	1, 5, 8, 10-12				
lime sulfur 2 gal (18.7 L)………..	2-4, 6-7, 9….	0.0(±0.0)	0.0(±0.0)	11.2(±15.4)	4.8(±7.8)
non-sprayed…………………………	1-12………..	0.0(±0.0)	1.2(±2.7)	9.2(±5.9)	0.0(±0.0)

2008

		Percent incidence on fruit[x]			
		3 Sep 2008			
Treatment and rate/A (rate/ha)	Application timing[y]	Sooty blotch	Flyspeck	Fruit rots	Lenticel blackening
potassium bicarbonate 3.75 lb (4.2 kg)	1-12………..	0.0(±0.0)[w]	39.4(±4.3) a	7.7(±5.8)	6.1(±2.1) b
Bacillus subtilis 3 lb (3.4 kg)………	1-12………..	0.0(±0.0)	34.8(±12.1) ab	6.4(±4.6)	12.4(±5.4) a
neem oil 2 gal (18.7 L)………..……	1-12………..	0.0(±0.0)	5.2(±6.4) c	4.4(±7.0)	5.2(±4.6) bc
sulfur 15 lb (16.8 kg)	8-12………..				
lime sulfur 2 gal (18.7 L)………..	1-7…………	0.0(±0.0)	0.5(±1.1) c	4.5(±3.6)	0.0(±0.0) c
non-sprayed…………………………	1-12………..	0.0(±0.0)	24.8(±13.8) b	6.8(±5.2)	3.6(±5.4) bc

[z]Application timings: 1 = (Green-tip) 26 Apr; 2 = (TC) 7 May; 3 = (Pink) 11 May; 4 = (Pink) 17 May; 5 = (Pink-Bloom) 24 May; 6 = (Petal fall) 29 May; 7 = 7 Jun; 8 = 14 Jun; 9 = 22 Jun; 10 = 29 Jun; 11 = 12 Jul; 12 = 23 Jul.

[y]Application timings: 1 = (Green-tip) 23 Apr; 2 = (TC) 1 May; 3 = (Pink) 7 May; 4 = (Bloom) 14 May; 5 = (Petal fall) 21 May; 6 = 30 May; 7 = 5 Jun; 8 = 12 Jun; 9 = 19 Jun; 10 = 26 Jun; 11 = 2 Jul; 12 = 17 Jul.

[x]Assessment of 50 fruit per tree on 5 single-tree replicates per treatment

[w]Numbers within columns followed by the same letter do not differ significantly, Fisher's Protected LSD, $P \leq 0.05$; columns with no letters following the numbers do not have a significant F-value, Analysis of Variance, $P \leq 0.05$ or Kruskal-Wallis, $P \leq 0.05$, when data normality could not be rescued with data transformation because of zeros in data.

Table 5. Incidence of mites on 'Empire' terminal leaves, 2007 & 2008.

2007

Treatment and rate/A (rate/ha)	Application timing[z]	Percent mite incidence, Terminal leaves, 22-24 Aug[x]: European red mites	Two-spotted spider mites
potassium bicarbonate 3.75 lb (4.2 kg)	1-12………..	45.3(±22.1)[w]	36.7(±13.4)
Bacillus subtilis 3 lb (3.4 kg)………	1-12………..	70.5(±26.8)	33.3(±27.7)
neem oil 2 gal (18.7 L)………..……	1-12………..	60.9(±23.0)	31.1(±20.0)
sulfur 15 lb (16.8 kg)	1, 5, 8, 10-12		
lime sulfur 2 gal (18.7 L)………..	2-4, 6-7, 9….	48.2(±29.7)	63.4(±18.2)
non-sprayed…………………………	1-12………..	65.9(±19.2)	34.3(±12.4)

2008

Treatment and rate/A (rate/ha)	Application timing[y]	Percent mite incidence, Terminal leaves, 12-15 Aug[x]: European red mites	Two-spotted spider mites
potassium bicarbonate 3.75 lb (4.2 kg)	1-12………..	4.8(±4.1)[v]	3.6(±2.7) b
Bacillus subtilis 3 lb (3.4 kg)………	1-12………..	2.9(±2.6)	1.0(±1.6) bc
neem oil 2 gal (18.7 L)………..……	1-12………..	3.2(±3.7)	0.0(±0.0) c
sulfur 15 lb (16.8 kg)	8-12………..		
lime sulfur 2 gal (18.7 L)………..	1-7………….	3.9(±5.1)	8.7(±4.6) a
non-sprayed…………………………	1-12………..	7.1(±4.1)	0.8(±0.5) b

[z]Application timings: 1 = (Green-tip) 26 Apr; 2 = (TC) 7 May; 3 = (Pink) 11 May; 4 = (Pink) 17 May; 5 = (Pink-Bloom) 24 May; 6 = (Petal fall) 29 May; 7 = 7 Jun; 8 = 14 Jun; 9 = 22 Jun; 10 = 29 Jun; 11 = 12 Jul; 12 = 23 Jul.

[y]Application timings: 1 = (Green-tip) 23 Apr; 2 = (TC) 1 May; 3 = (Pink) 7 May; 4 = (Bloom) 14 May; 5 = (Petal fall) 21 May; 6 = 30 May; 7 = 5 Jun; 8 = 12 Jun; 9 = 19 Jun; 10 = 26 Jun; 11 = 2 Jul; 12 = 17 Jul.

[x]Assessment of 10 terminals per tree on 5 single-tree replicates per treatment

[w]Columns with no letters following the numbers do not have a significant F-value, Analysis of Variance, $P \leq 0.05$ or Kruskal-Wallis, $P \leq 0.05$, when data normality could not be rescued with data transformation because of zeros in data.

