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The efficacy and non-target impacts of an organic disease management system containing biostimulants compared with two sulfur-based systems on four apple cultivars in Vermont

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THE EFFICACY AND NON-TARGET IMPACTS OF AN ORGANIC DISEASE MANAGEMENT SYSTEM CONTAINING BIOSTIMULANTS COMPARED WITH TWO SULFUR-BASED SYSTEMS ON FOUR APPLE CULTIVARS IN VERMONT

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ABSTRACT

Disease management in organic apple orchards in Vermont is focused on controlling diseases with sulfur fungicides. The objective of this two year study was to evaluate the target and non-target effects of an organic disease management system containing agricultural biostimulants compared to two sulfur-based systems on foliar and fruit diseases, pest and beneficial arthropods, tree growth, yield and fruit quality on four cultivars, 'Ginger Gold', 'Honeycrisp' and 'Liberty' and 'Zestar!'. Trees were arranged in a complete randomized design of five three-tree replications in a certified organic orchard. The two sulfur-based systems differed in the number of applications; in the third system, sulfur was replaced with biostimulants including pure neem oil, liquid fish, an activated microbial inoculant plus equisetum and stinging nettle teas. Each biostimulant application also included kelp meal, unsulfured organic molasses and yucca extract emulsifier. The biostimulant system did not successfully manage apple scab and rust diseases as well as the sulfur-based fungicide systems, and had variable results with other diseases. No differences were observed among the three systems in tree growth parameters; however, the length of the study may not have been sufficient to determine effects. Differences in the incidence of disease among the three systems were reflected in extrapolated figures for gross income per hectare which takes into account fruit yield and quality. In the higher fruit-bearing year of the study, it was estimated that the gross income per hectare of the biostimulant system would be significantly lower than the reduced-sulfur system and the full-sulfur system by at least $5,800 and $12,000, respectively. In that same year, it is estimated that the full-sulfur system would have generated approximately $6,500 more gross income per hectare than the reduced-sulfur system suggesting the number of sulfur sprays can influence fruit quality and income. The use of the agricultural biostimulants had very limited non-target effects and when present, they were beneficial in suppressing insect pest incidence and/or damage on foliage compared to one or both of the sulfur-based fungicide systems. However, many insect pests or their damage were not observed on the foliage or had incidence of less than 1% in any of the systems. The biostimulant system did appear to suppress European red mites in both years compared to both sulfur-based systems when data were averaged across cultivars. On fruit, no differences in non-target impacts on arthropod pests were observed among the three systems except for surface-feeding Lepidoptera and San Jose scale damage. In a separate phytophagous mite study on the cultivar 'Zestar!' leaf samples were evaluated for the number of motile phytophagous mites every 14 days from 1 July through 26 August each year. When there were differences, the biostimulant system had less mite incidence per leaf than one or both of the sulfur-based systems in both years. The difference in the number of sulfur sprays did not have a major effect on the mite populations. In summary, the use of the biostimulant system resulted in insufficient disease management which led to lower estimated gross income compared to the sulfur-based systems. These results show more research and further evaluation of new organic disease management tools, including the use of agricultural biostimulants, are necessary before growers consider replacing the use of standard sulfur fungicides for disease management in Vermont orchards.

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Introduction

Apple production in Vermont currently generates approximately 13.9 million dollars from about 648 ha of orchards, representing a significant component of the state's diversified agricultural industry (NASS, 2014). According to the Northeast Organic Farming Association of Vermont (NOFA-VT) there are currently 12 certified organic apple farms (including the University of Vermont Horticultural Research and Educational Center) representing 55 ha (Nicole Dehne, Pers. comm., 2013). Growers face daunting challenges that limit adoption of organic production including higher production costs, lower marketable yields, decreased tree vigor and the challenge of managing important arthropod pests and diseases (Delate et al., 2008; Peck et al., 2010; Percival and Boyle, 2005).

Successful disease management, especially the management of the fungal disease apple scab [*Venturia inaequalis* (Cooke) G. Winter], is a significant limiting factor in growing organic apples in New England (MacHardy, 1996, 2000). Part of the difficulty in managing this disease is related to the polycyclic lifecycle of the pathogen (MacHardy, 1996). *Venturia inaequalis* begins to form pseudothecia, or sexual fruiting bodies, in apple leaves on the orchard floor within about four weeks after leaf drop in autumn. The pseudothecia continue to mature throughout the winter and spring, culminating in the development of asci and ascospores. Ascospores, formed within asci in the pseudothecia, are forcibly discharged in the spring when there is sufficient rain and favorable temperatures (MacHardy, 1996). In most years and locations, this initial release corresponds to the timing of budbreak (MacHardy, 1996; Sutton et al., 2014). The length of the time period when the finite number of ascospores are released is called the primary scab season. The duration of the primary scab season varies from year to year depending on weather, but in Vermont this stage can last through June (MacHardy, 1996; Rosenberger and Cox, 2010). The ascospores infect young leaves, sepals, fruit and stems if temperature and duration of leaf wetness are favorable for infection after their release. The lesions resulting from infection produce asexual spores or conidia, usually within nine to seventeen days, which can re-infect apple leaves and fruit throughout the rest of the growing season when temperature and leaf wetness requirements are met. However, as apple leaves age they become less susceptible to *V. inaequalis*. This phenomenon, called ontogenic resistance, effectively limits the susceptible leaf tissue to the newest two to three leaves on the shoot (MacHardy et al., 2001). Conidia, disseminated by splashing rain and wind, are the principle inoculum that causes the increase of the disease over the summer. This stage of the disease is called the secondary scab stage. Depending on weather and disease pressure, up to 15 protectant fungicide spray applications may be necessary to manage this polycyclic disease on susceptible apple cultivars (Ellis et al., 1998; Holb, 2005b; Jamar et al., 2010; MacHardy, 1996, 2000). Growers strive to prevent infections during primary scab season to avoid additional scab sprays later in the season. Weather-based models have been developed to successfully predict apple scab infection based on length of time of leaf wetness and temperature (MacHardy and Gadoury, 1989; Mills, 1944). Accurate data from weather and infection models help the orchardist determine when to apply and how often to repeat scab fungicide sprays, helping to eliminate unnecessary sprays.

Apple scab causes fruit and foliar lesions which when severe, can impact the health and vigor of the tree and lead to premature defoliation, decreased fruit yield and decreased fruit marketability (Ellis et al., 1998; MacHardy, 1996). Severe infections from this fungal disease can also increase susceptibility of the tree to winter injury and may impact fruit bud formation in the following season (MacHardy, 1996). The lack of organic orchards in New England can be partially attributed to the high susceptibility of the widely planted cultivar 'McIntosh' to apple scab (MacHardy, 2000). Of the five apple cultivars ('Ginger Gold', 'Honeycrisp', 'Liberty', 'Macoun' and 'Zestar!') identified by growers as important to the future of the industry in Vermont, only 'Liberty' is apple scab-resistant (Berkett, Pers. comm., 2013).

Although the use of new scab-resistant cultivars can decrease the total number of fungicide sprays applied in the orchard during the growing season, many New England growers have been slow to replace 'McIntosh' trees (Berkett and Cooley, 1989). Resistance to apple scab is carried by a single *Vf* gene (Ellis et al., 1998; MacHardy et al., 2001). New races of *Venturia inaequalis* have emerged in Europe that have overcome resistance to this gene and will likely impact the future use of these cultivars as successful scab management tools in United States orchards (Gessler et al., 2006; Parisi et al., 1993).

Although the use of scab-resistant cultivars can virtually eliminate the need for fungicide sprays for this pathogen, there are many other economically important fungal diseases in the orchard that require management such as powdery mildew [*Podosphaera* *leucotricha* (Ellis & Everh.) Salmon] and the complex of rust diseases including cedar apple rust [*Gymnosporangium juniper-virginianae* (Schwein)]; hawthorn rust [*G. globosum* (Farlow) Farlow]; quince rust [*G. clavipes* (Cooke and Peck)] and Japanese apple rust [*G. yamadae* (Miyabe ex Yamada)] (Gregory et al., 2009; Yun et al., 2009). Fungal fruit rots (*Colletotrichum* spp. and *Botryosphaeria* spp.) as well as sooty blotch, which is caused by the complex of *Peltaster fruticola* (Johnson, Sutton, Hodges), *Geastrumia polystigmatus* (Batista & M.L. Farr), and *Lepodontium elatus* (G. Mangenot) De Hoog, *Gleodes pomigena* (Schwein) Colby, and the disease flyspeck [*Zygophiala jamaicensis* (E. Mason)] can also cause economic losses in orchards (Sutton et al., 2014). All of these diseases would need to be successfully managed in the organic apple orchard to produce a marketable crop of apples.

The pesticides used to manage diseases in certified organic orchards must be approved by the Organic Materials Review Institute (OMRI) and are limited in number compared to what is available for use in non-organic orchards (Cooley et al., 2014). Disease management in organic apple orchards is currently reliant on OMRI-approved copper- and sulfur-based pesticides and although organic, these compounds are not without significant negative impacts (Ellis et al., 1998; Holb et al., 2003).

In general, copper products are allowed in organic farming but are restricted in their use to minimize copper accumulation in soils [National Organic Standards Board (NOSB)]. Prolonged use of copper in various cropping systems has resulted in elevated levels in soils, impacting soil ecology and earthworm numbers (Paoletti et al., 1998; van Rhee, 1976). Since the traditional formulations of copper can increase chances of phytotoxicity after the phenological green tip stage in apple, these formulations are limited to the silver tip phenological stage where they are used as a bactericide for the management of overwintering fire blight [*Erwinia amylovora* (Burrill) Winslow] inoculum (Brown et al., 1996). Unfortunately, the new lower rate copper formulations have label limitations that do not allow applications at adequate rates for control of fire blight later in the growing season so are not appropriate past the green tip spray (Rosenberger, Pers. comm., 2014). Although these new materials are labelled for use against many of the summer fruit rot diseases, the amount of available copper ions in the applied rates may be substantially less than the traditional copper formulations. As a result, these lower rate formulations vary in their effectiveness against scab and fruit rots and have been shown to increase fruit russet. (Rosenberger, Pers. comm., 2014).

Sulfur and liquid lime sulfur remain the standard organic fungicides used to manage apple scab and other fungal diseases in the orchard (Ellis et al., 1991; Holb et al., 2003; MacHardy, 1996; Mills, 1947). Both are multi-site protectant fungicides, but liquid lime sulfur provides some activity against scab 48-72 hours post-infection (Hamilton and Keitt, 1928; Jamar and Lateur, 2006). Liquid lime sulfur, however, is highly caustic and its use can cause detrimental impacts on tree health, photosynthesis, pollen tube growth and can result in decreased fruit set and lowered yields. (Burrell, 1945; Holb et al., 2003; MacHardy, 1996; McArtney et al., 2006; Mills, 1947; Palmer et al., 2003). The use of this caustic material later in the season can result in russetting and burning of the fruit, especially under hot, humid conditions. (Holb et al., 2003; Noordijk and Schupp, 2003; Stopar, 2004). For these reasons, use of liquid lime sulfur is limited to curative sprays for apple scab after weather conditions conducive for infection have occurred (MacHardy and Gadoury, 1989; Penrose, 1995). Although wettable sulfur lacks post-infection activity, is a weaker protectant than liquid lime sulfur and can also impact photosynthesis, this material causes less phytotoxicity and consequently is the primary fungicide used in organic apple orchards (Holb and Heijne, 2001; Jamar et al., 2008, Palmer et al., 2003).

Sulfur fungicides can impact mite populations and have long been identified as general acaricides (Collyer and Kirby, 1959; Garman and Townsend, 1938; Lord, 1949; MacPhee and Sanford, 1954). Sulfur can have non-target effects on both beneficial and phytophagous mite populations in orchards and can impact predator to prey ratios in orchards, causing phytophagous mite populations to flare (Beers and Hull, 1987; Beers et al., 2009; Blommers, 1994; Bower et al., 1995; Holdsworth, 1972; MacPhee and Sanford, 1954; van de Vrie, 1962). European red mite [*Panonychus ulmi* (Koch)] and the two-spotted spider mite [*Tetranychus uritcae* (Koch)] are serious phytophagous mites in New England apple orchards and their feeding can cause off-color foliage; reduce net photosynthesis; cause defoliation; reduce fruit quality, decrease bloom, and can impact future bud set (Beers and Hull, 1987; Brunner and Howitt, 1981; Hall and Ferree, 1975; Jeppson et al., 1975; Lienk, 1980; Nyrop et al., 1989). These mites are in the family *Tetranychidae* and are commonly known as spider mites. The European red mite is the most destructive mite species attacking New England apples and was listed as the second worst problem affecting apple production after apple scab in a recent survey of Northeast and Canadian researchers and crop consultants (Agnello, 2012). European red mite overwinters on apple bark at the base of leaf and fruit spurs as fertilized eggs that typically hatch around the phenological stage of tight cluster. There are commonly four to nine generations of European red mite each season depending on orchard location and weather factors (Beers and Hull, 1987; Brunner et al., 1981; Jeppson et al., 1975; Lienk, 1980). Two-spotted spider mites overwinter as adults within bark crevices or on ground cover under the trees in the orchard and commonly produce six to eight generations in New England orchards (Agnello et al., 2006; Laing, 1969; van de Vrie, 1985). Management of mites in organic orchards is accomplished primarily through delayed dormant oil sprays, summer horticultural sprays and conservation of beneficial predatory mites (Agnello et al., 1994; MacHardy, 2000). Studies have shown when populations of the predatory mite *Typhlodromus pyri* (Scheuten) are protected in orchards, the need for other acaricide controls can be eliminated (Agnello et al., 1994, 2003; Nyrop et al., 1989).

Given the negative effects of sulfur and lime sulfur fungicides on tree health and the potential impacts to predatory mites, growers and researchers are searching for suitable alternatives for disease control in the orchard. Novel disease resistance elicitors, used alone or in combination with fungicides, may offer new, low environmental-impact options. The objective of this research was to evaluate the target and non-target effects of an organic disease management system containing biostimulants compared to two sulfur-based systems on foliar and fruit diseases, pest and beneficial arthropods, tree growth, yield and fruit quality on four apple cultivars in Vermont. The results will be reported in three separate articles.

Agricultural Biostimulants

Plant chemical defenses can be present in the plant all of the time or can be “induced” by an elicitor. The term ‘elicitor’ was originally used for compounds that would induce production of phytoalexins, but now the definition of elicitor has broadened to any compound that stimulates any plant defense. (Ebel and Cosio, 1994; Hahn, 1996; Thakur and Sohal, 2013). The term ‘agricultural biostimulant’ is often substituted for ‘elicitor’ when used in a field or agricultural setting. There are several studies demonstrating the successful use of agricultural biostimulants for suppression of diseases caused by several genera of pathogens in a wide variety of crops (Cherif et al., 1992; Elmer and Reglinski, 2006; French-Monar, 2010; Germar, 1934; Gillman et al., 2003; Kunoh and Ishizaki, 1975; Leusch and Buchenauer, 1989; Renard-Merlier et al., 2007; Rodgers-Gray and Shaw, 2004; Sun et al., 1994, 2002). In addition to triggering plant defenses, agricultural biostimulants can also improve physiological responses in plants. Improved crop yields and quality, increased plant buffering capacities for temperature and drought extremes, and improvements in plant nutrition have been noted in various crops following applications of agricultural biostimulants (Botta, 2013; Calvo et al., 2014; Chen et al., 2003; Miller et al., 1990) and evidence of positive benefits of application is increasing (Chen et al., 2003; Lyon et al., 1995; Paul and Sharma, 2002). Agricultural biostimulants that show promise for organic production systems include humic acids, seaweed, silica and other plant extracts, chitinous products from fungal sources and oligiosaccharides (Aziz et al., 2006; Colavita et al., 2011; Craigie, 2010; French-Monar et al., 2010; Khan et al., 2009; Leusch and Buchenauer, 1989; Lyon et al., 1995; Norrie et al., 2002; Volk et al., 1958; Wu et al., 2005). Increased interest in using these materials may be partially driven by the loss of synthetic and/or organically acceptable products available for disease management.

Physiological responses

There are several studies demonstrating the use of agricultural biostimulants in apple crops to improve physiological responses. Foliar sprays of seaweed-based extracts in Italy improved fruit color in "Mondial Gala' but not 'Fuji' apples. The spray did not increase yield, fruit size, foliar nutrition or shoot growth in either cultivar (Malaguti et al., 2002). Pre-harvest treatments in Poland using two seaweed extract products on four apple cultivars had a varying effect on fruit set and internal fruit quality but more constently improved the fruit size distribution (Basak, 2008). Depending on the cultivar, red color was either improved or diminished. In another study in Italy, a commercial seaweed extract product was applied to help mitigate the negative effects of alternate bearing in 'Fuji' apple (Spinelli et al., 2009). In nutrient-stressed trees, the soil-applied product increased chlorophyll and decreased yield fluctuations between heavy and light crop load years. In the same trees, average fruit weight also increased. These effects were not noted in nutritionally-sound trees, leading the researchers to hypothesize the product may be a potential tool in organic and low-input orchards to reduce alternate bearing (Spinelli et al., 2009). Another study in Italy applied several commercial biostimulant products based on seaweed extracts to three apple cultivars and found no benefits of biostimulant sprays on yield, fruit quality or return bloom in the nutritionally-sound research trees (Thalheimer and Paoli, 2002). A recent study performed in 2009-2011 at the University of Vermont Horticultural Research and Education Center found the use of two commercial seaweed extract sprays had little effect on yield, tree growth or fruit quality (Bradshaw et al., 2013).

Treatments after the occurrence of late spring frosts with amino acid-based biostimulants showed improved apple yield and quality (Porro et al., 1998). Italian researchers applied bloom sprays of amino acids and peptide biostimulants extracted from animal by-products and found increased pollen tube growth and fruit set on apple (Filiti et al., 1986). In Egypt, a Japanese commercial soil biostimulant, Effective Microorganisms or 'EM', was applied to 'Anna' apple trees to investigate the effects on vegetative growth, leaf mineral content, fruit yield and fruit quality. 'EM' contains more than 60 selected strains of "effective microorganisms" including photosynthetic and lactic acid bacteria, yeasts, actinomycetes and various other fungi. In general, the EM treatments increased the parameters measured, when compared to the non-treated trees (Sahain et al., 2007).

Disease suppression

There are several studies demonstrating the use of agricultural biostimulants for disease suppression in a wide variety of crops. To understand how agricultural biostimulants suppress disease, it is necessary to understand the complex ways plants resist disease. Plants have developed both passive and active mechanisms to defend themselves from plant pathogens and resist disease (Hammond-Kosack and Jones, 1996). Disease resistance can be as simple as the plant species not being a host for the pathogen. Plants are also able to resist disease through inherent structural or chemical passive defense mechanisms. These barriers include waxes, cuticles, cell walls, trichomes and anti-microbial compounds produced in plant cells. (Chamberland et al., 1994; Garcia-Brugger et al., 2006). A third method of resistance involves the activation of host defenses following plant recognition of a pathogen. As pathogens attack, they release a variety of substances including glycoproteins, chitosan, glucans, polysaccharides, toxins, fatty acids, peptides, carbohydrates and extracellular enzymes (Boller, 1995). These are the same active compounds found in agricultural biostimulants. These nonspecific elicitors are recognized by the plant, inducing a cascade of disease resistance responses, including the production of phytoalexins (Hammerschmidt, 1999; van Loon, 1998). Phytoalexins are high molecular weight antimicrobial compounds produced by the plant to restrict pathogen development (Hammerschmidt, 1999). This resistance mechanism is called “induced resistance” or “acquired resistance” and has been recognized in plant/pathogen interactions for over 100 years (Chester, 1933; Hammond-Kosack and Jones, 1996; Ross, 1961). The plant activates defenses that are expressed locally as well as systemically throughout the plant. The localized expression of defenses is called the hypersensitive response (HR). The HR is characterized by the rapid death of one or more cells surrounding the infection site, effectively eliminating the food source for the pathogen and arresting its growth (Stakman, 1915). The HR provides resistance to biotropic pathogens, like rusts (Basidiomycota) and powdery mildews (Ascomycota) that require living cells for their energy (Kombrink and Schmelzer, 2001; Kumar et al., 2001). Systemic acquired resistance (SAR) is the term used when defenses are activated systemically throughout the plant (Sticher et al., 1997). SAR, whether induced by a pathogen or by an agricultural biostimulant, provides broad-spectrum resistance to further attacks of fungal, bacterial, viral and nematode pathogens distal to the initial site of infection and unrelated to the original pathogen (Hammerschmidt, 1999; Heil and Bostock, 2002; Ton et al., 2002). Plants accomplish this through different and distinct pathways involving pathogen-related protein genes and small signaling molecules such as salicylic acid, jasmonic acid and ethylene. Which signaling molecule(s) are used is determined by the type of pathogen attacking (Ton et al., 2002). The deeper understanding of the SAR plant defense mechanism, pathogen elicitors and signaling pathways has helped stimulate the discovery of new novel elicitors that can be used to artificially induce defense reactions in plants without a pathogen present (Anderson et al., 2006; Klarzynski et al., 2000).

Silicates

The association between silicates and reduced incidence and severity of fungal diseases has been widely documented (Fauteux et al., 2005). Silicates are of interest due to their anti-fungal effects combined with low environmental and mammalian toxicity (Horst et al., 1992; Menzies et al., 1992). Reductions in the incidence of the following pathogens and crops due to application of silicates have been reported: *Phytophthora capsici* in paprika (*Capsicum annuum*), *Diplocarpon rosae* in rose (*Rosa* spp.), *Colletotrichum orbiculare* in cucumber (*Cucumis sativus* L.), *Pythium aphanidermatum* and *Fusarium moniliforme* in corn (*Zea mays* L.), *Septoria nodorum* and *Erysiphe graminis* in wheat (*Triticum aestivum* L.), *Pythium ultimum* in cucumber and *Alternaria* spp. in barley (*Hordeum vulgare* L.) (Cherif et al., 1992; French-Monar, 2010; Germar, 1934; Gillman et al., 2003; Kunoh and Ishizaki, 1975; Leusch and Buchenauer, 1989; Rodgers-Gray and Shaw, 2004; Sun et al., 1994, 2002). The exact role silica (SiO_2) plays in disease suppression is not totally understood and is still debated. Early studies proposed deposits on host tissue played a mechanical role in preventing fungal penetration (Datnoff et al., 2007; Kunoh and Ishizaki, 1975). Although this mechanism may partially explain silica’s role in plant disease, additional research has shown silica plays a role in activating natural defenses in plants and inducing or ‘eliciting’ resistance to disease by enhancing the accumulation of anti-fungal phytoalexins. (Fauteux et al., 2005; Fawe et al., 1998; van Loon et al., 1998). The success of silicates as elicitors to suppress plant diseases is dependent on the plant species and the pathogen involved. Both mechanical and elicitor mechanisms were noted in a study using soluble silicon sprays on grape (*Vitus vinifera* L.) to manage powdery mildew [*Uncinula necator* (Schwein) Burrill)] (Bowen et al., 1992). Researchers noted the reduced severity of the disease was partly due to the silica providing a physical barrier on the leaves preventing penetration by the fungus, yet they also observed silica absorbed by the leaf was translocated laterally through the leaf where it surrounded the appressoria arresting further infection (Bowen et al., 1992). This similar host-defense response was seen with powdery mildew when silica was applied to the roots of cucumber and barley (Kunoh and Ishizaki, 1975).

There have been discouraging results noted with the use of silicates for apple disease management. A study in Belgium applied a ‘during-infection’ spray of silicon (Si) for primary scab and found it slightly reduced apple scab on the fruit with no effect on foliar scab when compared with water controls (Jamar et al., 2010). When fruit quality and yield were evaluated, the results revealed poor scab control (Jamar et al., 2010). Since use of copper fungicides have been restricted in Europe and lime sulfur use has been banned in Belgium, silicon along with several plant extracts, copper, potassium bicarbonate and sulfur were tested to evaluate replacement materials for scab control in a Belgian study (Jamar et al., 2008). Results showed significant scab reduction by silicon only on the highly scab-susceptible cultivar ‘Pinova’. Low rates of sulfur combined with low rates of copper provided the best scab control (Jamar et al., 2008).

Plant extracts

Plant extracts have been used successfully in several crops to reduce plant disease (Fawcett and Spencer, 1970; Osborn, 1943; Spencer et al., 1957). Many plant species possess natural compounds that suppress disease by being directly toxic to the pathogen (Amadioha, 2000; Ansari, 1995; Aziz et al., 1998; Fiori et al., 2000; Fridlender et al., 1993; Osborn, 1943; Spencer et al., 1957; Wilson et al., 1997). Extracts have also been shown to suppress plant disease by inducing resistance to a variety of pathogens (Eldoksch et al., 2001; Kagale et al., 2005; Satish et al., 2007; Schneider and Ullrich, 1994). An extract of giant knotweed, *Reynoutria sachalinensis*, suppressed powdery mildew (*Sphaerotheca fuligenea*) in English cucumber as well as the standard conventional fungicide control (Daayf et al., 1995). Regalia®, an OMRI-approved commercial product, is formulated with a 5.0% extract of giant knotweed and is marketed for the management of bacterial and fungal disease control in peppers and tomatoes. A research study in Jordan showed anti-fungal activity of olive cake extracts against *Fusarium oxysporum*, *Pythium* sp., *Rhizopus* sp., *Mucor* sp., *Verticillium* sp., *Penicillium* sp., *Rhizoctonia solani*, *Stemphyllium solani*, *Cladosporium* sp. and *Colletotrichum* sp., yet no activity was noted against *Alternaria* sp. (Anfoka et al., 2001). Leaf extracts from 20 plant species were tested for their ability to suppress mycelial growth of *Alternaria solani*, a destructive tomato (*Solanum lycopersicum*) pathogen in many countries around the world. The researchers found an onion (*Allium cepa* L. x *Allium sativum* L.) extract was the best inhibitor of mycelial growth, yet they also saw evidence of induced resistance in the tomato to *A. solani* as a result of the extract application (Latha et al., 2009).

Neem oil, a plant extract from the neem (*Azadiractin indica*) tree, is a potent insect anti-feedant and has activity by effectively blocking insect molting hormones in a wider variety of insect species (Isman, 2006; Dayan et al., 2009; Mansour et al., 1997). Neem also has shown direct fungicidal activity (Abassi et al., 2003; Hoque et al., 2014; Pasini et al., 1997). Two common postharvest fruit rot fungi; *Botrytis cinerea* (Pers.) Fr. (gray mold) and *Glomerella cingulata* (Ston.) Spauld. and Schrenk. (bitter rot) were suppressed by neem extracts (Moline and Locke, 1993). However, when a University of Vermont study evaluated the efficacy of sulfur/lime sulfur and alternative fungicides on general "fruit rots" at harvest, no differences were found between the neem oil treatment and the non-treated control (Cromwell, 2009). The same researchers also found inadequate control of apple scab with neem oil (Cromwell et al., 2011). There is evidence neem can act as a biostimulant, inducing resistance to plant diseases in some crops. In one study, neem controlled barley leaf stripe (*Drechslera graminea*) at the same level as the fungicide control (Paul and Sharma, 2002). The neem did not suppress germination of the *D. graminea* conidia, supporting the researchers' hypothesis that the extract induced disease resistance. Another study found neem induced resistance to *Alternaria* leaf spot in sesame (*Sesamum indicum* L: Syn. *S. orientale* L.) (Guleria and Kumar, 2006). There is evidence of induced resistance with the use of neem for the management of apple scab (Jamphol et al., 2012). The neem extract used in the study reduced scab incidence in addition to showing significantly higher leaf antioxidant and phenolic activity. Since anti-oxidants and phenolics act as signaling compounds when plants are attacked by pathogens, this suggests a role in inducing plant defense mechanisms (Liu et al., 2007; Petkovsek et al., 2007).

Plant extracts have been tested in the laboratory and in orchards for the suppression of diseases in apple. A researcher tested extracts from 1,915 different plant species on conidial germination of *V. inaequalis* and found 440 exhibited varying degrees of inhibition, with ivy (*Hedera helix* L.) showing the best suppression (Gilliver, 1947). In addition, plant extracts of isolated saponins have provided high levels of scab control in greenhouse tests (Bosshard et al., 1987). Saponins are anti-fungal compounds common in many plant species that produce soap-like foams in water-based solutions (Bowyer et al., 1995). Bosshard found water-diluted ivy extracts inhibited conidial germination on glass slides (Bosshard, 1992). When the same dilutions were tested on apple seedlings, scab control ranged from 55.0% to 99.4% depending on the number of days before inoculation with the pathogen (Bosshard, 1992).

A detached leaf bioassay was used to evaluate several biostimulant products including seaweed extracts, betaine, molasses, humic acid, yucca extract, plant hormone/vitamin complex, salicylic acids, potassium phosphonate, potassium phosphite and harpin proteins on germination of apple scab conidia, formation of appressoria and reduction of foliar scab severity (Percival, 2010). Results showed the salicylic acids, harpin proteins and potassium products inhibited conidial germination and appressoria formation, and reduced severity of scab. Percival determined the seaweed extract, betaine, molasses, humic acid, yucca extract, and plant hormone/vitamin complex had no effect compared to water treated controls and their use in orchards for scab management appeared limited. A study in Belgium, trying to identify new scab management tools to reduce the reliance on copper fungicides, tested sulfur products, potassium bicarbonate, silicon and five plant extracts including orange (*Citrus* sp.) peel, soapbark (*Quillaja saponaira*), tea (*Malaleuca* sp.) seed, quinoa (*Chenopodium* sp.) seed and grapefruit (*Citrus x paradisi)* seed for efficacy against primary scab (Jamar et al., 2010). Results showed the extracts, the sulfur products, and the potassium bicarbonate all significantly decreased primary scab in organic apple orchards. None of the treatments caused phytotoxicity or russetting of fruit (Jamar et al., 2010).

In vitro studies showed oregano (*Origanum vulgare* spp. *Hirtum* Ietswaart) extracts were effective in inhibiting germination of conidia and germ-tube elongation of *Venturia inaequalis* (Arslan et al., 2013). However, in field studies when ammonium bicarbonate was applied to apple with and without the oregano extract, no reduction of scab incidence or severity was noted on leaves and fruit with the extract addition. Yucca (*Yucca schidegera*) extracts have been proven to reduce apple scab symptoms and sporulation in seedling studies in Denmark and field trials in Denmark and the Netherlands (Bengtsson et al., 2009; Heijne et al., 2007). Yucca extracts provided apple scab control comparable to sulfur in 'Jonagold' in research studies in Denmark (Kohl et al., 2006). However, a detached apple leaf bioassay found no effect on germination of apple scab conidia, appressoria development or foliar scab severity when yucca extracts were applied in the laboratory (Percival, 2010). Ivy and soapwort (*Saponaria officianalis*) extracts have demonstrated antifungal properties against apple scab ascospores in Switzerland (Bengstsson et al., 2004, 2009). A field study by the same researchers tested the 1% *Populus nigra* extract on 'Golden Delicious' and 'Jonathan' and found the extract significantly reduced apple scab severity on 'Golden Delicious' fruit and foliage. These results encouraged the researchers to recommend this application as a low-cost organic alternative for secondary scab control.

Foliar sprays of plant extracts, derived from wormwort (*Artemisia absinthium)*, stinging nettle (*Urtica dioica*) and horsetail (*Equisetum arvensae*), were combined with two antagonistic microorganisms, *Trichoderma asperellum* and *Pythium oligandrum*, and tested in organic apple orchards (Kowalska et al., 2010). The spray with only the microorganism *T. asperellum* showed the most efficacy during primary scab infection period and the level of scab was significantly different from the water control. During the secondary scab infection period, *T. asperellum* alone plus *T.asperellum* with each of the extracts and *P. oligandrum* alone showed significantly less apple scab when compared to the water control. No testing was done on the extracts alone. (Kowalska et al., 2010). Studies evaluating several plant extracts at different concentrations and using different extraction methods on scab control were conducted in the lab, greenhouse and orchard (Pfeiffer et al., 2004). Plant extracts from *Inula visocosa*, *Quillaja saponaria*, *Citrus* sp. and *Saponaria officinalis* showed efficacy against scab on apple seedlings in the greenhouse.

Seaweed extracts

Seaweed has a high content of polysaccharides and oligiosaccharides, and is an important source of disease elicitors (Allen et al., 2001; Vera et al., 2011). *Ascophyllum nodosum* (L) Le Jolis is the most common brown algal seaweed used in agriculture (Blunden and Gordon, 1986). Seaweed extracts have also been shown to have suppressive effects on nematode populations in soils without being directly nematicidal

(Featonby-Smith and van Staden 1983a; Wu et al., 1997). Foliar applications of seaweed extracts decreased *Phytophthora capsici* in pepper and downy mildew (*Plasmopara viticola)* in grapes (Lizzi et al., 1998). Another brown algal seaweed, *Laminaria digitata*, induced disease defense reactions in *in vitro* studies on tobacco (*Nicotiana* sp.), grape (*Vitus vinifera*) and rice (*Oryza* sp.) cells (Aziz et al., 2003; Inui et al., 1997; Klarzynski et al., 2000). Products derived from this seaweed have been used to manage powdery mildews (Ascomycota) and gray mold (*Botrytis cinerea*) in grapes and fire blight in apples (Elmer and Reglinski, 2006; Renard-Merlier et al., 2007). An apple scab study in Belgium tested seaweed extracts and found the applications suppressed scab, but not enough to be used without additional fungicide treatments. The researchers determined use of the extracts may be better suited to secondary scab applications (van Hemelrijck et al., 2013). Seaweed extracts did not affect conidial germination, appressoria formation and leaf severity in a detached leaf bioassay for apple scab as mentioned above (Percival, 2010). A recent two year study in Vermont showed seaweed extracts had no effect on apple disease incidence on foliage or fruit (Bradshaw et al., 2013). The applications did suppress the incidence of powdery mildew on one cultivar in one year.