[v]Numbers within columns followed by the same letter do not differ significantly, Kruskal-Wallis pairwise comparison, $P \leq 0.05$; columns with no letters following the numbers do not have a significant F-value, Analysis of Variance, $P \leq 0.05$ or Kruskal-Wallis, $P \leq 0.05$, when data normality could not be rescued with data transformation because of zeros in data.

Table 6. Insect pest incidence on 'Empire' terminal leaves, 2007 & 2008.

2007

Treatment and rate/A (rate/ha)	Application timing[z]	ST/AB[w] leafminer mines	Lyonetia mines	Green apple aphids	White apple leafhopper	White apple leafhopper damage	Potato leafhopper	Potato leafhopper damage	Japanese beetle damage
		Percent insect pest incidence — Terminal leaves, 22-24 Aug 2007[x]							
potassium bicarbonate 3.75 lb (4.2 kg)	1-12………..	24.6(±16.7)[v]	0.0(±0.0)	0.4(±0.6)	0.9(±1.2)	0.0(±0.0)	2.8(±1.7)	1.8(±1.6) ab	0.1(±0.2)
Bacillus subtilis 3 lb (3.4 kg)………	1-12………..	32.3(±10.3)	0.1(±0.2)	0.9(±0.7)	0.7(±1.2)	0.0(±0.0)	3.4(±3.4)	3.0(±1.1) a	0.3(±0.5)
neem oil 2 gal (18.7 L)………..……	1-12………..	20.9(±19.1)	0.2(±0.4)	1.7(±1.2)	0.6(±1.0)	0.0(±0.0)	1.6(±1.2)	1.1(±1.0) b	0.0(±0.0)
sulfur 15 lb (16.8 kg)	1, 5, 8, 10-12								
lime sulfur 2 gal (18.7 L)………..	2-4, 6-7, 9….	32.8(±6.8)	0.0(±0.0)	0.3(±0.5)	0.3(±0.5)	0.0(±0.0)	0.9(±0.9)	0.6(±0.7) b	0.2(±0.4)
non-sprayed…………………………	1-12………..	32.6(±11.3)	0.0(±0.0)	0.5(±0.6)	0.9(±0.9)	0.0(±0.0)	3.3(±2.7)	1.2(±0.6) b	0.0(±0.0)

2008

Treatment and rate/A (rate/ha)	Application timing[y]	ST/AB leafminer mines	Lyonetia mines	Green apple aphids	White apple leafhopper	White apple leafhopper damage	Potato leafhopper	Potato leafhopper damage	Japanese beetle damage
		Percent insect pest incidence — Terminal leaves, 12-15 Aug 2008[x]							
potassium bicarbonate 3.75 lb (4.2 kg)	1-12………..	6.0(±3.3)[u]	1.5(±1.0)	0.1(±0.2)	1.8(±1.5) ab	5.6(±4.2)	2.8(±1.1)	7.8(±5.0)	0.1(±0.2)
Bacillus subtilis 3 lb (3.4 kg)………	1-12………..	5.7(±2.3)	0.5(±0.4)	0.1(±0.1)	2.7(±1.9) a	8.0(±6.8)	1.3(±1.1)	6.4(±4.3)	0.1(±0.3)
neem oil 2 gal (18.7 L)………..……	1-12………..	4.5(±2.9)	1.4(±0.9)	0.0(±0.0)	1.3(±1.8) abc	3.1(±3.0)	2.0(±2.0)	10.0(±2.4)	0.3(±0.4)
sulfur 15 lb (16.8 kg)	8-12………..								
lime sulfur 2 gal (18.7 L)………..	1-7………….	4.3(±2.6)	0.8(±0.5)	0.8(±0.9)	0.6(±0.9) bc	1.6(±1.4)	3.4(±1.1)	4.7(±3.1)	0.5(±1.1)
non-sprayed…………………………	1-12………..	6.5(±1.6)	0.7(±0.3)	0.2(±0.2)	0.3(±0.4) c	3.0(±1.8)	2.4(±1.7)	9.2(±2.6)	0.0(±0.0)

[z]Application timings: 1 = (Green-tip) 26 Apr; 2 = (TC) 7 May; 3 = (Pink) 11 May; 4 = (Pink) 17 May; 5 = (Pink-Bloom) 24 May; 6 = (Petal fall) 29 May; 7 = 7 Jun; 8 = 14 Jun; 9 = 22 Jun; 10 = 29 Jun; 11 = 12 Jul; 12 = 23 Jul.

[y]Application timings: 1 = (Green-tip) 23 Apr; 2 = (TC) 1 May; 3 = (Pink) 7 May; 4 = (Bloom) 14 May; 5 = (Petal fall) 21 May; 6 = 30 May; 7 = 5 Jun; 8 = 12 Jun; 9 = 19 Jun; 10 = 26 Jun; 11 = 2 Jul; 12 = 17 Jul.

[x]Assessment of 10 terminals per tree on 5 single-tree replicates per treatment

[w]ST/AB = spotted tentiform or apple blotch leafminer (mines appear similar and were not distinguished)

[v]Numbers within columns followed by the same letter do not differ significantly, Fisher's Protected LSD, $P \leq 0.05$; columns with no letters following the numbers do not have a significant F-value, Analysis of Variance, $P \leq 0.05$ or Kruskal-Wallis, $P \leq 0.05$, when data normality could not be rescued with data transformation because of zeros in data.

[u]Numbers within columns followed by the same letter do not differ significantly, Kruskal-Wallis pairwise comparison, $P \leq 0.05$; columns with no letters following the numbers do not have a significant F-value, Analysis of Variance, $P \leq 0.05$ or Kruskal-Wallis, $P \leq 0.05$, when data normality could not be rescued with data transformation because of zeros in data.