Microbial inoculants

Microbial inoculants for inducing disease defenses generally consist of free-living bacteria and fungi that have been isolated from a range of environments (Berg, 2009; Dodd and Ruiz-Lozano, 2012; Vessey, 2003). Several fungal and bacterial microbial inoculant products have been formulated and include the genera: *Gliocladium, Trichoderma, Ampelomyces, Candida, Coniothyrium, Pseudomonas, Streptomyces, Agrobacterium and Bacillus* (Vinale et al., 2008). When plants are infected by pathogens, defense-related compounds are activated including chitinases that hydrolyze the chitin-based cell wall of the pathogen (Felix et al., 1993; Legrand et al., 1987). *Trichoderma,* a common microbial inoculant, colonizes the plant's rhizosphere and also secretes broad-spectrum anti-fungal chitinases, breaking down cell walls of pathogens and presumably eliciting disease responses in plants (Harman et al., 2004). Several *Trichoderma* species have reduced foliar disease severity in plants through this mechanism of induced resistance (Ahmed et al., 2000; De Meyer et al., 1998; McBeath and Kirk, 2000; Yedida et al., 1999). The development of transgenic plants that overexpress chitinases has been a recent strategy for increasing resistance in plants (Collinge et al., 1993; Schickler and Chet, 1997). A Cornell study developed a transgenic 'Marshall McIntosh' apple line that expressed endochitinase from *T. harzianum* to test the effects on apple scab susceptibility and found the transgenic lines had less disease severity than the non-transgenic lines (Bolar et al., 2000).

There have been studies showing the successful use of microbial inoculants for apple storage diseases, but this is generally due to antagonism/antibiosis rather than actual induced resistance (Janisiewicz, 1987, 1988). Antibiotic activity has also been noted with the use of *Erwinia herbicola* to control *E. amylovora,* the organism causing fire blight in apple (Beer et al., 1984). *Bacillus subtilis*, used as a biological fungicide rather than a disease defense elicitor has been tested in Vermont apple orchards for its impact on disease, yield and fruit quality with variable but not impressive results (Cromwell et al., 2011).

Another type of microbial-based inoculant uses a fermented mix of cultures from several beneficial microorganisms (Calvo et al., 2014). The finished product includes the complex microbial populations and the resulting fermentation metabolites. An example of this category of microbial inoculant is the product ‘EM’. EM or “Effective Microorganisms” was first described one hundred years ago as a mixture of “about 80 species of microorganisms” fermented together with organic wastes and molasses (Khaliq et al., 2006). The microorganisms in the EM microbial mix include lactic acid and photosynthetic bacteria, actinomycetes, yeasts, and fermenting fungi such as *Aspergillus* and *Penicillium* (Hu and Qi, 2013). There have been studies showing variable effects on yield and soil quality effects of the mixture (Hu and Qi, 2013; Khaliq et al., 2006). There have not been any studies reported in the literature on the use of EM in apple systems for disease suppression.

Agricultural Biostimulants in the marketplace

As consumers have become more aware and concerned about the potential health risks and environmental impacts of pesticide use, there has been an increased demand for organic products (Gessler and Pertot, 2012; Reganold et al., 2001; Tilman, 1999). Organic agriculture in the U.S. currently represents a $31.5 billion dollar industry [Organic Trade Association (OTA), 2012]. The organic food sector grew by $2.5 billion during 2011, with the fruit and vegetable category representing half of the increase (OTA, 2012). This increased demand for organic products has also been reflected in Vermont, with the total organic product sales almost doubling from the 2007 USDA Census ($38 million) to the 2012 USDA Census ($62 million) (NASS 2007, 2012). According to Vermont Organic Farmers (VOF), LLC, the primary organic certification program of NOFA-VT, 585 producers on 42,044 ha were certified in 2013, representing sales of over 155 million dollars (Northeast Organic Farmers Association-Vermont (NOFA-VT), 2013). Organic agriculture is the fastest growing sector of Vermont agriculture (NOFA-VT, 2013).

The increased demand for organic food has helped stimulate the search for alternative strategies for the control of arthropod pests and disease pathogens (Guleria and Kumar, 2006; Lyon et al., 1995). As a result, the interest in agricultural biostimulants worldwide is increasing. The First World Congress on the Use of Agricultural Biostimulants was held in November, 2012 in Strasbourg, France with over 700 attendees representing 30 countries (http://www.biostimulants2012.com/). The increased demand for these novel materials, coupled with documented successes in the field and laboratory, have resulted in the projection that the expansion of the global agricultural biostimulant market will reach $2,241 million by 2018 (Calvo et al., 2014). Europe currently represents the largest market for biostimulants, with an estimate of three million hectares treated with biostimulants in 2013 [European Biostimulants Industry Council (EBIC), 2013]. This amount is projected to expand by 10% each year. Defining the economic benefits of these tools has been difficult, but some estimated impacts include: minimum yield increases of five to ten percent, increased fertilizer use efficiency by 5% to 25%, enhanced quality of the crop (improved fruit set, better color, increased size, etc.) by 15%, and 10% to 15% savings in pesticides as a result of the use of biostimulants (EBIC, 2013).

Research Objectives

Organic apple growers in Vermont and New England are searching for University-based research that evaluates new and novel materials for management of disease and arthropod pest problems (Berkett, Pers. comm., 2013). The use of agricultural biostimulants for disease management in apples was introduced by a New England orchardist in a popular trade book called *The Holistic Orchard- Tree Fruits and Berries the Biological Way* (Phillips, 2011). Phillips' book promotes whole system health in the tree and orchard as a way to avoid "short term" solutions to disease management through the use of pesticides. Four 'holistic' sprays of biostimulants in the spring are prescribed at the phenological growth stage of ¼ green, early pink, petal fall, and in the 'first cover' spray, which is a week to ten days after petal fall. (Phillips, 2011). These biostimulant sprays include a tank mix of pure neem oil, liquid fish and a complex of diverse microbes that are applied to the foliage and trunk to "promote beneficial fungi and stimulate tree immunity to ward off disease." These early season sprays are timed to cover the primary infection period for apple scab and infection by other pathogens. After the four spring applications, stinging nettle and horsetail tea are added to the applications and are made on a ten day to fourteen day schedule throughout the rest of the growing season (Phillips, 2011). The primary objective of this study was to test the efficacy this disease management approach against economically important diseases of apple, following Phillips' recommended application schedule, and compare this novel approach with two management approaches using the standard sulfur-based fungicides used by commercial organic orchardists.

The distinguishing components of the three organic management systems (OMS) evaluated in this research were:

OMS-1 included sulfur fungicides throughout the season except for the three to four week period of rapid shoot elongation following the petal fall phenological stage when no sulfur-based fungicides were used. Sulfur was avoided during this critical time period of rapid growth to minimize the potential for cumulative negative impacts on photosynthesis (Palmer et al., 2003). Palmer et al. found sulfur fungicides (lime sulfur and sulfur) had pronounced effects on leaf photosynthesis rate with the greatest effect after shoot growth had ended. The researchers hypothesized that several applications of sulfur over the course of the season or over several years may have a cumulative effect on leaf area and shoot growth.

OMS-2 replaced sulfur fungicides with the agricultural biostimulants promoted in "*The Holistic Orchard- Tree Fruits and Berries the Biological Way* " and included: pure neem oil (Ahimsa Organics Neem Oil; The Ahimsa Alternative, Inc., Bloomington, MN), liquid fish (OrganicGem Liquid Fish Fertilizer 3-3-0; Advanced Marine Technologies, New Bedford, MA), an activated microbial inoculant (Dr. Higa's Original EM·1 Microbial Inoculant; TeraGanix, Alto, TX), equisetum (*Equisetum arvense*) and stinging nettle (*Urtica doica*) teas, kelp meal (SeaLife Kelp Meal; North American Kelp, Waldsboro, ME), unsulfured organic molasses and yucca extract emulsifier (Therm X-70; Cellu-Con, Inc., Strathmore, CA) (Phillips, 2011).

OMS-3 included sulfur fungicides throughout the season and is the standard organic management system applied by commercial organic apple growers in New England. OMS-3 serves as the control in this two year study.

The potential non-target impacts of sulfur and lime sulfur fungicides on arthropods have been evaluated in other scientific studies (Cromwell et al., 2011; Holdsworth, 1972; MacPhee and Sanford, 1954, 1956; van de Vrie, 1962) but the potential non-target arthropod impacts of a management system that included the agricultural biostimulants described in Phillips' book have not been previously studied. Since the non-target impacts of organic disease management systems on the major arthropod pests destructive to apple crops are an important consideration that influences adoption of a novel disease management system, another objective of this research was to evaluate the non-target impacts of the biostimulant compared to the two sulfur-based systems on the following arthropods and/or their damage: apple maggot fly [*Rhagoletis pomonella* (Walsh)]; spotted tentiform leafminer (STLM) [*Phyllonorycter blandcardella* (Fabr.)]; lyonetia mines [*Lyonetia prunifoliella* (Hubner)]; other leafminer mines; white apple leafhoppers (WALH) [*Typhlocyba pomaria* (McAtee)]; green aphids [*Aphis pomi* (De Geer)] or [*Aphis spiraecola* (Patch)]; rosy apple aphids [*Dysaphis plantaginea* (Passerini)]; European red mites [*Panonychus ulmi* (Koch)] and two-spotted spider mites [*Tetranychus urticae* (Koch)]; Japanese beetle [*Popillia japonica* (Newman)]; potato leafhopper (PLH) [*Empoasca fabae* (Harris)]; European apple sawfly [*Hoplocampa testudinea* (Klug)]; plum curculio [*Conotrachelus nenuphar* (Herbst)]; tarnished plant bug [*Lygus lineolaris* (Palisot de Beauvois)]; stink bugs (Hemiptera: Pentomideae); surface feeding Lepidoptera, including obliquebanded [*Choristoneura rosaceana*

(Harris)] and red-banded [*Argyrotaenia velutinana* (Walker)] leafrollers; internal Lepidoptera including codling moth [*Cydia pomonella* (L.)], oriental fruit moth [*Grapholita molesta* (Busck)] and lesser appleworm [*Grapholita prunivora* (Walsh)] and San Jose scale [*Quadraspidiotus perniciosus* (Comstock)].

The impacts of the three systems were also evaluated on tree growth, yield and fruit quality and on the following beneficial arthropods: predacious mites [*Typhlodromus pyri* (Scheuten)]; ladybeetle (Coleoptera: Coccinellidae) eggs, larvae and adults; gall midge (Diptera: Cecidomyiidae) larvae; hover [Diptera: Syrphidae) fly eggs and larvae; green lacewing (Neuroptera: Chrysopidae) eggs and larvae; spider mite destroyer [*Stethorus punctum* (LeConte)] larvae and adults; black hunter thrips [*Leptothrips mali* (Fitch)]; spiders (Arachnida); minute pirate bugs [*Orius insidiousus* (Say)] and mullein plant bug [*Campylomma verbasci* (Meyer)] nymphs.

The primary hypothesis of this research was that the organic agricultural biostimulant system would have target and non-target effects on foliar and fruit diseases, pest and beneficial arthropods, tree growth, yield, and fruit quality on four apple cultivars when compared to the sulfur-based fungicides. A second hypothesis was that the number of sulfur applications would impact foliar and fruit diseases, pest and beneficial arthropods, tree growth, yield, and fruit quality. The long term goal of the research is to identify new, sustainable and effective organic disease and arthropod management strategies to increase the number and the viability of commercial organic apple orchards in Vermont and New England.

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CHAPTER 1. JOURNAL ARTICLE

The efficacy and non-target impacts of an organic disease management system containing biostimulants compared with two sulfur-based systems on foliar and fruit diseases, tree growth, yield and fruit quality on three apple cultivars in Vermont.

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Abstract

Disease management in organic apple orchards in Vermont is focused on controlling diseases with sulfur fungicides. The objective of this two-year study was to evaluate the target and non-target effects of an organic disease management system containing agricultural biostimulants compared to two sulfur-based systems on foliar and fruit diseases, tree growth, yield and fruit quality. Trees were arranged in a complete randomized design of five three-tree replications in a certified organic orchard. The two sulfur-based systems differed in the number of applications; in the third system, sulfur was replaced with biostimulants including pure neem oil, liquid fish, an activated microbial inoculant, and equisetum and stinging nettle teas. Each biostimulant application also included kelp meal, unsulfured organic molasses and yucca extract emulsifier. The biostimulant system did not successfully manage apple scab and rust diseases as well as the sulfur-based fungicide systems, and had variable results with other diseases. No differences were observed among the three systems in tree growth parameters; however, the length of the study may not have been sufficient to determine effects. Differences in the incidence of disease among the three systems were reflected in extrapolated figures for gross income per hectare, which takes into account fruit yield and quality. In the higher fruit-bearing year of the study, it was estimated that the gross income per hectare of the biostimulant system would be significantly lower than the reduced-sulfur system and the full-sulfur system by at least $5,800 and $12,000, respectively. In that same year, it is estimated that the full-sulfur system would have generated approximately $6,500 more gross income per hectare than the reduced-sulfur system suggesting the number of sulfur sprays can influence fruit quality and income. Further evaluation of agricultural biostimulants is necessary before growers replace the standard sulfur fungicides for apple disease management in Vermont orchards.

Introduction

Apple scab [*Venturia inaequalis* (Cooke) Wint.] is the most challenging disease to manage in New England apple [*Malus sylvestris* (L.) Mill. var. *domestica* (Borkh.) Mansf.] orchards (MacHardy, 1996, 2000). Depending on weather and disease pressure, up to 15 protectant fungicide spray applications may be necessary to manage apple scab on susceptible apple cultivars (Ellis et al., 1998; Holb, 2005b; Jamar et al., 2010; MacHardy, 1996, 2000). Apple scab causes fruit and foliar lesions, which when severe, can impact the health and vigor of the tree and lead to premature defoliation, decreased fruit yield and decreased fruit marketability (Ellis et al., 1998; MacHardy, 1996; Sutton et al., 2014). Severe infections from this fungal disease can also increase susceptibility of the tree to winter injury and may impact fruit bud formation in the following season (MacHardy, 1996). Although the use of new scab-resistant cultivars can decrease the total number of fungicide sprays applied in the orchard during the growing season, many New England growers have been slow to replace 'McIntosh' trees (Berkett and Cooley, 1989). The lack of organic orchards in New England can be partially attributed to the high susceptibility of the widely planted cultivar 'McIntosh' to apple scab (MacHardy, 2000).

Although the use of scab-resistant cultivars can virtually eliminate the need for fungicide sprays for this pathogen, there are many other economically important fungal diseases in the orchard that require management such as powdery mildew [*Podosphaera leucotricha* (Ellis & Everh.) Salmon] and the complex of rust diseases including cedar apple rust [*Gymnosporangium juniper-virginianae* (Schwein)]; hawthorn rust [*G. globosum* (Farlow) Farlow]; quince rust [*G. clavipes* (Cooke and Peck)] and Japanese apple rust [*G. yamadae* (Miyabe ex Yamada)] (Gregory et al., 2009; Yun et al., 2009). Fungal fruit rots (*Colletotrichum* spp. and *Botryosphaeria* spp.) as well as sooty blotch, which is caused by the complex of *Peltaster fruticola* (Johnson, Sutton, Hodges), *Geastrumia polystigmatus* (Batista & M.L. Farr), *Lepodontium elatus* (G. Mangenot) De Hoog and *Gleodes pomigena* (Schwein) Colby, and the disease flyspeck [*Zygophiala jamaicensis* (E. Mason)] can also cause economic losses in orchards (Sutton et al., 2014). All of these diseases would need to be successfully managed in organic apple orchards to produce a marketable crop of apples.

Disease management in organic apple orchards is currently reliant on OMRI-approved copper- and sulfur-based pesticides and although organic, these compounds are not without significant negative impacts (Ellis et al., 1998; Holb et al., 2003). In general, prolonged use of copper in various cropping systems has resulted in elevated levels in soils, impacting soil ecology and earthworm numbers (Paoletti et al., 1998; van Rhee, 1976). Since the traditional formulations of copper can increase chances of phytotoxicity after the phenological green tip stage in apple, these formulations are limited to the silver tip phenological stage where it is used as a bactericide for the management of overwintering fire blight inoculum (Brown et al., 1996). Unfortunately, the new lower rate copper formulations have label limitations that do not allow applications at adequate rates for control of fire blight [*Erwinia amylovora* (Burrill) Winslow] later in the growing season so are not appropriate past the green tip spray (Rosenberger, Pers. comm., 2014). Although these new materials are labelled for use against many of the summer fruit rot diseases, the reduced amount of available copper ions in the applied rates may be substantially less than the traditional copper formulations. As a result, these lower rate formulations vary in their effectiveness against scab and fruit rots and have been shown to increase fruit russet. (Rosenberger, Pers. comm., 2014).

Sulfur and liquid lime sulfur remain the standard organic fungicides used to manage apple scab and other fungal diseases in the orchard (Ellis et al., 1991; Holb et al., 2003; MacHardy, 1996; Mills, 1947). Both are multi-site protectant fungicides, but liquid lime sulfur provides some activity against scab 48-72 hours post-infection (Hamilton and Keitt, 1928; Jamar and Lateur, 2006). Liquid lime sulfur, however, is highly caustic and its use can cause detrimental impacts on tree health, photosynthesis, pollen tube growth and can result in decreased fruit set and lowered yields. (Burrell, 1945; Holb et al., 2003; MacHardy, 1996; McArtney et al., 2006; Mills, 1947; Palmer et al., 2003). The use of this caustic material later in the season can result in russetting and burning of the fruit, especially under hot, humid conditions. (Holb et al., 2003; Noordijk and Schupp, 2003; Stopar, 2004). For these reasons, use of liquid lime sulfur is limited to curative sprays for apple scab after weather conditions conducive for infection have occurred (MacHardy and Gadoury, 1989; Penrose, 1995). Although wettable sulfur lacks post-infection activity, is a weaker protectant than liquid lime sulfur and can also impact photosynthesis, this material causes less phytotoxicity and consequently is the primary fungicide used in organic apple orchards (Holb and Heijne, 2001; Jamar et al., 2008; Palmer et al., 2003).

Sulfur fungicides can impact mite populations and have long been identified as general acaricides (Collyer and Kirby, 1959; Garman and Townsend, 1938; Lord, 1949; MacPhee and Sanford, 1954). Sulfur can have non-target effects on both beneficial and phytophagous mite populations in orchards and can impact predator to prey ratios in orchards, causing phytophagous mite populations to flare (Beers and Hull, 1987; Beers et al., 2009; Blommers, 1994; Bower et al., 1995; Holdsworth, 1972; MacPhee and Sanford, 1954; van de Vrie, 1962).

Given the negative effects of sulfur and lime sulfur fungicides on tree health and the potential impacts to predatory mites, growers and researchers are searching for suitable alternatives for disease control in the orchard. Novel disease resistance elicitors, used alone or in combination with fungicides, may offer new, low environmental-impact options. Plant chemical defenses can be present in the plant all the time or can be "induced" by an elicitor. The term 'elicitor' was originally used for compounds that would induce production of phytoalexins, but now the definition of elictor has broadened to any compound that stimulates any plant defense (Ebel and Cosio, 1994; Hahn, 1996; Thakur and Sohal, 2013). The term 'agricultural biostimulant' is often substituted for 'elicitor' when used in a field or agricultural setting. There are several studies demonstrating the successful use of agricultural biostimulants for suppression of diseases caused by several genera of pathogens in a wide variety of crops (Cherif et al., 1992; Elmer and Reglinski, 2006; French-Monar, 2010; Germar, 1934; Gillman et al., 2003; Kunoh and Ishizaki, 1975; Leusch and Buchenauer, 1989; Renard-Merlier et al., 2007; Rodgers-Gray and Shaw, 2004; Sun et al., 1994, 2002). In addition to triggering plant defenses, agricultural biostimulants can also improve physiological responses in plants. Improved crop yields and quality, increased plant buffering capacities for temperature and drought extremes, and improvements in plant nutrition have been noted in various crops following applications of agricultural biostimulants (Botta, 2012; Calvo et al., 2014; Chen et al., 2003; Miller et al., 1990) and evidence of positive benefits of application is increasing (Chen et al., 2003; Lyon et al., 1995; Paul and Sharma, 2002). Agricultural biostimulants that show promise for organic production systems include humic acids, seaweed, silica and other plant extracts, chitinous products from fungal sources and oligiosaccharides (Aziz et al., 2006; Colavita et al., 2011; Craigie, 2010; French-Monar et al., 2010; Khan et al. 2009; Leusch and Buchenauer, 1989; Lyon et al., 1995; Norrie et al., 2002; Volk et al., 1958; Wu et al., 2005). Increased interest in using these materials may be partially driven by the loss of synthetic and/or organically acceptable products available for disease management.

The objective of this research was to evaluate the efficacy and non-target effects of an organic disease management system containing biostimulants compared with two sulfur-based systems on foliar and fruit diseases, tree growth, yield and fruit quality on three apple cultivars in Vermont. The use of agricultural biostimulants for disease management in apples was introduced by a New England orchardist in a popular trade book called *The Holistic Orchard-Tree Fruits and Berries the Biological Way* (Phillips, 2011). Phillips' book promotes whole system health in the tree and orchard as a way to avoid "short term" solutions to disease management using pesticides. Four 'holistic' sprays of biostimulants in the spring are prescribed at the phenological growth stage of ¼ green, early pink, petal fall, in addition to the 'first cover' spray, which is at a week to ten days after petal fall (Phillips, 2011). These biostimulant sprays include a tank mix of pure neem oil, liquid fish and a complex of diverse microbes that are applied to the foliage and trunk to "promote beneficial fungi and stimulate tree immunity to ward off disease." These early season sprays are timed to cover the primary infection period for apple scab and infection by other pathogens. After the four spring applications, stinging nettle and horsetail tea are added to the applications and are made on a ten day to fourteen-day schedule throughout the rest of the growing season (Phillips, 2011). This study was designed to test the efficacy of this disease management approach, following Phillips' recommended application schedule, and compare this novel approach with the standard sulfur-based fungicides used by commercial organic orchardists.

This research is part of an overall evaluation of the target and non-target effects of these three organic disease management systems on pest and beneficial arthropods, which is reported in separate articles.

Materials and Methods

The study was conducted at the University of Vermont Horticulture Research Center in South Burlington, VT, USA. The research orchard was planted in 2006 and certified organic in 2008. The planting includes five cultivars: 'Ginger Gold', 'Liberty', 'Macoun', 'Honeycrisp' and 'Zestar!'. Three-tree plots of each cultivar were planted in a complete randomized design across eight rows at a tree spacing of 1.5 m X 4.6 m and trained to a vertical axis system. All cultivars were grafted on Budagovsky 9 (Bud. 9) dwarfing rootstock except 'Honeycrisp' which was on Malling 26 (M 26). The cultivars 'Ginger Gold', 'Honeycrisp' and 'Liberty' were used for this study (Appendix A, Research Plot Map).

Sprays were applied to five three-tree plots for each organic management system (OMS): OMS-1, OMS-2 and OMS-3. The treatment OMS-1 was based on the use of sulfur fungicides throughout the season except for the three to four week period of rapid shoot elongation following the petal fall phenological stage when no sulfur-based fungicides were applied. These were not applied due to sulfur's potential cumulative negative impact on photosynthesis during this critical period of growth (Palmer et al., 2003). Palmer et al. found sulfur fungicides (lime sulfur and sulfur) had pronounced effects on leaf photosynthesis rate with the greatest effect after shoot growth had ended. The researchers hypothesized that several applications of sulfur over the course of the season or over several years may have a cumulative effect on leaf area and shoot growth. In OMS-2, the use of sulfur sprays was replaced with a combination of agricultural biostimulants throughout the growing season. OMS-3 was based on the use of sulfur fungicides throughout the season. Liquid lime sulfur was also a fungicide option in both OMS-1 and OMS-3 if its post-infection properties against apple scab infection were warranted. See Tables 1.1 and 1.2 for application dates, materials and rates for 2013 and 2014, respectively, for the three management systems. Because of limited orchard size, a 'non-treated' system could not be incorporated into the experimental design. OMS-3 is the standard organic management system applied by commercial organic apple growers in New England and serves as the control in this applied study. All materials used were OMRI-approved. The three systems were applied to the same trees over two consecutive growing seasons (2013, 2014) to assess multi-year effects of their target impacts on foliar and fruit diseases as well as non-target effects.

Weather was monitored with a RainWise MK-III Weather Station (RainWise, Inc.; Trenton, ME) and networked to the Cornell University Network for Environmental and Weather Applications (NEWA, http://newa.cornell.edu/). NEWA output was used to determine apple scab infection periods, fire blight risk, and the risk of sooty blotch and flyspeck infection. This information, with apple phenological bud stages, was used to determine timing and frequency of spray applications.

Sprays were applied dilute to drip to the foliage with a 189-L hydraulic sprayer (Nifty Fifty; Rears Mfg. Co., Eugene, OR) with an attached handgun (Green Garde JD9-C; H.D. Hudson Mfg. Co., Chicago, IL) with an L tip at a pressure of 6.8 atm. Cupric hydroxide (Champ WG; NuFarm Americas, Inc., Burr Ridge, IL) and cupric hydroxide/cupric oxychloride (Badge SC; Gowan Products, Yuma, AZ) were applied at the silver tip phenological stage for fire blight management in OMS-1 and OMS-3 in 2013 and 2014, respectively (Tables 1.1 and 1.2). The fungicide used in OMS-1 and OMS-3 was micronized wettable sulfur (Microthiol Disperss; United Phosphorus, Inc., King of Prussia, PA). In 2013, OMS-3 also included one application of liquid lime sulfur (Miller's Liquid Lime Sulfur; Waynesboro, MS) to provide post-infection apple scab management after a heavy rain event (Table 1.1). Agricultural biostimulants in OMS-2 included pure neem oil (Ahimsa Organics Neem Oil**:** The Ahimsa Alternative, Inc., Bloomington, MN**)**, liquid fish (OrganicGem Liquid Fish Fertilizer 3-3-0; Advanced Marine Technologies, New Bedford, MA), activated microbial inoculant (Dr. Higa's Original EM·1 Microbial Inoculant; TeraGanix, Alto, TX), equisetum (*Equisetum arvense*) tea and stinging nettle (*Urtica doica*) tea. Each of these applications also included kelp meal (SeaLife Kelp Meal; North American Kelp, Waldsboro, ME), unsulfured organic molasses and yucca extract emulsifier (Therm X-70; Cellu-Con, Inc., Strathmore, CA). Teas and activated microbial inoculant were prepared according to protocols described in *The Holistic Orchard- Tree Fruits and Berries the Biological Way* (Phillips, 2011). The OMS-2 sprays at the ¼-½ inch green and early pink phenological stages were applied to thoroughly wet branches, trunk and ground while the later sprays were applied only to the foliage (Phillips, 2011). Tables 1.1 and 1.2 list dates of application and rates for 2013 and 2014, respectively, for the three management systems.

Organic insecticides were applied following a standard integrated pest management approach based on phenological bud stages plus arthropod scouting and monitoring. Materials were applied with a 756 L airblast sprayer (Pul-Blast 200; Rears Mfg Co., Eugene, OR) calibrated to deliver 543 $L \cdot ha^{-1}$ at a pressure of 13.6 atm with a tractor driven at 3 km/hour. All materials were applied to the entire orchard and included: kaolin clay (Surround WP; Tessenderlo Kerley, Inc., Phoenix, AZ), azadiractin (Aza-Direct Biological Insecticide; Gowan Co., Yuma, AZ), pyrethrin (PyGanic Crop Protection EC 5.0; MGK Company, Minneapolis, MN), granulosis virus (CYD-X Biological Insecticide; Certis USA L.L.C., Columbia, MD), *Bacillus thuringiensis* (Dipel DF; Valent USA Corp., Walnut Creek, CA) and spinosad (Entrust; Dow AgroSciences, L.L.C., Indianapolis, IN). In addition, horticultural oil (JMS Stylet oil; JMS Flower Farms, Inc., Vero Beach, FL) was applied to OMS-1 and OMS-3 following standard organic management procedures for arthropod management.

The following assessments were used to evaluate target and non-target impacts of the three organic disease management systems on diseases and orchard productivity including tree growth, yield, and fruit quality.

Disease Assessments:

Foliar Disease Assessment on 24 June 2013 and 20 June 2014

Two fruit clusters per tree (six clusters per three-tree plot with five replications per cultivar) and two vegetative apical terminals (six terminals per three-tree plot with five replications per cultivar) were selected at random around the tree canopy for evaluation. With the aid of head-piece magnifying glasses (10X magnification), both sides of all leaves in the clusters and terminal shoots were assessed for the presence of: apple scab lesions, rust diseases (cedar apple rust, hawthorn rust and/or Japanese apple rust, which were not differentiated in the data), powdery mildew and non-specific necrotic leaf spots resembling frog-eye leaf spot [*Botryosphaeria obtusa* (Schwein.) Shoemaker]. The presence of the disease (incidence) was recorded per leaf. The total number of leaves and the number of leaves with each disease were recorded for each cluster and terminal shoot. The scab results in this assessment approximate the infections that occurred during the primary scab infection period.

Foliar Disease Assessment on 1, 2 August 2013 and 4, 5 August 2014

Two vegetative terminal shoots (six shoots per three-tree plot with five replications per cultivar) were selected at random around the tree canopy for evaluation. Bourse shoots were substituted when sufficient apical shoots were not available and only the leaves above the fruit cluster were assessed. Using headpiece magnifying glasses (10X magnification), both sides of all leaves on each terminal were counted and evaluated for the presence of: apple scab lesions, rust diseases (cedar apple rust, hawthorn rust and/or Japanese apple rust, which were not differentiated in the data), powdery mildew and necrotic leaf spots. Both the presence of disease (incidence) and the number of lesions (severity) were recorded for each leaf. The number of leaves without disease symptoms were also recorded for each terminal. The scab results in this assessment represent those infections that occurred in the primary and secondary scab infection periods.

Fruit Disease Assessment at Harvest

All the fruit from each cultivar were picked on the same date but the dates of harvest for each cultivar varied: 'Ginger Gold' was harvested on 19 August 2013 and 28 August 2014; 'Honeycrisp', on 11 September 2013 and 10 September 2014; and 'Liberty' on 25 September 2013 and 22 September 2014. Harvested fruit was stored in regular cold air storage at 2 C until grading which occurred within one week of picking. Random samples of ten fruit from each tree in each of the five three-tree plots were assessed for symptoms of: apple scab; cedar apple rust; quince rust; sooty blotch; fly speck; Brook's spot [*Mycosphaerella pomi* (Pass.) Lindau], general fruit rots and lenticel blackening, which may indicate early symptoms of black rot [*Botryosphaeria obtusa* (Schwein.) Shoemaker]. Presence of abiotic disorders such as bitter pit, cracking, sunburn, spray burn, frost rings, general russet (not fitting the frost ring or spray burn patterns) were also recorded. The proportions of fruit with symptoms of each disease and fruit without symptoms of disease were calculated.

Orchard Productivity Assessments:

Tree Growth Assessment

Tree height and canopy width were measured by a two-person team using a survey rod (Crain Enterprises, Inc. Mound City, IL) in 2012 and 2014 in late summer after terminal growth had ceased. Two canopy width measurements were collected per tree (north-south and east-west) and averaged to determine mean canopy width. Tree growth was measured by calculating trunk cross sectional area (TCSA cm^2) by collecting and averaging two diameter measurements at 30 cm above the graft union using a caliper (Absolute Digimatic CD-8'CS, Mitutoyo U.S.A., Aurora, IL) on 26 November 2012 and 10 October 2014. Vegetative terminal length was assessed by selecting five terminal shoots per tree at random around the tree canopy and measuring from the base of the current year's terminal growth to the end of the shoot on 14 December 2012 and 10 October 2014.

Yield Assessment

All the fruit from each cultivar were picked on the same date determined by fruit flavor, color and pre-harvest fruit drop conditions. All the fruit on the tree were counted and were weighed using a field scale (SV-100, Acculab U.S.A., Bohemia, NY). Fruit that had dropped to the ground before harvest were also counted and weighed for each tree. Market yield efficiency (kg yield of fruit on tree divided by TCSA cm^2) was determined for each tree.

Fruit Quality Assessment

Fruit quality was evaluated at the same time as the fruit disease assessment on the same random samples of ten fruit from each tree. The same observer using the 2002 USDA fruit quality standards (Appendix B, USDA Apple Grading Standards) assessed fruit quality. These standards are tools that are widely used by the industry for marketing apples. USDA standards allow two adjoining grades to be combined; therefore, for the purposes of this study 'US Fancy' and 'US#1' were combined and assigned the grade 'US#1'. Each apple was placed in one of the following grades using the guidelines below:

- '**US#1**': fruit must weigh at least 100 grams, have blemishes smaller than 0.2 cm and have more than 25% red color. The fruit in the US#1 grade commands a higher price in the marketplace and represents the primary economic return for a commercial orchard.

  US#1 fruit were sorted into two subgrades based on fruit size:

  1. '**US#1 Count**' (>140 g)
  2. '**US#1 Bag**' (100-140 g)

- **Utility**: fruit that weigh less than 100 g and are free from rots or broken skin. This grade has minimal economic value unless the fruit is used for processing into a value-added product.
- **Cull**: all fruit weigh less than 100g and may be misshapen and/or have unhealed punctures or rots. This fruit has no value to the producer.