Table 7. Incidence of foliage clean of arthropod pests and their damage on 'Empire' terminal leaves, 2008.

		Percent insect pest incidence
		Terminal leaves, 12-15 Aug[y]
Treatment and rate/A (rate/ha)	Application timing[z]	Clean of pest and damage
potassium bicarbonate 3.75 lb (4.2 kg)	1-12………..	50.7(±9.5) b[x]
Bacillus subtilis 3 lb (3.4 kg)………	1-12………..	51.1(±6.1) ab
neem oil 2 gal (18.7 L)………..……	1-12………..	60.3(±9.1) a
sulfur 15 lb (16.8 kg)	8-12………..	
lime sulfur 2 gal (18.7 L)………..	1-7…………	35.1(±3.7) c
non-sprayed…………………………	1-12………..	55.8(±5.9) ab

[z]Application timings: 1 = (Green-tip) 23 Apr; 2 = (TC) 1 May; 3 = (Pink) 7 May; 4 = (Bloom) 14 May; 5 = (Petal fall) 21 May; 6 = 30 May; 7 = 5 Jun; 8 = 12 Jun; 9 = 19 Jun; 10 = 26 Jun; 11 = 2 Jul; 12 = 17 Jul.

[y]Assessment of 10 terminals per tree on 5 single-tree replicates per treatment

[x]Numbers within columns followed by the same letter do not differ significantly, Fisher's Protected LSD, $P \leq 0.05$.

Table 8. Beneficial insect incidence on 'Empire' terminal leaves, 2007 & 2008.

2007

Treatment and rate/A (rate/ha)	Application timing[z]	Percent beneficial insect incidence: Terminal leaves, 22-24 Aug[x]				
		Lady beetle adult	Lady beetle larvae	Cecidomyiid larvae	Syrphid fly larvae	Chrysopid egg
potassium bicarbonate 3.75 lb (4.2 kg)	1-12………..	0.0(±0.0)[w]	0.0(±0.0)	0.0(±0.0)	0.0(±0.0)	0.0(±0.0)
Bacillus subtilis 3 lb (3.4 kg)………	1-12………..	0.0(±0.0)	0.2(±0.3)	0.0(±0.0)	0.0(±0.0)	0.1(±0.2)
neem oil 2 gal (18.7 L)………..……	1-12………..	0.0(±0.0)	0.0(±0.0)	0.0(±0.0)	0.0(±0.0)	0.0(±0.0)
sulfur 15 lb (16.8 kg)	1, 5, 8, 10-12					
lime sulfur 2 gal (18.7 L)………..	2-4, 6-7, 9….	0.0(±0.0)	0.0(±0.0)	0.0(±0.0)	0.0(±0.0)	0.0(±0.0)
non-sprayed…………………………	1-12………..	0.1(±0.2)	0.1(±0.3)	0.0(±0.0)	0.0(±0.0)	0.0(±0.0)

2008

Treatment and rate/A (rate/ha)	Application timing[y]	Percent beneficial insect incidence: Terminal leaves, 12-15 Aug[x]				
		Lady beetle adult	Lady beetle larvae	Cecidomyiid larvae	Syrphid fly larvae	Chrysopid egg
potassium bicarbonate 3.75 lb (4.2 kg)	1-12………..	0.0(±0.0)[w]	0.0(±0.0)	0.2(±0.3)	0.0(±0.0)	0.0(±0.0)
Bacillus subtilis 3 lb (3.4 kg)………	1-12………..	0.0(±0.0)	0.0(±0.0)	0.0(±0.0)	0.0(±0.0)	0.0(±0.0)
neem oil 2 gal (18.7 L)………..……	1-12………..	0.0(±0.0)	0.0(±0.0)	0.0(±0.0)	0.0(±0.0)	0.0(±0.0)
sulfur 15 lb (16.8 kg)	8-12………..					
lime sulfur 2 gal (18.7 L)………..	1-7…………	0.0(±0.0)	0.0(±0.0)	0.6(±0.7)	0.0(±0.0)	0.2(±0.2)
non-sprayed…………………………	1-12………..	0.0(±0.0)	0.0(±0.0)	0.1(±0.2)	0.0(±0.0)	0.1(±0.1)

[z]Application timings: 1 = (Green-tip) 26 Apr; 2 = (TC) 7 May; 3 = (Pink) 11 May; 4 = (Pink) 17 May; 5 = (Pink-Bloom) 24 May; 6 = (Petal fall) 29 May; 7 = 7 Jun; 8 = 14 Jun; 9 = 22 Jun; 10 = 29 Jun; 11 = 12 Jul; 12 = 23 Jul.

[y]Application timings: 1 = (Green-tip) 23 Apr; 2 = (TC) 1 May; 3 = (Pink) 7 May; 4 = (Bloom) 14 May; 5 = (Petal fall) 21 May; 6 = 30 May; 7 = 5 Jun; 8 = 12 Jun; 9 = 19 Jun; 10 = 26 Jun; 11 = 2 Jul; 12 = 17 Jul.

[x]Assessment of 10 terminals per tree on 5 single-tree replicates per treatment

[w]Numbers within columns followed by the same letter do not differ significantly, Fisher's Protected LSD, $P \leq 0.05$; columns with no letters following the numbers do not have a significant F-value, Analysis of Variance, $P \leq 0.05$ or Kruskal-Wallis, $P \leq 0.05$, when data normality could not be rescued with data transformation because of zeros in data.

Table 9. Incidence of insect damage on 'Empire' fruitlets, 2007 & 2008.