Statistical Analysis

The primary hypothesis of this research was that the application of the organic agricultural biostimulant system will affect disease incidence and severity, tree growth, yield and fruit quality on three apple cultivars when compared to the sulfur-based fungicides. A second hypothesis was that the number of sulfur applications would impact the disease incidence and severity, tree growth, yield and fruit quality. The experimental design allowed for a two-way analysis of variance with independent cultivar and organic management system treatments. The statistical analyses of data were performed with SAS PROC MIXED (SAS Institute; Cary, NC) using a two-way analysis of variance (ANOVA) with a significance level of $P < 0.05$. If the overall F-test for a main effect (cultivar or OMS) was significant, pairwise comparisons were performed using Tukey's HSD. If the interaction was significant then pairwise comparison of OMS was done within cultivar using Tukey's HSD. Data in the form of proportions were transformed using the arc sin square root transformation and the analyses were performed on the transformed data. The results are summarized in tables. Actual means are reported even though the analysis for some of the measures was conducted on the transformed data.

Results and Discussion

Foliar and Fruit Disease

Apple Scab. 'Liberty' trees, which were bred to be scab-resistant (Lamb et al., 1979), had no scab and are not included in the scab analysis (Table 1.3). Minor amounts of scab (0.0%-1.7% incidence) were observed on the cultivar 'Honeycrisp' (Table 1.3) which is considered "moderately resistant" (Biggs et al., 2010). The cultivar 'Ginger

Gold', which is considered to be the most susceptible of the three cultivars to apple scab (Biggs et al., 2010), was the only cultivar that exhibited significant differences in apple scab among the three organic disease management systems in either year (Table 1.3). During the June assessments in both years, which predominantly evaluated primary scab, when there were significant differences in incidence of foliar scab on 'Ginger Gold' trees, OMS-2 treated trees had higher levels than OMS-1 and OMS-3 treated trees. During the August foliar assessments, which evaluate both primary and secondary scab, OMS-2 treated trees had more foliar scab than OMS-3 in both years, but was only significantly higher than OMS-1 in 2014. On the fruit at harvest, scab was only observed on 'Ginger Gold' and trees treated with OMS-2 had significantly higher scab incidence compared to OMS-1 and OMS-3 in 2013; in 2014, fruit scab incidence was not significantly different on OMS-2 and OMS-1 trees but both systems had significantly higher fruit scab than OMS-3.

When evaluating scab between the two sulfur-based systems, significant differences were only detected in the August 2013 foliar assessment and the harvested fruit evaluation, and in the 2014 fruit evaluation. In each of these assessments, OMS-3 had significantly less scab incidence or severity than OMS-1, which indicates that the extra sprays in OMS-3 compared to OMS 1 were somewhat beneficial in reducing scab particularly on the harvested fruit.

In general, scab incidence appeared higher in 2013 than 2014, most likely a result of the wetter weather in 2013. In 2013, four primary scab infection periods spanned a total of 15 days (Figure 1). In 2014, seven primary scab infection periods spanned 19 days (Figure 2). The secondary scab infection period began on 6 June in 2013 and by the end of the season, there were 54 days with high potential for secondary infection compared with 32 days from the start of the secondary scab period in 2014. Scab was difficult to manage later in the season in 2013 because infection periods often coincided with heavy rainfall, making access into the orchard problematic and the maintenance of fungicide coverage difficult. In May, June and July 2013 over 48.26 cm of rain were measured in the orchard compared with 30.35 cm in the same months in 2014.

Regarding timing of biostimulant sprays and ascospore maturity, by the end of the primary scab infection period on 3 June, all four early season biostimulant sprays had been applied in OMS-2, which matched the timing proposed in Phillips' book to address this critical disease period. However, in 2014, timing of the biostimulant sprays extended past the primary scab infection period since 100% ascospore maturity was reached on 26 May but petal fall did not occur until 5 June. If applying the four biostimulant sprays within the period of primary scab is critical to the success of the 'holistic' system, it would be advisable for growers to align the timing with ascospore maturity rather than basing the sprays on phenological growth stages. Based on the timing used in this study, OMS-2 did not produce a better result (i.e., less scab) on the harvested fruit compared to the standard sulfur-based system (OMS-3).

Rust Diseases. Severe rust infections can decrease fruit size and cause premature defoliation of trees, and are often the major disease problem in scab-resistant apple trees (Aldwinckle, 1974; Sutton et al., 2014). All cultivars showed susceptibility to rust disease(s) as shown in Table 1.4. In general, the overall level of rust incidence did not appear to be very different between 2013 and 2014 although the years differed in wetness. As noted previously, cedar apple rust, hawthorn rust and/or Japanese apple rust lesions were not differentiated during data collection. However, fruit were specifically evaluated for quince rust lesions but none were observed in either year.

When comparing systems within cultivars, statistical differences were only found in the June 2013 cluster leaf assessment on ‘Ginger Gold’ and ‘Honeycrisp’, where OMS-2 had higher incident of rust lesions than OMS-3 on both cultivars, and higher incidence than OMS-1 on ‘Honeycrisp’ trees. However, when the three systems were compared across all cultivars, significant differences were detected in all but one assessment (i.e., fruit assessment, 2014); in the total of eight incidence assessments, OMS-2 had higher incidence of rust than both of the sulfur-based systems in five assessments. In the June foliar assessments in both years, OMS-2 had higher incidence of rust lesions than OMS-1 and OMS-3. In the August assessments, mean separation among systems varied between 2013 and 2014, with OMS-2 not significantly different from OMS-1 and both significantly higher than OMS-3 in 2013; in 2014, OMS-2 had significantly higher incidence of rust than either OMS-1 or OMS-3. On the fruit, OMS-2 had a similar level of rust incidence compared to OMS-3, and a significantly higher incidence compared to OMS-1 in 2013. In 2014, no significant differences were detected among the systems across all of the cultivars.

Comparing the rust incidence or severity between the two sulfur-based systems, no significant differences were detected on foliage between the two systems within cultivars, but when data were summarized across all cultivars, a few significant differences were observed. In those assessments, OMS-3 had significantly less foliar rust than OMS-1. In both years, there were no significant differences on fruit between the two systems.

Necrotic Leaf Spot. All cultivars had necrotic leaf spots (NLS), yet there were no statistical differences detected among management systems within cultivars or across all cultivars on any assessment date (Table 1.5). As noted previously, the necrotic leaf spots resembled frog-eye leaf spot [*Botryosphaeria obtusa* (Schwein.) Shoemaker]. In general, it appeared that 'Ginger Gold' had a higher incidence of NLS than the other two cultivars in both years. It is interesting to note that if the NLS were actually frog-eye leaf spots, one might expect to see more lenticel blackening on 'Ginger Gold' than on the other two cultivars, since the fungus that causes frog-eye leaf spots also cause a fruit rot (i.e., black rot) which starts out as lenticel blackening. This appears to be reflected in the lenticel blackening data (Table 1.9).

Powdery Mildew. There was little to no powdery mildew noted in any cultivar in either 2013 or 2014. The only symptoms observed were in the terminal leaf assessment in August 2013, with less than 1% percent incidence of powdery mildew observed in OMS-1 and OMS-2 on 'Ginger Gold' and 'Honeycrisp' foliage (Table 1.6). Since 'Ginger Gold' is rated as "very susceptible" to powdery mildew and the cultivar 'Honeycrisp' is rated as "moderately susceptible", the absence of disease may be related to the wet summer conditions and/or lack of inoculum in the orchard (Biggs et al., 2009).

Phytotoxicity. There was little to no phytotoxicity noted on the foliage (non-specific unidentified necrotic areas not resembling frog-eye leaf spot) in any cultivar and there were no differences among systems when cultivars were averaged in either year as noted in Table 1.7.

Leaves Without Disease Symptoms. The overarching assessment of 'leaves without disease symptoms' showed no significant differences among the three systems within cultivars, but when cultivars were averaged across the systems, OMS-2 had significantly fewer 'leaves without disease symptoms' (19.7% in 2013 and 12.5% in 2014) than both OMS-1 (32.2% in 2013 and 36.2% in 2014) and OMS-3 (37.6 in 2013 and 42.5% in 2014) as noted in Table 1.8. High number of leaves with disease symptoms, especially apple scab, can cause premature defoliation and can reduce tree growth and yield for one to several years (MacHardy, 1996). This loss in vigor can also result in increased susceptibility to winter injury (MacHardy, 1996). When the two sulfur-based systems were compared, there were no statistical differences noted between the two systems either within or across cultivars, but OMS-3 had a numerically higher percent of 'leaves without disease' for both years when compared with OMS-1 when cultivar data were combined.

Fruit Rots and Lenticel Blackening. The types of fruit rots observed were not differentiated into specific diseases. Fruit rot assessments showed no significant differences among the three systems within cultivars or when data were averaged across cultivars in both years (Table 1.9). Averaged over all cultivars, OMS-2 had the lowest numerical incidence of rot in 2013, but the highest in 2014 when compared to the other two systems. OMS-3 had a numerically lower incidence of fruit rots when data were averaged across cultivars compared to OMS-1 in both years, but no significant differences were detected. The data on lenticel blackening was previously mentioned in the NLS section. Assessments showed no significant differences among the three systems within cultivars or when data were averaged across cultivars in 2013 year (Table

1.9). In 2014, when data were averaged across cultivars, OMS-2 had significantly more blackened lenticels than OMS-3, but was not significantly different than OMS-1. Again, in the second year of the study, no difference was detected between OMS-1 and OMS-3.

Sooty Blotch and Flyspeck. These two diseases are the most common 'summer diseases' in the Northeast and although caused by separate organisms, the environmental conditions conducive for infection are similar (Williamson and Sutton, 2000). Infections for both begin around the time of 'first cover' (i.e., a week to ten days after petal fall) and continue throughout the summer through secondary infections under high humidity or wet conditions. Given the wetter weather in the summer of 2013 compared to 2014, one might expect to observe more sooty blotch and flyspeck in 2013 and that appears to be reflected in the data (Table 1.9). There were significant differences among systems in sooty blotch in all cultivars in 2013, with each cultivar showing significantly more disease in OMS-2 than both sulfur-based systems with the exception in 'Liberty' where OMS-2 and OMS-1 were not significantly different. When cultivars were averaged across the systems, OMS-2 had a significantly higher incidence of sooty blotch than OMS-1 and OMS-3, which were not significantly different. In 2014, sooty blotch was only observed on 'Honeycrisp' in OMS-2 treated trees, and the incidence was significantly higher compared to OMS-1 and OMS-3 treated trees. No differences were detected between the two sulfur-based systems in both years. Regarding flyspeck, there were no differences between the two sulfur-based systems within each cultivar and across cultivars in 2013. Significantly lower amounts of flyspeck were noted in OMS-1 and OMS-3 when compared with OMS-2 in 'Honeycrisp' and 'Liberty' in 2013. In 2014, no flyspeck was observed on any cultivar in any system.

Brook's Spot. Brook's spot is a minor disease but can degrade fruit if prevalent. In 2013, significant differences were detected among the systems on 'Honeycrisp' and 'Liberty' and when incidence was analyzed across all three cultivars, OMS-2 was shown to have significantly higher Brook's spot than the other two systems (Table 1.9). In 2014, there was no to low incidence of Brook's spot and no differences were detected among the systems within or across the cultivars.

Fruit Without Disease Symptoms. The overarching assessment of 'fruit without disease symptoms' showed no statistical differences among systems within each cultivar in either year, yet in both years, OMS-2 had a numerically lower incidence of fruit without disease symptoms in each cultivar (Table 1.10). In 2013, when averaged across cultivars, OMS-2 had significantly lower numbers of fruit without disease symptoms (6.6%) compared with OMS-1 (32.1%) and OMS-3 (40.7%). Although numerically different, OMS-1 and OMS-3 were not significantly different. In 2014, OMS-2 (69.8%) had significantly fewer 'fruit without disease symptoms' compared only with OMS-3 (88.0%). There were no significant differences noted between OMS-1 (79.9%) and OMS-3.

Abiotic Fruit Disorders. There were no significant differences among the three systems in the abiotic disorders listed in Table 1.11 except for spray burn and bitter pit. In 2013, when data were averaged across all cultivars, significantly less spray burn was detected in OMS-2 compared to both of the sulfur-based systems. Sulfur sprays are known to cause phytotoxicity particularly if applied under poor drying conditions or under hot conditions. (Holb et al., 2003; Noordijk and Schupp, 2003; Stopar, 2004). The spray burn in 2013 may be related to higher temperatures in the growing season with nine days over 31.1^0 C recorded in the orchard compared with two days in 2014. Spray burn damage in OMS-1 and OMS-3 was not statistically different indicating the burn may have occurred at a time when sulfur was applied in both systems. Bitter pit is caused by reduced calcium availability in the developing fruit and is characterized by small brown-pitted spots about .6 cm in diameter. The majority of the pitting occurs just beneath the apple skin, is typically concentrated at the calyx end of the fruit, and rarely shows up until harvest (Sutton et al., 2014). There were no significant differences in incidence of bitter pit among the three systems within or across cultivars in 2013. However, in 2014, 'Honeycrisp' and 'Liberty' had significantly more damage in OMS-2 when compared to OMS-3 (Table 1.11). When averaged across cultivars in 2014, bitter pit was significantly higher in OMS-2 (29.6%) than OMS-1 (13.5%) and OMS-3 (7%). In general, it appeared that more bitter pit was present in 2014 than 2013, particularly on 'Honeycrisp' and 'Liberty'. The fruit load in 2014 was considered 'light' and followed a heavy crop load in 2013. The seemingly higher incidence of bitter pit in 2014 aligns with a New Zealand study noting higher incidence of this disorder in years with lighter crop loads (Ferguson and Watkins, 1992).

Orchard Productivity

Tree Growth. There were no significant differences noted among the three systems within each cultivars or across cultivars in annual measurements of trunk cross sectional area, tree height, canopy width or terminal growth in either year, indicating none of the systems negatively or positively affected growth and vigor of the tree within this two year study when compared with each other (Table 1.12 and Table 1.13). However, the length of the study may not have been sufficient to determine if repeated use over several years of the agricultural biostimulant system would positively affect tree growth compared to the sulfur-based systems. Since there were no differences between the sulfur-based systems, it appears the increased number of sulfur sprays applied during the rapid growth stage in OMS-3 did not reduce photosynthesis to the extent that it resulted in shortened terminal growth. Again, repeated use of the systems over several years may be necessary to determine if there are any long-term effects. Foliar analysis performed on the trees each year indicated the nutrient ranges of the foliage in all systems were within the optimal range.

Yield. Yield (kg fruit harvested per tree) varied widely between 2013 and 2014 as a result of the effects of biennial bearing; the larger crop load in 2013 was followed by a smaller crop load the following year (Table 1.14). There were no significant differences in yield of fruit harvested on the tree or gross yield (i.e., kg fruit harvested per tree and the ground) among the three systems within each cultivar or across cultivars in 2013 (Table 1.14). However, there was significantly more fruit on the ground in the OMS-2 system when compared to the full sulfur system in the cultivar ‘Liberty’. In 2014, there were no differences in yield of fruit per tree or gross yield among the three systems when averaged across cultivars. There were differences in yield of fruit per tree and weight of fruit on the ground in the cultivar ‘Honeycrisp’ with the reduced sulfur system having higher yield on the tree and more dropped fruit than OMS-2 and OMS-3, which were not significantly different. These differences were reflected in the gross yield, with ‘Honeycrisp” showing a higher gross yield in the reduced sulfur system compared with OMS-2 and OMS-3. Combined abiotic and biotic factors can be responsible for premature fruit drop in orchards but both ‘Liberty’ and ‘Honeycrisp’ are rated as “more prone to drop” and ‘Ginger Gold’ as less prone (Irish et al., 2013).

Market yield efficiency: Market yield efficiency is an important relative measure used to compare the yield per tree relative to the size of the tree and is calculated by dividing the yield weight (kg) of fruit harvested from each tree by the TCSA cm^2. In 2013, there were no significant differences among systems within cultivars, but differences were detected when data were averaged across cultivars; OMS-2 had significantly less market yield efficiency than OMS-3, which means that OMS-2 had less fruit relative to size of trees (Table 1.14). There was no difference in market yield efficiency between the sulfur-based systems. In 2014, the only difference that was detected among the three systems was on the cultivar ‘Honeycrisp’ with OMS-1 showing a higher market yield efficiency than OMS-3. There were no differences when data were averaged across cultivars.

Fruit Quality. USDA grades are widely used by the fruit industry for marketing products (Appendix B, USDA Apple Grading Standards). The price per grade can vary year to year and is determined by local and regional markets. In this study, the prices of $3.14, $2.10, $0.52, and $0.00 per kg were used for US#1 count, US#1 bag, Utility, and Cull grades, respectively. These prices were based on retail farm market prices determined through a survey of local orchards and from the actual pricing at the retail apple stand at the University of Vermont orchards and reflect current prices for premium organic fruit in Vermont.