		2007		
		Percent insect pest incidence		
		Fruit, 18-20 Jun[x]		
Treatment and rate/A (rate/ha)	Application timing[z]	Plum curculio	Tarnished plant bug	European Apple Sawfly
potassium bicarbonate 3.75 lb (4.2 kg)	1-12………..	2.0(±4.5) b[w]	11.5(±13.2)	1.5(±2.2)
Bacillus subtilis 3 lb (3.4 kg)………	1-12………..	9.2(±4.9) a	12.7(±6.9)	4.3(±6.0)
neem oil 2 gal (18.7 L)………..……	1-12………..	1.0(±2.2) b	8.0(±15.1)	1.7(±3.7)
sulfur 15 lb (16.8 kg)	1, 5, 8, 10-12			
lime sulfur 2 gal (18.7 L)………..	2-4, 6-7, 9….	0.0(±0.0) b	2.2(±2.2)	3.3(±4.1)
non-sprayed…………………………	1-12………..	2.0(±3.0) b	11.2(±9.2)	9.2(±7.5)

		2008		
		Percent insect pest incidence		
		Fruit, 16-18 Jun[x]		
Treatment and rate/A (rate/ha)	Application timing[y]	Plum curculio	Tarnished plant bug	European Apple Sawfly
potassium bicarbonate 3.75 lb (4.2 kg)	1-12………..	6.0(±5.5)[w]	15.2(±10.6)	12.5(±7.5)
Bacillus subtilis 3 lb (3.4 kg)………	1-12………..	23.3(±24.4)	8.0(±9.1)	16.0(±8.2)
neem oil 2 gal (18.7 L)………..……	1-12………..	10.0(±10.0)	3.0(±6.7)	4.7(±5.1)
sulfur 15 lb (16.8 kg)	8-12………..			
lime sulfur 2 gal (18.7 L)………..	1-7………….	4.7(±6.5)	2.7(±4.3)	6.7(±4.4)
non-sprayed…………………………	1-12………..	13.0(±12.0)	15.7(±15.9)	8.2(±7.2)

[z]Application timings: 1 = (Green-tip) 26 Apr; 2 = (TC) 7 May; 3 = (Pink) 11 May; 4 = (Pink) 17 May; 5 = (Pink-Bloom) 24 May; 6 = (Petal fall) 29 May; 7 = 7 Jun; 8 = 14 Jun; 9 = 22 Jun; 10 = 29 Jun; 11 = 12 Jul; 12 = 23 Jul.

[y]Application timings: 1 = (Green-tip) 23 Apr; 2 = (TC) 1 May; 3 = (Pink) 7 May; 4 = (Bloom) 14 May; 5 = (Petal fall) 21 May; 6 = 30 May; 7 = 5 Jun; 8 = 12 Jun; 9 = 19 Jun; 10 = 26 Jun; 11 = 2 Jul; 12 = 17 Jul.

[x]Assessment of individual fruit on 10 fruit clusters per tree on 5 single-tree replicates per treatment

[w]Numbers within columns followed by the same letter do not differ significantly, Fisher's Protected LSD, $P \leq 0.05$; columns with no letters following the numbers do not have a significant F-value, Analysis of Variance, $P \leq 0.05$ or Kruskal-Wallis, $P \leq 0.05$, when data normality could not be rescued with data transformation because of zeros in data.

Table 10. Incidence of insect damage on 'Empire' fruit at harvest, 2007 & 2008.

2007

Treatment and rate/A (rate/ha)	Application timing[z]	Percent insect pest damage incidence, Fruit, 10 Sep 2007[x]: Plum curculio	Tarnished plant bug	European apple sawfly	Apple maggot fly	Internal Lepidoptera	Surface Lepidoptera
potassium bicarbonate 3.75 lb (4.2 kg)	1-12………..	5.2(±6.6)[w]	22.0(±11.2)	2.8(±2.7)	6.4(±3.8)	4.8(±4.6)	22.0(±11.4)
Bacillus subtilis 3 lb (3.4 kg)………	1-12………..	8.4(±3.6)	18.4(±10.7)	3.6(±3.3)	7.6(±2.6)	4.8(±3.6)	26.4(±11.2)
neem oil 2 gal (18.7 L)………..……	1-12………..	5.6(±5.0)	4.0(±2.9)	0.0(±0.0)	4.4(±3.6)	2.0(±2.0)	10.0(±9.0)
sulfur 15 lb (16.8 kg)	1, 5, 8, 10-12						
lime sulfur 2 gal (18.7 L)………..	2-4, 6-7, 9….	1.6(±1.7)	14.4(±10.4)	1.6(±1.7)	13.2(±5.2)	1.6(±1.7)	16.4(±8.2)
non-sprayed…………………………	1-12………..	8.4(±5.2)	18.4(±14.1)	1.6(±1.7)	13.6(±13.5)	3.2(±3.6)	21.6(±9.1)