In 2013, in the higher value grade of US#1 Counts, a significant difference within the cultivars was only observed in 'Honeycrisp', where OMS-2 had a significantly lower percentage of fruit compared to both sulfur-based systems (Table 1.15). When data were averaged across cultivars, OMS-2 again had a significantly lower percentage of fruit in this higher value grade. In the Utility grade, there were no significant differences among the systems within cultivars, but when data were averaged across cultivars, a higher percentage of Utility grade apples were associated with OMS-2 than both sulfur-based systems. In the other two grades, no differences were detected. Many abiotic and biotic factors, including both disease and arthropod damage, may impact fruit grades. The differences between the OMS-2 and sulfur-based systems are most likely a result of higher disease incidence on the fruit and more damage from surface lepidopterans in the OMS-2 system (Hazelrigg, 2015). In 2014, no differences among the three systems were detected within any grade for each cultivar or across cultivars (Table 1.15). The lack of differences could be due to the light fruit load encountered in 2014. The US#1 (Count and Bag) grade represents the majority of income for an orchard and all the percentages of fruit in this category in both years are well below the 90-95% US#1 grade fruit expected in conventionally managed orchards in the region (Agnello et al., 2005). Although none of the systems resulted in commercially acceptable levels of high value fruit, the use of the OMS-2 system represents a lower economic return compared with the sulfur-based systems. Comparing OMS-1 with OMS-3 indicates the number of sulfur sprays did not siginificantly impact the percentage of apples within any grade.

Crop Value. Comparison of gross income per hectare is the ultimate metric used to evaluate whether the use of any organic disease management system is a viable option for New England orchards. The gross income takes into account the yield per tree (kg fruit harvested per tree and does not include dropped fruit), percentage of fruit in each grade and the current standard market price for that grade based on 1430 trees per hectare. In 2013, when data are extrapolated to a hectare basis, there were significant differences in gross income per hectare among the three systems within and across cultivars (Table 1.16). The use of the agricultural biostimulant system (OMS-2) would result in a potential gross income of $9,135 per hectare when all cultivars are averaged, which was significantly lower by $5,871 and $12,397, than OMS-1 and OMS-3, respectively. Between the two sulfur-based systems, OMS-3 generated significantly more gross income per hectare than OMS-1, with the difference being approximately $6,000 per hectare in 2013, indicating the absence of sprays during critical disease infection periods has a direct effect on income for the grower. Both ‘Ginger Gold’ and ‘Honeycrisp’ in the OMS-2 system generated significantly less income when compared with the full sulfur system. In 2014, the light crop load is reflected in the gross income per hectare calculations across cultivars, with income per hectare being much lower than the previous year in all systems: OMS-1 ($3,967), OMS-2 ($2,053) and OMS-3 ($2,270). The calculated potential gross income for OMS-2 compared to the other two systems was always numerically lower, but a statistical difference was only detected within ‘Honeycrisp’, where OMS-2 had less potential income than OMS-2 but was not different than OMS-3. The low income in the orchard in 2014 suggests successful crop load management may be a more critical production issue in the organic orchard than disease management in some years. These calculations do not account for differences in cost of spray materials or labor involved in spray preparation. An estimate of the cost for the growing season per hectare showed the materials in the biostimulant system cost more than double the cost of fungicides for the full sulfur system each year. This estimate does not include the higher labor costs required for preparing the two herbal teas in the biostimulant system.

Summary and Conclusions

The use of the agricultural biostimulants did not successfully manage two major fungal apple diseases, apple scab and rusts, as well as the sulfur-based fungicide systems. In both years in the late season foliar assessment, incidence and severity of both diseases were significantly higher in the biostimulant system compared to one or both of the sulfur-based systems when data were averaged across all cultivars. This lack of scab and rust management in the biostimulant system was also reflected in the fruit assessment of both diseases in 2013.

Although the use of the agricultural biostimulant system showed variable results managing some of the minor diseases, the overarching "foliage without disease symptoms" and "fruit without disease symptoms" assessments confirmed that the agricultural biostimulant system did not manage disease as well as one or both of the sulfur-based systems in either year when data were averaged across all cultivars. In comparing the two sulfur systems, no differences were detected in these overarching categories nor in most of the other specific disease categories for each cultivar or across cultivars. In the few foliage or fruit analyses where there were differences between the reduced- and full sulfur-based systems, the latter had less disease incidence. Regarding tree growth parameters, no differences were observed among the three systems within this two-year study; however, the length of the study may not have been sufficient to determine if repeated use over several more years of the agricultural biostimulants would positively affect tree growth compared to the sulfur-based systems. Since there were no differences between the sulfur-based systems, it appears the increased number of sulfur sprays applied during the rapid growth stage did not reduce photosynthesis to the extent that it resulted in shortened terminal growth. Again, repeated use of the systems over several years may be necessary to determine if there are any long-term effects.

It is important to note that the difference in the incidence of disease between the agricultural biostimulant system and the sulfur-based systems was reflected in the extrapolated figures for gross income per hectare which takes into account fruit yield and quality (i.e., the percentage of fruit placed in the various fruit grades). In the higher fruit-bearing year (2013) of the two-year study, it is estimated the agricultural biostimulant system would result in a gross income per hectare across all cultivars that would be significantly lower than the reduced-sulfur system and the full-sulfur system by at least $5,800 and $12,000, respectively. In that same year, it is estimated that the full-sulfur system would generate approximately $6,500 more gross income per hectare than the reduced-sulfur system suggesting the number of sulfur sprays can influence fruit quality and income in some years and that elimination of critical sprays may have serious economic ramifications.

The results of this study indicate that more research and further evaluation of new organic disease management tools, including the use of agricultural biostimulants, are necessary before growers consider replacing the use of standard sulfur fungicides for disease management in Vermont orchards.

Table 1.1. Organic management system (OMS) application materials, rates and timing in 2013

	Application materials and rates								
	OMS -1 [z]		OMS -2 [y]					OMS -3 [x]	
Application Timing	Cupric hydroxide kg·ha^{-1}	Micronized wettable sulfur kg·ha^{-1}	Pure Neem oil %	Liquid fish %	Activated microbial inoculant %	*Equisetum arvense* tea %	*Urtica dioica* tea %	Cupric hydroxide kg·ha^{-1}	Micronized wettable sulfur kg·ha^{-1}
18 Apr	11.2							11.2	
26 Apr			1.0	4.0	1.0				
2 May			0.5	2.0	1.0				
8 May		16.8							16.8
15 May		16.8							16.8
21 May			0.5	2.0	1.0				11.2
22 May									* LLS
27 May			0.5	2.0	1.0	5.0	5.0		11.2
5 Jun			0.5		1.0	5.0	5.0		11.2
13 Jun			0.5		1.0	5.0	5.0		11.2
20 Jun		11.2	0.5		1.0	5.0	5.0		11.2
27 Jun		11.2	0.5		1.0	5.0	5.0		11.2
5 Jul		11.2	0.5		1.0	5.0	5.0		11.2
12 Jul		11.2	0.5		1.0	5.0	5.0		11.2
25 Jul			0.5		1.0	5.0	5.0		
7 Aug			0.5		1.0	5.0	5.0		

[z] OMS-1: Use of sulfur fungicides except for the 3-4 week period of rapid shoot elongation following petal fall stage. Dates of application for 2013: 18 Apr; 8 May; 15 May; 20 June; 27 June; 5 July; 12 July

[y] OMS-2: Replaces use of sulfur fungicides with a combination of agricultural biostimulants. Each application included 0.23 kg·ha^{-1} kelp meal, 0.5% unsulfured organic molasses and 0.03% yucca extract emulsifier. Dates of application for 2013: 26 Apr (¼-inch green); 2 May (early pink); 21 May (petal fall); 27 May (first cover); 5 June; 13 June; 20 June; 27 June; 5 July; 12 July; 25 July; 7 Aug.

[x] OMS-3: Use of sulfur fungicides throughout the season. Liquid lime sulfur (*LLS) was applied on 22 May 2013 at 18.7 L·ha^{-1} to provide post-infection apple scab management. Dates of application for 2013: 18 Apr; 8 May; 15 May; 21 May; 27 May; 5 June; 13 June; 20 June; 27 June; 5 July; 12 July

Table 1.2. Organic management system (OMS) application materials, rates and timing in 2014

	Application materials and rates								
	OMS -1 [z]		OMS -2 [y]					OMS -3 [x]	
Application Timing	Cupric hydroxide/ oxychloride kg·ha $^{-1}$	Micronized wettable sulfur kg·ha $^{-1}$	Pure Neem oil %	Liquid fish %	Activated microbial inoculant %	*Equisetum arvense* tea %	*Urtica dioica* tea %	Cupric hydroxide/ oxychloride kg·ha $^{-1}$	Micronized wettable sulfur kg·ha $^{-1}$
21 Apr	7.9							7.9	
28 Apr		11.2							11.2
2 May		11.2	1.0	4.0	1.0				11.2
8 May		11.2							11.2
13 May		11.2	0.5	2.0	1.0				11.2
20 May		11.2							11.2
24 May		11.2	0.5	2.0	1.0				11.2
29 May									11.2
5 Jun			0.5	2.0	1.0	5.0	5.0		
11 Jun			0.5		1.0	5.0	5.0		11.2
20 Jun			0.5		1.0	5.0	5.0		
3 Jul		11.2	0.5		1.0	5.0	5.0		11.2
17 Jul		11.2	0.5		1.0	5.0	5.0		11.2
17 Jul		11.2	0.5		1.0	5.0	5.0		11.2
15 Aug			0.5		1.0	5.0	5.0		

[z] OMS-1: Use of sulfur fungicides except for the 3-4 week period of rapid shoot elongation following petal fall stage. Dates of application for 2014: 21 Apr; 28 Apr; 2 May; 8 May; 13 May; 20 May; 24 May; 3 July; 17 July; 1 Aug.

[y] OMS-2: Replaces use of sulfur fungicides with a combination of agricultural biostimulants. Each application included 0.23 kg·ha $^{-1}$ kelp meal, 0.5% unsulfured organic molasses and 0.03% yucca extract emulsifier. Dates of application for 2014: 2 May (¼-inch green); 13 May (early pink); 24 May (petal fall); 5 June (first cover); 11 June; 20 June; 3 July; 17 July; 1 Aug; 15 Aug.

[x] OMS-3: Use of sulfur fungicides throughout the season. Dates of application for 2014: 21 Apr; 28 Apr; 2 May; 8 May; 13 May; 20 May; 24 May; 29 May; 11 June; 3 July; 17 July; 1 Aug.

Table 1.3. Foliage and fruit with apple scab on 'Ginger Gold' (GG) and 'Honeycrisp' (HC) in 2013 and 2014

2013															
	Percent Incidence						Percent Incidence			Severity [x]			Percent Incidence		
	Cluster leaves [z]			Terminal leaves [y]			Terminal leaves						Fruit [w]		
	24 Jun						1-2 Aug								
Systems	GG	HC	All	GG	HC	All	GG	HC	All	GG	HC	All	GG	HC	All
OMS [v]-1 [u]	0.0	0.0	0.0 [r]	2.7 b	0.0 a	1.4 b	65.8 a	0.5 a	33.2 a	9.8 a	0.0 a	4.9 a	25.3 b	0.0 a	12.7 b
OMS-2 [t]	2.4	0.0	1.2	17.3 a	0.4 a	8.9 a	62.4 a	1.7 a	35.4 a	9.8 a	0.1 a	5.5 a	59.7 a	0.0 a	29.8 a
OMS-3 [s]	1.7	0.0	0.9	1.7 b	0.0 a	0.8 b	33.1 b	1.4 a	17.2 b	1.6 b	0.0 a	0.8 b	5.6 c	0.0 a	2.8 c

2014															
	Percent Incidence						Percent Incidence			Severity			Percent Incidence		
	Cluster leaves			Terminal leaves			Terminal leaves						Fruit		
	20 Jun						4-5 Aug								
Systems	GG	HC	All	GG	HC	All	GG	HC	All	GG	HC	All	GG	HC	All
OMS-1	0.5 b	0.0 a	0.2 b	0.9	0.0	0.5	14.7 b	0.0 a	7.3 b	0.4 b	0.0 a	0.2 b	12.9 a	0.0 a	6.4 a
OMS-2	6.4 a	0.3 a	3.4 a	3.3	5.0	4.2	29.5 a	0.2 a	14.8 a	3.0 a	0.0 a	1.5 a	10.3 a	0.0 a	5.7 ab
OMS-3	0.0 b	0.0 a	0.0 b	0.2	0.0	0.1	13.1 b	0.0 a	6.6 b	0.8 b	0.0 a	0.4 b	1.3 b	0.0 a	0.7 b

[z] Assessment of all leaves on six fruit clusters on five three-tree replicates per cultivar per OMS

[y] Assessment of all leaves on six terminal shoots on five three-tree replicates per cultivar per OMS

[x] Mean number of lesions per leaf

[w] Assessment of 30 fruit from five three-tree replicates per cultivar per OMS. All fruit from each cultivar were harvested on the same date, dates of harvest varied by cultivar

[v] OMS: Organic Management System

[u] OMS-1: Use of sulfur fungicides except for the 3-4 week period of rapid shoot elongation following petal fall stage. Dates of application for 2013: 18 Apr; 8 May; 15 May; 20 June; 27 June; 5 July; 12 July. Dates for 2014: 21 Apr; 28 Apr; 2 May; 8 May; 13 May; 20 May; 24 May; 3 July; 17 July; 1 Aug.

[t] OMS-2: Replaces use of sulfur fungicides with a combination of agricultural biostimulants. Each application included 0.23 $kg \cdot ha^{-1}$ kelp meal, 0.5% unsulfured organic molasses and 0.03% yucca extract emulsifier. Dates of application for 2013: 26 Apr (¼ inch green); 2 May (early pink); 21 May (petal fall); 27 May (first cover); 5 June; 13 June; 20 June; 27 June; 5 July; 12 July; 25 July; 7 Aug. Dates for 2014: 2 May (¼ inch green); 13 May (early pink); 24 May (petal fall); 5 June (first cover); 11 June; 20 June; 3 July; 17 July; 1 Aug; 15 Aug.

[s] OMS-3: Use of sulfur fungicides throughout the season. Liquid lime sulfur (LLS) was applied on 22 May 2013 at 18.7 $L \cdot ha^{-1}$ to provide post-infection apple scab management. Dates of application for 2013: 18 Apr; 8 May; 15 May; 21 May; 27 May; 5 June; 13 June; 20 June; 27 June; 5 July; 12 July. Dates of application for 2014: 21 Apr; 28 Apr; 2 May; 8 May; 13 May; 20 May; 24 May; 29 May; 11 June; 3 July; 17 July; 1 Aug.

[r] Means within columns followed by the same letter do not differ significantly at $p < 0.05$, Tukey-Kramer HSD; means in columns without letters are not significantly different from each other at $p < 0.05$, Oneway Analysis of Variance

Table 1.4. Foliage and fruit with rust [z] on 'Ginger Gold' (GG), 'Honeycrisp' (HC), and 'Liberty' (L) in 2013 and 2014

2013																				
	Percent Incidence								Percent Incidence				Severity [w]				Percent Incidence			
	Cluster leaves [y]				Terminal leaves [x]				Terminal leaves								Fruit [v]			
	24 Jun								1-2 Aug											
Systems	GG	HC	L	All	GG	HC	L	All	GG	HC	L	All	GG	HC	L	All	GG	HC	L	All
OMS [u]-1 [t]	28.3 ab	11.5 b	9.9 a	16.5 b [q]	39.8	54.5	16.5	36.9 b	49.1	57.2	29.9	45.4 a	0.5	0.6	0.3	0.5 a	8.0	8.0	0.7	5.6 b
OMS-2 [s]	48.8 a	46.5 a	17.8 a	37.7 a	52.5	72.7	31.0	52.1 a	56.9	67.1	34.9	51.9 a	0.6	0.7	0.4	0.5 a	22.3	11.6	2.7	12.2 a
OMS-3 [r]	11.8 b	18.7 b	4.5 a	11.7 b	25.0	40.6	8.9	24.8 c	37.9	50.5	13.5	34.0 b	0.4	0.5	0.1	0.3 b	10.3	7.5	3.3	7.0 ab

2014																				
	Percent Incidence								Percent Incidence				Severity				Percent Incidence			
	Cluster leaves				Terminal leaves				Terminal leaves								Fruit			
	20 Jun								4-5 Aug											
Systems	GG	HC	L	All	GG	HC	L	All	GG	HC	L	All	GG	HC	L	All	GG	HC	L	All
OMS-1	16.5	16.0	9.4	14.0 b	33.5	31.3	21.8	28.9 b	57.1	54.0	30.4	47.2 b	0.6	0.5	0.3	0.5 b	21.6	0.7	0.7	7.7
OMS-2	63.9	59.3	33.6	52.3 a	55.3	57.9	43.0	52.0 a	79.8	81.0	56.6	72.5 a	0.8	0.8	0.6	0.7 a	25.1	8.5	1.9	12.1
OMS-3	14.0	20.3	8.7	14.3 b	22.6	32.7	16.6	24.0 b	42.4	42.1	30.9	38.5 c	0.4	0.4	0.3	0.4 c	9.1	4.2	0.0	4.4

[z] Rust symptoms may include cedar apple rust, hawthorn rust or Japanese rust and were not differentiated

[y] Assessment of all leaves on six fruit clusters on five three-tree replicates per cultivar per OMS

[x] Assessment of all leaves on six terminal shoots on five three-tree replicates per cultivar per OMS

[w] Mean number of lesions per leaf

[v] Assessment of 30 fruit from five three-tree replicates per cultivar per OMS. All fruit from each cultivar were harvested on the same date, dates of harvest varied by cultivar

[u] OMS: Organic Management System

[u] OMS-1: Use of sulfur fungicides except for the 3-4 week period of rapid shoot elongation following petal fall stage. Dates of application for 2013: 18 Apr; 8 May; 15 May; 20 June; 27 June; 5 July; 12 July. Dates for 2014: 21 Apr; 28 Apr; 2 May; 8 May; 13 May; 20 May; 24 May; 3 July; 17 July; 1 Aug.

[t] OMS-2: Replaces use of sulfur fungicides with a combination of agricultural biostimulants. Each application included 0.23 $kg \cdot ha^{-1}$ kelp meal, 0.5% unsulfured organic molasses and 0.03% yucca extract emulsifier. Dates of application for 2013: 26 Apr (¼ inch green); 2 May (early pink); 21 May (petal fall); 27 May (first cover); 5 June; 13 June; 20 June; 27 June; 5 July; 12 July; 25 July; 7 Aug. Dates for 2014: 2 May (¼ inch green); 13 May (early pink); 24 May (petal fall); 5 June (first cover); 11 June; 20 June; 3 July; 17 July; 1 Aug; 15 Aug.

[s] OMS-3: Use of sulfur fungicides throughout the season. Liquid lime sulfur (LLS) was applied on 22 May 2013 at 18.7 $L \cdot ha^{-1}$ to provide post-infection apple scab management. Dates of application for 2013: 18 Apr; 8 May; 15 May; 21 May; 27 May; 5 June; 13 June; 20 June; 27 June; 5 July; 12 July. Dates of application for 2014: 21 Apr; 28 Apr; 2 May; 8 May; 13 May; 20 May; 24 May; 29 May; 11 June; 3 July; 17 July; 1 Aug.

[r] Means within columns followed by the same letter do not differ significantly at $p < 0.05$, Tukey-Kramer HSD; means in columns without letters are not significantly different from each other at $p < 0.05$, Oneway Analysis of Variance

Table 1.5. Foliage with necrotic leaf spot [z] on 'Ginger Gold' (GG), 'Honeycrisp' (HC), and 'Liberty' (L) in 2013 and 2014

	2013																2014															
	Percent Incidence								Percent Incidence				Severity [w]				Percent Incidence								Percent Incidence				Severity			
	Cluster leaves [y]				Terminal leaves [x]				Terminal leaves								Cluster leaves				Terminal leaves				Terminal leaves							
	24 Jun								1-2 Aug								20 Jun								4-5 Aug							
Systems	GG	HC	L	All	GG	HC	L	All	GG	HC	L	All	GG	HC	L	All	GG	HC	L	All	GG	HC	L	All	GG	HC	L	All	GG	HC	L	All
OMS [v]-1 [u]	29.8	3.9	12.6	15.5 [r]	34.4	24.4	20.0	26.3	42.6	32.8	38.4	37.9	1.8	0.8	1.0	1.2	26.4	2.1	3.0	10.5	29.0	3.4	7.3	13.3	53.5	14.0	25.3	30.9	2.8	0.3	0.4	1.1
OMS-2 [t]	17.4	6.5	15.6	13.2	30.4	21.9	34.3	28.9	48.2	21.8	46.2	40.0	2.2	0.4	1.4	1.4	17.9	7.7	12.0	12.5	25.8	13.8	22.6	20.8	34.7	23.4	34.4	30.8	1.0	0.6	0.8	0.8
OMS-3 [s]	25.3	4.2	9.0	12.9	28.2	6.6	21.3	18.7	51.8	18.9	30.5	33.7	3.2	0.4	0.6	1.4	21.3	5.0	4.9	10.4	22.8	6.3	7.5	12.2	38.1	20.7	19.8	26.2	3.1	0.4	0.3	1.3

[z] Non-specific necrotic leaf spots resembling frog-eye leaf spot [*Botryosphaeria obtusa* (Schwein.) Shoemaker]

[y] Assessment of all leaves on six fruit clusters on five three-tree replicates per cultivar per OMS

[x] Assessment of all leaves on six terminal shoots on five three-tree replicates per cultivar per OMS

[w] Mean number of lesions per leaf

[v] OMS: Organic Management System

[u] OMS-1: Use of sulfur fungicides except for the 3-4 week period of rapid shoot elongation following petal fall stage. Dates of application for 2013: 18 Apr; 8 May; 15 May; 20 June; 27 June; 5 July; 12 July. Dates for 2014: 21 Apr; 28 Apr; 2 May; 8 May; 13 May; 20 May; 24 May; 3 July; 17 July; 1 Aug.

[t] OMS-2: Replaces use of sulfur fungicides with a combination of agricultural biostimulants. Each application included 0.23 $kg \cdot ha^{-1}$ kelp meal, 0.5% unsulfured organic molasses and 0.03% yucca extract emulsifier. Dates of application for 2013: 26 Apr (¼ inch green); 2 May (early pink); 21 May (petal fall); 27 May (first cover); 5 June; 13 June; 20 June; 27 June; 5 July; 12 July; 25 July; 7 Aug. Dates for 2014: 2 May (¼ inch green); 13 May (early pink); 24 May (petal fall); 5 June (first cover); 11 June; 20 June; 3 July; 17 July; 1 Aug; 15 Aug.

[s] OMS-3: Use of sulfur fungicides throughout the season. Liquid lime sulfur (LLS) was applied on 22 May 2013 at 18.7 $L \cdot ha^{-1}$ to provide post-infection apple scab management. Dates of application for 2013: 18 Apr; 8 May; 15 May; 21 May; 27 May; 5 June; 13 June; 20 June; 27 June; 5 July; 12 July. Dates of application for 2014: 21 Apr; 28 Apr; 2 May; 8 May; 13 May; 20 May; 24 May; 29 May; 11 June; 3 July; 17 July; 1 Aug.

[r] Means within columns followed by the same letter do not differ significantly at $p < 0.05$, Tukey-Kramer HSD; means in columns without letters are not significantly different from each other at $p < 0.05$, Oneway Analysis of Variance

Table 1.6. Foliage with powdery mildew on 'Ginger Gold' (GG), 'Honeycrisp' (HC), and 'Liberty' (L) in 2013 and 2014

2013

	Percent Incidence								Percent Incidence				Severity [x]			
	Cluster leaves [z]				Terminal leaves [y]				Terminal leaves							
	24 Jun								1-2 Aug							
Systems	GG	HC	L	All	GG	HC	L	All	GG	HC	L	All	GG	HC	L	All
OMS [w]-1 [v]	0.0	0.0	0.0	0.0 [s]	0.0	0.0	0.0	0.0	0.7	0.5	0.0	0.4	1.0	1.0	0.0	0.0
OMS-2 [u]	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.8	0.2	0.0	0.4	1.0	0.0	0.0	0.0
OMS-3 [t]	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

2014

	Percent Incidence								Percent Incidence				Severity			
	Cluster leaves				Terminal leaves				Terminal leaves							
	20 Jun								4-5 Aug							
Systems	GG	HC	L	All	GG	HC	L	All	GG	HC	L	All	GG	HC	L	All
OMS [w]-1 [v]	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
OMS-2 [u]	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
OMS-3 [t]	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

[z] Assessment of all leaves on six fruit clusters on five three-tree replicates per cultivar per OMS

[y] Assessment of all leaves on six terminal shoots on five three-tree replicates per cultivar per OMS

[x] Mean number of lesions per leaf

[w] OMS: Organic Management System

[v] OMS-1: Use of sulfur fungicides except for the 3-4 week period of rapid shoot elongation following petal fall stage. Dates of application for 2013: 18 Apr; 8 May; 15 May; 20 June; 27 June; 5 July; 12 July. Dates for 2014: 21 Apr; 28 Apr; 2 May; 8 May; 13 May; 20 May; 24 May; 3 July; 17 July; 1 Aug.

[u] OMS-2: Replaces use of sulfur fungicides with a combination of agricultural biostimulants. Each application included 0.23 $kg{\cdot}ha^{-1}$ kelp meal, 0.5% unsulfured organic molasses and 0.03% yucca extract emulsifier. Dates of application for 2013: 26 Apr (¼ inch green); 2 May (early pink); 21 May (petal fall); 27 May (first cover); 5 June; 13 June; 20 June; 27 June; 5 July; 12 July; 25 July; 7 Aug. Dates for 2014: 2 May (¼ inch green); 13 May (early pink); 24 May (petal fall); 5 June (first cover); 11 June; 20 June; 3 July; 17 July; 1 Aug; 15 Aug.

[t] OMS-3: Use of sulfur fungicides throughout the season. Liquid lime sulfur (LLS) was applied on 22 May 2013 at 18.7 $L{\cdot}ha^{-1}$ to provide post-infection apple scab management. Dates of application for 2013: 18 Apr; 8 May; 15 May; 21 May; 27 May; 5 June; 13 June; 20 June; 27 June; 5 July; 12 July. Dates of application for 2014: 21 Apr; 28 Apr; 2 May; 8 May; 13 May; 20 May; 24 May; 29 May; 11 June; 3 July; 17 July; 1 Aug.

[s] Means within columns followed by the same letter do not differ significantly at $p < 0.05$, Tukey-Kramer HSD; means in columns without letters are not significantly different from each other at $p < 0.05$, Oneway Analysis of Variance

Table 1.7. Foliage with phytotoxicity [z] on ‘Ginger Gold' (GG), 'Honeycrisp' (HC), and Liberty' (L) in 2013 and 2014

2013

	Percent Incidence								Percent Incidence			
	Cluster leaves [y]				Terminal leaves [x]				Terminal leaves			
	24 Jun								1-2 Aug			
Systems	GG	HC	L	All	GG	HC	L	All	GG	HC	L	All
OMS [w]-1 [v]	0.0	0.0	0.0	0.0 [s]	0.0	0.3	0.0	0.1	0.0	0.0	3.7	1.2
OMS-2 [u]	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.8	0.3
OMS-3 [t]	0.0	0.0	0.7	0.2	0.0	0.0	0.4	0.1	0.0	0.8	0.0	0.3

2014

	Percent Incidence								Percent Incidence			
	Cluster leaves				Terminal leaves				Terminal leaves			
	20 Jun								4-5 Aug			
Systems	GG	HC	L	All	GG	HC	L	All	GG	HC	L	All
OMS-1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
OMS-2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
OMS-3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

[z] Phytotoxicity: non-specific unidentified necrotic areas not resembling frog-eye leaf spot [*Botryosphaeria obtusa* (Schwein.) Shoemaker]
[y] Assessment of all leaves on six fruit clusters on five three-tree replicates per cultivar per OMS
[x] Assessment of all leaves on six terminal shoots on five three-tree replicates per cultivar per OMS
[w] OMS: Organic Management System
[v] OMS-1: Use of sulfur fungicides except for the 3-4 week period of rapid shoot elongation following petal fall stage. Dates of application for 2013: 18 Apr; 8 May; 15 May; 20 June; 27 June; 5 July; 12 July. Dates for 2014: 21 Apr; 28 Apr; 2 May; 8 May; 13 May; 20 May; 24 May; 3 July; 17 July; 1 Aug.
[u] OMS-2: Replaces use of sulfur fungicides with a combination of agricultural biostimulants. Each application included 0.23 $kg{\cdot}ha^{-1}$ kelp meal, 0.5% unsulfured organic molasses and 0.03% yucca extract emulsifier. Dates of application for 2013: 26 Apr (¼ inch green); 2 May (early pink); 21 May (petal fall); 27 May (first cover); 5 June; 13 June; 20 June; 27 June; 5 July; 12 July; 25 July; 7 Aug. Dates for 2014: 2 May (¼ inch green); 13 May (early pink); 24 May (petal fall); 5 June (first cover); 11 June; 20 June; 3 July; 17 July; 1 Aug; 15 Aug.
[t] OMS-3: Use of sulfur fungicides throughout the season. Liquid lime sulfur (LLS) was applied on 22 May 2013 at 18.7 $L{\cdot}ha^{-1}$ to provide post-infection apple scab management. Dates of application for 2013: 18 Apr; 8 May; 15 May; 21 May; 27 May; 5 June; 13 June; 20 June; 27 June; 5 July; 12 July. Dates of application for 2014: 21 Apr; 28 Apr; 2 May; 8 May; 13 May; 20 May; 24 May; 29 May; 11 June; 3 July; 17 July; 1 Aug.
[s] Means within columns followed by the same letter do not differ significantly at $p < 0.05$, Tukey-Kramer HSD; means in columns without letters are not significantly different from each other at $p < 0.05$, Oneway Analysis of Variance

Table 1.8. Foliage without disease symptoms on 'Ginger Gold' (GG), 'Honeycrisp' (HC), and 'Liberty' (L) in 2013 and 2014

	Percent Incidence							
	Terminal leaves [z]							
	1-2 Aug 2013				4-5 Aug 2014			
Systems	GG	HC	L	All	GG	HC	L	All
OMS [y]-1 [x]	14.2	33.5	48.9	32.2 a[u]	22.5	38.6	47.5	36.2 a
OMS-2 [w]	7.0	21.4	31.1	19.7 b	9.3	10.2	18.2	12.5 b
OMS-3 [v]	20.1	39.0	53.6	37.6 a	35.4	35.6	56.3	42.5 a

[z] Assessment of all leaves on six terminal shoots on five three-tree replicates per cultivar per OMS

[y] OMS: Organic Management System

[x] OMS-1: Use of sulfur fungicides except for the 3-4 week period of rapid shoot elongation following petal fall stage. Dates of application for 2013: 18 Apr; 8 May; 15 May; 20 June; 27 June; 5 July; 12 July. Dates for 2014: 21 Apr; 28 Apr; 2 May; 8 May; 13 May; 20 May; 24 May; 3 July; 17 July; 1 Aug. w OMS-2: Replaces use of sulfur fungicides with a combination of agricultural biostimulants. Each application included 0.23 kg.ha-1 kelp meal, 0.5% unsulfured organic molasses and 0.03% yucca extract emulsifier. Dates of application for 2013: 26 Apr (¼ inch green); 2 May (early pink); 21 May (petal fall); 27 May (first cover); 5 June; 13 June; 20 June; 27 June; 5 July; 12 July; 25 July; 7 Aug. Dates for 2014: 2 May (¼ inch green); 13 May (early pink); 24 May (petal fall); 5 June (first cover); 11 June; 20 June; 3 July; 17 July; 1 Aug; 15 Aug.

[v] OMS-3: Use of sulfur fungicides throughout the season. Liquid lime sulfur (LLS) was applied on 22 May 2013 at 18.7 L.ha-1 to provide post-infection apple scab management. Dates of application for 2013: 18 Apr; 8 May; 15 May; 21 May; 27 May; 5 June; 13 June; 20 June; 27 June; 5 July; 12 July. Dates of application for 2014: 21 Apr; 28 Apr; 2 May; 8 May; 13 May; 20 May; 24 May; 29 May; 11 June; 3 July; 17 July; 1 Aug.

[u] Means within columns followed by the same letter do not differ significantly at $p < 0.05$, Tukey-Kramer HSD; means in columns without letters are not significantly different from each other at $p < 0.05$, Oneway Analysis of Variance

Table 1.9. Fruit with disease symptoms at harvest on 'Ginger Gold' (GG), 'Honeycrisp' (HC), and 'Liberty' (L) in 2013 and 2014

2013

	Percent Incidence																			
	Fruit [z]																			
	Fruit rot				Lenticel blackening				Sooty blotch				Flyspeck				Brook's spot			
Systems	GG	HC	L	All	GG	HC	L	All	GG	HC	L	All	GG	HC	L	All	GG	HC	L	All
OMS [y]-1 [x]	8.7	9.8	0.0	6.2 [u]	6.0	2.0	2.0	3.3	0.0 b	8.7 b	8.7 ab	5.8 b	0.0 a	1.3 b	0.7 b	0.7 b	2.0 a	84.8 ab	74.7 b	53.8 b
OMS-2 [w]	3.7	0.0	0.0	1.2	8.7	2.0	0.0	3.6	7.7 a	42.0 a	18.0 a	22.6 a	2.7 a	26.7 a	16.7 a	15.3 a	3.3 a	95.3 a	99.3 a	66.0 a
OMS-3 [v]	6.1	1.1	0.0	2.4	2.2	1.1	5.1	2.8	0.0 b	5.0 b	3.3 b	2.8 b	0.0 a	0.0 b	0.6 b	0.2 b	4.4 a	80.3 b	64.7 b	49.8 b

2014

	Percent Incidence																			
	Fruit																			
	Fruit rot				Lenticel blackening				Sooty blotch				Flyspeck				Brook's spot			
Systems	GG	HC	L	All	GG	HC	L	All	GG	HC	L	All	GG	HC	L	All	GG	HC	L	All
OMS-1	27.0	3.0	0.0	10.0	19.8	9.7	3.6	11.0 ab	0.0 a	0.0 b	0.0 a	0.0 b	0.0	0.0	0.0	0.0	0.7	0.0	0.0	0.2
OMS-2	51.7	4.4	0.0	19.7	55.4	5.6	9.3	24.7 a	0.0 a	1.7 a	0.0 a	0.5 a	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
OMS-3	17.8	2.7	1.0	7.1	4.5	14.0	0.7	6.4 b	0.0 a	0.0 b	0.0 a	0.0 b	0.0	0.0	0.0	0.0	2.2	0.0	0.0	0.7

[z] Assessment of 30 fruit from five three-tree replicates per cultivar per OMS. All fruit from each cultivar were harvested on the same date, dates of harvest varied by cultivar

[y] OMS: Organic Management System

[x] OMS-1: Use of sulfur fungicides except for the 3-4 week period of rapid shoot elongation following petal fall stage. Dates of application for 2013: 18 Apr; 8 May; 15 May; 20 June; 27 June; 5 July; 12 July. Dates for 2014: 21 Apr; 28 Apr; 2 May; 8 May; 13 May; 20 May; 24 May; 3 July; 17 July; 1 Aug.