2008

Treatment and rate/A (rate/ha)	Application timing[y]	Percent insect pest damage incidence, Fruit, 3 Sep 2008[x]: Plum curculio	Tarnished plant bug	European apple sawfly	Apple maggot fly	Internal Lepidoptera	Surface Lepidoptera	Stink bug
potassium bicarbonate 3.75 lb (4.2 kg)	1-12………..	16.1(±6.7) bc[w]	14.1(±12.0)	3.6(±3.8)	4.2(±6.7)	33.2(±21.0)	55.0(±6.4) a	15.3(±6.9)
Bacillus subtilis 3 lb (3.4 kg)………	1-12………..	39.2(±19.1) a	14.8(±8.6)	6.0(±5.1)	4.0(±2.8)	25.2(±14.8)	44.0(±10.7) ab	15.2(±6.9)
neem oil 2 gal (18.7 L)………..……	1-12………..	30.0(±14.4) ab	7.2(±5.9)	1.2(±2.7)	0.8(±1.8)	18.4(±13.1)	28.0(±8.8) c	11.6(±7.4)
sulfur 15 lb (16.8 kg)	8-12………..							
lime sulfur 2 gal (18.7 L)………..	1-7…………	13.8(±2.0) c	3.7(±3.6)	0.8(±1.1)	7.4(±9.4)	39.2(±12.3)	57.7(±6.0) a	15.3(±4.2)
non-sprayed…………………………	1-12………..	23.6(±7.1) bc	16.0(±6.6)	2.8(±1.1)	4.0(±3.7)	31.6(±8.8)	40.0(±16.8) bc	9.6(±3.6)

[z]Application timings: 1 = (Green-tip) 26 Apr; 2 = (TC) 7 May; 3 = (Pink) 11 May; 4 = (Pink) 17 May; 5 = (Pink-Bloom) 24 May; 6 = (Petal fall) 29 May; 7 = 7 Jun; 8 = 14 Jun; 9 = 22 Jun; 10 = 29 Jun; 11 = 12 Jul; 12 = 23 Jul.

[y]Application timings: 1 = (Green-tip) 23 Apr; 2 = (TC) 1 May; 3 = (Pink) 7 May; 4 = (Bloom) 14 May; 5 = (Petal fall) 21 May; 6 = 30 May; 7 = 5 Jun; 8 = 12 Jun; 9 = 19 Jun; 10 = 26 Jun; 11 = 2 Jul; 12 = 17 Jul.

[x]Assessment of 50 fruit per tree on 5 single-tree replicates per treatment

[w]Numbers within columns followed by the same letter do not differ significantly, Fisher's Protected LSD, $P \leq 0.05$; columns with no letters following the numbers do not have a significant F-value, Analysis of Variance, $P \leq 0.05$ or Kruskal-Wallis, $P \leq 0.05$, when data normality could not be rescued with data transformation because of zeros in data.

Table 11. Phytotoxic effects of treatments on 'Empire' fruit at harvest, 2007 & 2008.

		2007	
Treatment and rate/A (rate/ha)	Application timing[z]	Percent phytotoxic burn incidence Fruit[x] 10 Sep	Percent russet incidence Fruit 10 Sep
potassium bicarbonate 3.75 lb (4.2 kg)	1-12………..	0.0(±0.0)[w]	0.4(±0.9)[w]
Bacillus subtilis 3 lb (3.4 kg)………	1-12………..	0.0(±0.0)	0.0(±0.0)
neem oil 2 gal (18.7 L)………..……	1-12………..	0.0(±0.0)	0.4(±0.9)
sulfur 15 lb (16.8 kg)	1, 5, 8, 10-12		
lime sulfur 2 gal (18.7 L)………..	2-4, 6-7, 9….	8.8(±8.9)	5.2(±2.3)
non-sprayed…………………………	1-12………..	0.0(±0.0)	0.4(±0.9)

		2008	
Treatment and rate/A (rate/ha)	Application timing[y]	Percent phytotoxic burn incidence Fruit[x] 3 Sep	Percent russet incidence Fruit 3 Sep
potassium bicarbonate 3.75 lb (4.2 kg)	1-12………..	0.0(±0.0)	3.5(±3.2) b[v]
Bacillus subtilis 3 lb (3.4 kg)………	1-12………..	0.0(±0.0)	2.0(±2.0) b
neem oil 2 gal (18.7 L)………..……	1-12………..	0.0(±0.0)	8.8(±5.2) a
sulfur 15 lb (16.8 kg)	8-12………..		
lime sulfur 2 gal (18.7 L)………..	1-7…………	0.0(±0.0)	5.0(±4.9) ab
non-sprayed…………………………	1-12………..	0.0(±0.0)	1.2(±1.8) b

[z]Application timings: 1 = (Green-tip) 26 Apr; 2 = (TC) 7 May; 3 = (Pink) 11 May; 4 = (Pink) 17 May; 5 = (Pink-Bloom) 24 May; 6 = (Petal fall) 29 May; 7 = 7 Jun; 8 = 14 Jun; 9 = 22 Jun; 10 = 29 Jun; 11 = 12 Jul; 12 = 23 Jul.

[y]Application timings: 1 = (Green-tip) 23 Apr; 2 = (TC) 1 May; 3 = (Pink) 7 May; 4 = (Bloom) 14 May; 5 = (Petal fall) 21 May; 6 = 30 May; 7 = 5 Jun; 8 = 12 Jun; 9 = 19 Jun; 10 = 26 Jun; 11 = 2 Jul; 12 = 17 Jul.

[x]Assessment of 50 fruit per tree on 5 single-tree replicates per treatment

[w]Numbers within columns are significantly different, Kruskal-Wallis, $P \leq 0.05$.

[v]Numbers within columns followed by the same letter do not differ significantly, Fisher's Protected LSD, $P \leq 0.05$.

Table 12. Incidence of 'Empire' fruit clean of disease at harvest, 2007 & 2008.

	Percent clean of disease incidence	
	Fruit[z]	Fruit[z]
Treatment and rate/A (rate/ha)	10 Sep 2007	3 Sep 2008
potassium bicarbonate 3.75 lb (4.2 kg)	81.6(±9.4)[y]	31.4(±11.3) c
Bacillus subtilis 3 lb (3.4 kg)………	69.2(±7.0)	25.6(±7.4) c
neem oil 2 gal (18.7 L)………..……	81.1(±11.3)	60.0(±14.4) b
sulfur 15 lb (16.8 kg)		
lime sulfur 2 gal (18.7 L)………..	82.8(±15.7)	92.1(±5.4) a
non-sprayed…………………………	65.2(±9.5)	29.6(±11.1) c

[z]Assessment of 50 fruit per tree on 5 single-tree replicates per treatment

[y]Numbers within columns followed by the same letter do not differ significantly, Fisher's Protected LSD, $P \leq 0.05$; columns with no letters following the numbers do not have a significant F-value, Analysis of Variance, $P \leq 0.05$ or Kruskal-Wallis, $P \leq 0.05$, when data normality could not be rescued with data transformation because of zeros in data.

Table 13. Incidence of 'Empire' fruit clean of insect damage at harvest, 2007 & 2008.

	Percent clean of insect damage incidence	
	Fruit[z]	Fruit[z]
Treatment and rate/A (rate/ha)	10 Sep 2007	3 Sep 2008
potassium bicarbonate 3.75 lb (4.2 kg)	52.8(±17.9) b[y]	19.6(±10.0) b
Bacillus subtilis 3 lb (3.4 kg)………	45.6(±7.7) b	20.0(±6.8) b
neem oil 2 gal (18.7 L)………..……	77.1(±16.4) a	37.6(±5.2) a
sulfur 15 lb (16.8 kg)		
lime sulfur 2 gal (18.7 L)………..	59.6(±12.8) ab	17.5(±8.5) b
non-sprayed…………………………	50.8(±17.9) b	26.0(±7.6) b

[z]Assessment of 50 fruit per tree on 5 single-tree replicates per treatment

[y]Numbers within columns followed by the same letter do not differ significantly, Fisher's Protected LSD, $P \leq 0.05$.

Table 14. USDA fruit grade of ‘Empire’ fruit at harvest, 2008.

	Percent USDA fruit grade incidence			
	US-1 Count	US-1 Bag	U.S. Utility	Cull
Treatment and rate/A (rate/ha)	3 Sep	3 Sep	3 Sep	3 Sep
potassium bicarbonate 3.75 lb (4.2 kg)	2.4(±1.7)[z]	8.3(±6.6) b[y]	13.4(±9.0) bc[y]	75.9(±13.2) a[y]
Bacillus subtilis 3 lb (3.4 kg)………	0.4(±0.9)	4.8(±3.3) b	24.0(±9.4) a	70.8(±10.4) ab
neem oil 2 gal (18.7 L)………..……	4.4(±5.5)	18.4(±7.0) a	17.6(±9.2) ab	59.6(±7.9) b
sulfur 15 lb (16.8 kg)				
lime sulfur 2 gal (18.7 L)………..	5.6(±4.6)	10.7(±3.6) b	5.9(±4.5) c	77.4(±6.3) a
non-sprayed…………………………	4.0(±2.0)	5.2(±3.6) b	22.0(±5.5) ab	68.8(±4.8) ab

[z]columns with no letters following the numbers do not have a significant F-value, Analysis of Variance, $P \leq 0.05$ (or Kruskal-Wallis, $P \leq 0.05$, when data normality could not be rescued with data transformation because of zeros in data).

[y]Numbers within columns followed by the same letter do not differ significantly, Fisher's Protected LSD, $P \leq 0.05$

APPENDIX H. Chapter 3:

DIX H. Chapter 3: Tables 1-9

Table 1. Apple scab on 'McIntosh' trees, 2007.

Treatment and rate/A (rate/ha)	Application timing[z]	Scab Incidence % Terminal leaves[y] 18-20 Jun	Scab Incidence % Terminal leaves[y] 22-24 Aug	Scab Incidence % Fruit[x] 10 Sep	Scab Severity[v] Terminal leaves 18-20 Jun	Scab Severity[v] Terminal leaves 22-24 Aug
non-sprayed….....................	1-12………..	28.7(±7.2)[w]	76.0(±4.4)	97.3(±1.3)	3.3(±1.2)	12.0(±3.6)
raw milk 34 gal (0.32 kl)….	1-12………..	23.8(±8.7)	74.2(±5.5)	96.0(±4.0)	3.5(±1.1)	10.6(±2.9)

[z]Application timings: 1 = (Green-tip) 26 Apr; 2 = (TC) 7 May; 3 = (Pink) 11 May; 4 = (Pink) 17 May; 5 = (Pink-Bloom) 24 May; 6 = (Petal fall) 29 May; 7 = 7 Jun; 8 = 14 Jun; 9 = 22 Jun; 10 = 29 Jun; 11 = 12 Jul; 12 = 23 Jul.

[y]Assessment of 10 terminals per tree on 3 single-tree replicates per treatment

[x]Assessment of 50 fruit per tree on 3 single-tree replicates per treatment

[w]Numbers within columns followed by the same letter do not differ significantly, Fisher's Protected LSD, $P \leq 0.05$; columns with no letters following the numbers do not have a significant F-value, Analysis of Variance, $P \leq 0.05$.

[v]Mean number of lesions per infected leaf

Table 2. Cedar apple rust (CAR) on 'McIntosh' trees, 2007.

		CAR Incidence %			CAR Severity[v]	
	Application	Terminal leaves[y]		Fruit[x]	Terminal leaves	
Treatment and rate/A (rate/ha)	timing[z]	18-20 Jun	22-24 Aug	10 Sep	18-20 Jun	22-24 Aug
non-sprayed…......................	1-12………..	5.8(±1.0)[w]	22.7(±4.7)	0.0(±0.0)	0.6(±0.1)	1.8(±0.2)
raw milk 34 gal (0.32 kl)….	1-12………..	3.6(±1.0)	26.1(±5.9)	0.0(±0.0)	0.4(±0.1)	1.4(±0.3)

[z]Application timings: 1 = (Green-tip) 26 Apr; 2 = (TC) 7 May; 3 = (Pink) 11 May; 4 = (Pink) 17 May; 5 = (Pink-Bloom) 24 May; 6 = (Petal fall) 29 May; 7 = 7 Jun; 8 = 14 Jun; 9 = 22 Jun; 10 = 29 Jun; 11 = 12 Jul; 12 = 23 Jul.

[y]Assessment of 10 terminals per tree on 3 single-tree replicates per treatment

[x]Assessment of 50 fruit per tree on 3 single-tree replicates per treatment

[w]Numbers within columns followed by the same letter do not differ significantly, Fisher's Protected LSD, $P \leq 0.05$; columns with no letters following the numbers do not have a significant F-value, Analysis of Variance, $P \leq 0.05$.

[v]Mean number of lesions per infected leaf

Table 3. Pin-point purple lesions (PPP) on 'McIntosh' trees, 2007.

Treatment and rate/A (rate/ha)	Application timing[z]	PPP Incidence % Terminal leaves[y] 18-20 Jun	PPP Incidence % Terminal leaves[y] 22-24 Aug	PPP Severity[w] Terminal leaves 18-20 Jun	PPP Severity[w] Terminal leaves 22-24 Aug
non-sprayed…......................	1-12………..	35.8(±2.0) a[x]	21.5(±3.2)	7.2(±3.5)	4.0(±0.9)
raw milk 34 gal (0.32 kl)….	1-12………..	28.7(±3.5) b	25.0(±7.1)	5.0(±0.6)	4.1(±1.1)

[z]Application timings: 1 = (Green-tip) 26 Apr; 2 = (TC) 7 May; 3 = (Pink) 11 May; 4 = (Pink) 17 May; 5 = (Pink-Bloom) 24 May; 6 = (Petal fall) 29 May; 7 = 7 Jun; 8 = 14 Jun; 9 = 22 Jun; 10 = 29 Jun; 11 = 12 Jul; 12 = 23 Jul.

[y]Assessment of 10 terminals per tree on 3 single-tree replicates per treatment

[x]Numbers within columns followed by the same letter do not differ significantly, Fisher's Protected LSD, $P \leq 0.05$; columns with no letters following the numbers do not have a significant F-value, Analysis of Variance, $P \leq 0.05$.

[w]Mean number of lesions per infected leaf

Table 4. Necrotic leaf spots on 'McIntosh' trees, 2007.trees, 2007.

		Necrotic leaf spot Incidence %		Necrotic leaf spot Severity[w]	
	Application	Terminal leaves[y]		Terminal leaves	
Treatment and rate/A (rate/ha)	timing[z]	18-20 Jun	22-24 Aug	18-20 Jun	22-24 Aug
non-sprayed….....................	1-12………..	10.7(±1.2) b[x]	24.4(±10.4) b	1.2(±0.2)	4.4(±3.6)
raw milk 34 gal (0.32 kl)….	1-12………..	28.9(±2.0) a	53.9(±5.6) a	6.9(±3.8)	10.9(±3.6)

[z]Application timings: 1 = (Green-tip) 26 Apr; 2 = (TC) 7 May; 3 = (Pink) 11 May; 4 = (Pink) 17 May; 5 = (Pink-Bloom) 24 May; 6 = (Petal fall) 29 May; 7 = 7 Jun; 8 = 14 Jun; 9 = 22 Jun; 10 = 29 Jun; 11 = 12 Jul; 12 = 23 Jul.

[y]Assessment of 10 terminals per tree on 3 single-tree replicates per treatment

[x]Numbers within columns followed by the same letter do not differ significantly, Fisher's Protected LSD, $P \leq 0.05$; columns with no letters following the numbers do not have a significant F-value, Analysis of Variance, $P \leq 0.05$.

[w]Mean number of lesions per infected leaf

Table 5. Incidence of disease and phytotoxicity on 'McIntosh' fruit, 2007.

		Fruit[y]					
		10 Sep					
Treatment and rate/A (rate/ha)	Application timing[z]	Flyspeck	Sooty blotch	Soft rots	Lenticel blackening	Phytotoxic burn	Russet
non-sprayed….....................	1-12………..	1.3(±2.3)[x]	0.0(±0.0)	19.4(±9.7)	1.4(±2.4)	0.0(±0.0)	0.0(±0.0)
raw milk 34 gal (0.32 kl)….	1-12………..	2.7(±1.2)	0.0(±0.0)	11.3(±7.6)	4.7(±4.2)	0.0(±0.0)	10.0(±12.5)

[z]Application timings: 1 = (Green-tip) 26 Apr; 2 = (TC) 7 May; 3 = (Pink) 11 May; 4 = (Pink) 17 May; 5 = (Pink-Bloom) 24 May; 6 = (Petal fall) 29 May; 7 = 7 Jun; 8 = 14 Jun; 9 = 22 Jun; 10 = 29 Jun; 11 = 12 Jul; 12 = 23 Jul.

[y]Assessment of 50 fruit per tree on 3 single-tree replicates per treatment

[x]Numbers within columns followed by the same letter do not differ significantly, Fisher's Protected LSD, $P \leq 0.05$; columns with no letters following the numbers do not have a significant F-value, Analysis of Variance, $P \leq 0.05$.

Table 6. Incidence of foliage and fruit clean of disease symptoms on 'McIntosh' trees, 2007.

		Clean Incidence %	
	Application	Terminal leaves[y]	Fruit[x]
Treatment and rate/A (rate/ha)	timing[z]	18-20 Jun	10 Sep
non-sprayed….....................	1-12………..	37.6(±8.7)[w]	1.4(±2.4)
raw milk 34 gal (0.32 kl)….	1-12………..	34.7(±5.1)	2.7(±3.1)

[z]Application timings: 1 = (Green-tip) 26 Apr; 2 = (TC) 7 May; 3 = (Pink) 11 May; 4 = (Pink) 17 May; 5 = (Pink-Bloom) 24 May; 6 = (Petal fall) 29 May; 7 = 7 Jun; 8 = 14 Jun; 9 = 22 Jun; 10 = 29 Jun; 11 = 12 Jul; 12 = 23 Jul.

[y]Assessment of 10 terminals per tree on 3 single-tree replicates per treatment

[x]Assessment of 50 fruit per tree on 3 single-tree replicates per treatment

[w]Numbers within columns followed by the same letter do not differ significantly, Fisher's Protected LSD, $P \leq 0.05$; columns with no letters following the numbers do not have a significant F-value, Analysis of Variance, $P \leq 0.05$.

Table 7. Arthropod pest and damage incidence on ‘McIntosh’ trees, 2007.

		Percent arthropod pest and damage incidence									
		22-24 Aug, Terminal leaves[x]									
Treatment and rate/A (rate/ha)	Application timing[z]	ST/AB leafminer mines	Lyonetia mines	Green apple aphids	European red mites	Two-spotted spider mites	White apple leafhoppers	White apple leafhopper damage	Potato leafhoppers	Potato leafhopper damage	Japanese beetle damage
non-sprayed…......................	1-12………..	14.8(±5.9)[w]	0.0(±0.0)	0.0(±0.0)	4.5(±4.2)	0.0(±0.0)	0.9(±1.0)	0.0(±0.0)	2.1(±0.8)	0.0(±0.0)	0.0(±0.0)
raw milk 34 gal (0.32 kl)….	1-12………..	19.7(±7.7)	0.0(±0.0)	0.7(±0.6)	4.5(±4.1)	0.0(±0.0)	1.0(±1.0)	0.0(±0.0)	4.2(±4.7)	0.0(±0.0)	0.0(±0.0)

[z]Application timings: 1 = (Green-tip) 26 Apr; 2 = (TC) 7 May; 3 = (Pink) 11 May; 4 = (Pink) 17 May; 5 = (Pink-Bloom) 24 May; 6 = (Petal fall) 29 May; 7 = 7 Jun; 8 = 14 Jun; 9 = 22 Jun; 10 = 29 Jun; 11 = 12 Jul; 12 = 23 Jul.

[y]ST/AB = Spotted tentiform/Apple blotch leafminers

[x]Assessment of 10 terminals per tree on 3 single-tree replicates per treatment

[w]Numbers within columns followed by the same letter do not differ significantly, Fisher's Protected LSD, $P \leq 0.05$; columns with no letters following the numbers do not have a significant F-value, Analysis of Variance, $P \leq 0.05$.

Table 8. Incidence of insect damage on 'McIntosh' fruit, 2007.

		Percent insect damage incidence						
		10 Sep, Fruit[y]						
Treatment and rate/A (rate/ha)	Application timing[z]	Clean of insect damage	Plum curculio	European Apple Sawfly	Tarnished plant bug	Apple maggot fly	Surface lepidoptera	Internal lepidoptera
non-sprayed…......................	1-12………..	26.1(±19.2)[x]	48.2(±14.3)	2.0(±3.5)	16.9(±3.5)	6.2(±5.6)	21.7(±6.7)	6.7(±2.2)
raw milk 34 gal (0.32 kl)….	1-12………..	26.0(±5.3)	60.7(±2.3)	1.3(±1.2)	15.3(±5.0)	2.0(±2.0)	14.0(±5.3)	7.3(±6.1)

[z]Application timings: 1 = (Green-tip) 26 Apr; 2 = (TC) 7 May; 3 = (Pink) 11 May; 4 = (Pink) 17 May; 5 = (Pink-Bloom) 24 May; 6 = (Petal fall) 29 May; 7 = 7 Jun; 8 = 14 Jun; 9 = 22 Jun; 10 = 29 Jun; 11 = 12 Jul; 12 = 23 Jul.

[y]Assessment of 50 fruit per tree on 3 single-tree replicates per treatment

[x]Numbers within columns followed by the same letter do not differ significantly, Fisher's Protected LSD, $P \leq 0.05$; columns with no letters following the numbers do not have a significant F-value, Analysis of Variance, $P \leq 0.05$.

Table 9. Yellow leaf analysis on 'McIntosh' trees, 2007.

Treatment and rate/A (rate/ha)	Application timing[z]	Average number of yellow leaves[y] 18-20 Jun
non-sprayed…......................	1-12………..	166.7(±37.3) b[x]
raw milk 34 gal (0.32 kl)….	1-12………..	288.3(±44.8) a

[z]Application timings: 1 = (Green-tip) 26 Apr; 2 = (TC) 7 May; 3 = (Pink) 11 May; 4 = (Pink) 17 May; 5 = (Pink-Bloom) 24 May; 6 = (Petal fall) 29 May; 7 = 7 Jun; 8 = 14 Jun; 9 = 22 Jun; 10 = 29 Jun; 11 = 12 Jul; 12 = 23 Jul.

[y]Each tree was assessed for 5 minutes, counting the number of yellow leaves first in the lower 3m of the canopy, then the remaining upper canopy while circling the tree.

[x]Numbers within columns followed by the same letter do not differ significantly, Fisher's Protected LSD, $P \leq 0.05$; columns with no letters following the numbers do not have a significant F-value, Analysis of Variance, $P \leq 0.05$.