[w] OMS-2: Replaces use of sulfur fungicides with a combination of agricultural biostimulants. Each application included 0.23 kg.ha-1 kelp meal, 0.5% unsulfured organic molasses and 0.03% yucca extract emulsifier. Dates of application for 2013: 26 Apr (¼ inch green); 2 May (early pink); 21 May (petal fall); 27 May (first cover); 5 June; 13 June; 20 June; 27 June; 5 July; 12 July; 25 July; 7 Aug. Dates for 2014: 2 May (¼ inch green); 13 May (early pink); 24 May (petal fall); 5 June (first cover); 11 June; 20 June; 3 July; 17 July; 1 Aug; 15 Aug.

[v] OMS-3: Use of sulfur fungicides throughout the season. Liquid lime sulfur (LLS) was applied on 22 May 2013 at 18.7 L.ha-1 to provide post-infection apple scab management. Dates of application for 2013: 18 Apr; 8 May; 15 May; 21 May; 27 May; 5 June; 13 June; 20 June; 27 June; 5 July; 12 July. Dates of application for 2014: 21 Apr; 28 Apr; 2 May; 8 May; 13 May; 20 May; 24 May; 29 May; 11 June; 3 July; 17 July; 1 Aug.

[u] Means within columns followed by the same letter do not differ significantly at $p < 0.05$, Tukey-Kramer HSD; means in columns without letters are not significantly different from each other at $p < 0.05$, Oneway Analysis of Variance

Table 1.10. Fruit without disease symptoms at harvest on 'Ginger Gold' (GG), 'Honeycrisp' (HC), and 'Liberty' (L) in 2013 and 2014

	Percent Incidence									
	Fruit [z]									
	2013					2014				
Systems	GG	HC	L	All		GG	HC	L	All	
OMS [y]-1 [x]	62.7	10.9	22.7	32.1	a [u]	44.0	96.3	99.3	79.9	ab
OMS-2 [w]	18.3	0.7	0.7	6.6	b	28.8	85.4	98.2	69.7	b
OMS-3 [v]	76.9	13.6	31.4	40.7	a	71.8	93.2	99.1	88.0	a

[z] Assessment of 30 fruit from five three-tree replicates per cultivar per OMS. All fruit from each cultivar were harvested on the same date, dates of harvest varied by cultivar
[y] OMS: Organic Management System
x OMS-1: Use of sulfur fungicides except for the 3-4 week period of rapid shoot elongation following petal fall stage. Dates of application for 2013: 18 Apr; 8 May; 15 May; 20 June; 27 June; 5 July; 12 July. Dates for 2014: 21 Apr; 28 Apr; 2 May; 8 May; 13 May; 20 May; 24 May; 3 July; 17 July; 1 Aug.
[w] OMS-2: Replaces use of sulfur fungicides with a combination of agricultural biostimulants. Each application included 0.23 kg.ha-1 kelp meal, 0.5% unsulfured organic molasses and 0.03% yucca extract emulsifier. Dates of application for 2013: 26 Apr (¼ inch green); 2 May (early pink); 21 May (petal fall); 27 May (first cover); 5 June; 13 June; 20 June; 27 June; 5 July; 12 July; 25 July; 7 Aug. Dates for 2014: 2 May (¼ inch green); 13 May (early pink); 24 May (petal fall); 5 June (first cover); 11 June; 20 June; 3 July; 17 July; 1 Aug; 15 Aug.
[v] OMS-3: Use of sulfur fungicides throughout the season. Liquid lime sulfur (LLS) was applied on 22 May 2013 at 18.7 L.ha-1 to provide post-infection apple scab management. Dates of application for 2013: 18 Apr; 8 May; 15 May; 21 May; 27 May; 5 June; 13 June; 20 June; 27 June; 5 July; 12 July. Dates of application for 2014: 21 Apr; 28 Apr; 2 May; 8 May; 13 May; 20 May; 24 May; 29 May; 11 June; 3 July; 17 July; 1 Aug.
[u] Means within columns followed by the same letter do not differ significantly at $p < 0.05$, Tukey-Kramer HSD; means in columns without letters are not significantly different from each other at $p < 0.05$, Oneway Analysis of Variance

Table 1.11. Fruit with abiotic disorders at harvest on 'Ginger Gold' (GG), 'Honeycrisp' (HC), and 'Liberty' (L) in 2013 and 2014

2013

Percent Incidence — Fruit [z]

	Spray burn				Russet				Bitter pit				Frost ring				Cracking			
Systems	GG	HC	L	All	GG	HC	L	All	GG	HC	L	All	GG	HC	L	All	GG	HC	L	All
OMS [y]-1 [x]	15.3	8.0	10.0	11.1 a [u]	10.0	1.3	2.0	4.4	0.0	2.0	0.0	0.7	0.0	0.0	0.0	0.0	0.7	1.3	1.3	1.1
OMS-2 [w]	0.7	1.3	5.3	2.4 b	6.7	7.3	10.0	8.0	0.7	8.7	0.0	3.1	0.0	0.0	0.0	0.0	0.0	0.7	0.7	0.4
OMS-3 [v]	10.0	5.6	8.3	8.0 a	14.4	2.5	8.4	8.5	0.0	0.6	0.0	0.2	0.0	0.0	0.0	0.0	0.0	1.7	0.0	0.6

2014

Percent Incidence — Fruit

	Spray burn				Russet				Bitter pit				Frost ring				Cracking			
Systems	GG	HC	L	All	GG	HC	L	All	GG	HC	L	All	GG	HC	L	All	GG	HC	L	All
OMS-1	0.0	0.0	0.0	0.0	2.9	1.3	0.0	1.4	0.0 a	31.7 ab	8.9 ab	13.5 b	4.9	5.3	0.0	3.4	0.0	0.0	0.0	0.0
OMS-2	0.0	0.0	0.0	0.0	6.8	4.2	1.4	4.1	0.0 a	60.4 a	34.6 a	29.6 a	7.8	4.4	0.0	4.1	0.0	0.0	0.0	0.0
OMS-3	0.0	0.0	0.0	0.0	5.2	1.7	0.0	2.3	2.0 a	15.5 b	3.5 b	7.0 b	3.6	3.4	0.7	2.5	0.0	0.0	0.0	0.0

[z] Assessment of 30 fruit from five three-tree replicates per cultivar per OMS. All fruit from each cultivar were harvested on the same date dates of harvest varied by cultivar

[y] OMS: Organic Management System

[x] OMS-1: Use of sulfur fungicides except for the 3-4 week period of rapid shoot elongation following petal fall stage. Dates of application for 2013: 18 Apr; 8 May; 15 May; 20 June; 27 June; 5 July; 12 July. Dates for 2014: 21 Apr; 28 Apr; 2 May; 8 May; 13 May; 20 May; 24 May; 3 July; 17 July; 1 Aug.

[w] OMS-2: Replaces use of sulfur fungicides with a combination of agricultural biostimulants. Each application included 0.23 kg.ha-1 kelp meal, 0.5% unsulfured organic molasses and 0.03% yucca extract emulsifier. Dates of application for 2013: 26 Apr (¼ inch green); 2 May (early pink); 21 May (petal fall); 27 May (first cover); 5 June; 1 3 June; 20 June; 27 June; 5 July; 12 July; 25 July; 7 Aug. Dates for 2014: 2 May (¼ inch green); 13 May (early pink); 24 May (petal fall); 5 June (first cover); 11 June; 20 June; 3 July; 17 July; 1 Aug; 15 Aug.

[v] OMS-3: Use of sulfur fungicides throughout the season. Liquid lime sulfur (LLS) was applied on 22 May 2013 at 18.7 L.ha-1 to provide post-infection apple scab management. Dates of application for 2013: 18 Apr; 8 May; 15 May; 21 May; 27 May; 5 June; 13 June; 20 June; 27 June; 5 July; 12 July. Dates of application for 2014: 21 Apr; 28 Apr; 2 May; 8 May; 13 May; 20 May; 24 May; 29 May; 11 June; 3 July; 17 July; 1 Aug.

[u] Means within columns followed by the same letter do not differ significantly at $p < 0.05$, Tukey-Kramer HSD; means in columns without letters are not significantly different from each other at $p < 0.05$, Oneway Analysis of Variance

Table 1.12. Tree canopy of 'Ginger Gold' (GG), 'Honeycrisp' (HC), and 'Liberty' (L) in 2012 and 2014

	Measurements [z]															
	2012								2014							
	Height (m)				Width (m)				Height (m)				Width (m)			
Systems	GG	HC	L	All	GG	HC	L	All	GG	HC	L	All	GG	HC	L	All
OMS [y]-1[x]	2.5	2.2	1.8	2.1 [u]	1.7	1.6	1.4	1.6	2.5	2.2	1.8	2.2	2.0	2.0	1.7	1.9
OMS-2[w]	2.3	2.2	1.8	2.1	1.8	1.5	1.5	1.6	2.4	2.2	1.8	2.1	2.0	2.0	1.8	1.9
OMS-3[v]	2.5	2.2	1.8	2.1	1.8	1.7	1.4	1.6	2.5	2.1	1.7	2.1	2.1	2.0	1.7	1.9

[z] Assessment of five three-tree replicates per cultivar per OMS

[y] OMS: Organic Management System

[x] OMS-1: Use of sulfur fungicides except for the 3-4 week period of rapid shoot elongation following petal fall stage. Dates of application for 2013: 18 Apr; 8 May; 15 May; 20 June; 27 June; 5 July; 12 July. Dates for 2014: 21 Apr; 28 Apr; 2 May; 8 May; 13 May; 20 May; 24 May; 3 July; 17 July; 1 Aug.

[w] OMS-2: Replaces use of sulfur fungicides with a combination of agricultural biostimulants. Each application included 0.23 kg.ha-1 kelp meal, 0.5% unsulfured organic molasses and 0.03% yucca extract emulsifier. Dates of application for 2013: 26 Apr (¼ inch green); 2 May (early pink); 21 May (petal fall); 27 May (first cover); 5 June; 13 June; 20 June; 27 June; 5 July; 12 July; 25 July; 7 Aug. Dates for 2014: 2 May (¼ inch green); 13 May (early pink); 24 May (petal fall); 5 June (first cover); 11 June; 20 June; 3 July; 17 July; 1 Aug; 15 Aug.

[v] OMS-3: Use of sulfur fungicides throughout the season. Liquid lime sulfur (LLS) was applied on 22 May 2013 at 18.7 L.ha-1 to provide post-infection apple scab management. Dates of application for 2013: 18 Apr; 8 May; 15 May; 21 May; 27 May; 5 June; 13 June; 20 June; 27 June; 5 July; 12 July. Dates of application for 2014: 21 Apr; 28 Apr; 2 May; 8 May; 13 May; 20 May; 24 May; 29 May; 11 June; 3 July; 17 July; 1 Aug.

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Table 1.13. Terminal length and trunk cross-sectional area (TCSA) of ‘Ginger Gold' (GG), 'Honeycrisp' (HC), and 'Liberty' (L) in 2012 and 2014

	Measurements [z]															
	2012								2014							
	Terminal length (cm)				TCSA (cm^2)				Terminal length (cm)				TCSA (cm^2)			
Systems	GG	HC	L	All	GG	HC	L	All	GG	HC	L	All	GG	HC	L	All
OMS [y]-1[x]	19.1	14.6	8.2	14.0 [u]	8.4	11.6	6.6	8.9	17.5	14.0	11.3	14.3	12.3	17.0	8.7	12.7
OMS-2[w]	16.5	10.3	9.9	12.2	8.1	10.7	7.1	8.6	20.6	10.9	12.0	14.5	11.2	13.8	9.4	11.5
OMS-3[v]	19.1	10.2	9.4	12.9	7.6	10.6	6.4	8.2	18.1	11.8	11.0	13.6	11.2	16.1	8.5	11.9

[z] Assessment of five three-tree replicates per cultivar per OMS

[y] OMS: Organic Management System

[x] OMS-1: Use of sulfur fungicides except for the 3-4 week period of rapid shoot elongation following petal fall stage. Dates of application for 2013: 18 Apr; 8 May; 15 May; 20 June; 27 June; 5 July; 12 July. Dates for 2014: 21 Apr; 28 Apr; 2 May; 8 May; 13 May; 20 May; 24 May; 3 July; 17 July; 1 Aug.

[w] OMS-2: Replaces use of sulfur fungicides with a combination of agricultural biostimulants. Each application included 0.23 kg.ha-1 kelp meal, 0.5% unsulfured organic molasses and 0.03% yucca extract emulsifier. Dates of application for 2013: 26 Apr (¼ inch green); 2 May (early pink); 21 May (petal fall); 27 May (first cover); 5 June; 13 June; 20 June; 27 June; 5 July; 12 July; 25 July; 7 Aug. Dates for 2014: 2 May (¼ inch green); 13 May (early pink); 24 May (petal fall); 5 June (first cover); 11 June; 20 June; 3 July; 17 July; 1 Aug; 15 Aug.

[v] OMS-3: Use of sulfur fungicides throughout the season. Liquid lime sulfur (LLS) was applied on 22 May 2013 at 18.7 L.ha-1 to provide post-infection apple scab management. Dates of application for 2013: 18 Apr; 8 May; 15 May; 21 May; 27 May; 5 June; 13 June; 20 June; 27 June; 5 July; 12 July. Dates of application for 2014: 21 Apr; 28 Apr; 2 May; 8 May; 13 May; 20 May; 24 May; 29 May; 11 June; 3 July; 17 July; 1 Aug.

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Table 1.14. Fruit yield, weight, gross yield and market yield efficiency of 'Ginger Gold' (GG), 'Honeycrisp' (HC), and 'Liberty' (L) in 2013 and 2014

2013

	Measurements [z]															
	Yield of fruit per tree (kg)				Weight of fruit on ground (kg)				Gross yield (kg) [y]				Market yield efficiency [x]			
Systems	GG	HC	L	All	GG	HC	L	All	GG	HC	L	All	GG	HC	L	All
OMS [w]-1 [v]	10.1	9.0	8.8	9.29 [s]	1.1 a	1.5 a	1.2 ab	1.2 a	11.2	10.5	10.0	10.5	1.1	0.7	1.2	1.0 ab
OMS-2 [u]	8.2	8.7	7.0	8.0	0.6 a	0.8 a	2.5 a	1.3 a	8.8	9.4	9.4	9.2	0.9	0.7	0.9	0.8 b
OMS-3 [t]	9.8	14.0	8.1	10.6	0.7 a	1.7 a	0.9 b	1.1 a	10.6	15.7	9.0	11.8	1.1	1.0	1.0	1.1 a

2014

	Measurements															
	Yield of fruit per tree (kg)				Weight of fruit on ground (kg)				Gross yield (kg)				Market yield efficiency			
Systems	GG	HC	L	All	GG	HC	L	All	GG	HC	L	All	GG	HC	L	All
OMS-1	0.7 a	5.9 a	1.3 a	2.6 a	0.0 a	0.4 a	0.0 a	0.1 a	0.7 a	6.3 a	1.3 a	2.8 a	0.1 a	0.3 a	0.1 a	0.2 a
OMS-2	0.9 a	1.3 b	1.2 a	1.1 a	0.0 a	0.1 b	0.0 a	0.0 b	0.9 a	1.4 b	1.2 a	1.2 a	0.1 a	0.1 ab	0.1 a	0.1 a
OMS-3	1.4 a	1.7 b	0.6 a	1.2 a	0.0 a	0.1 b	0.0 a	0.0 b	1.4 a	1.8 b	0.6 a	1.3 a	0.1 a	0.1 b	0.1 a	0.1 a

[z] All fruit from each cultivar were harvested on the same date, dates of harvest varied by cultivar

[y] Gross yield: weight of fruit on tree and on ground

[x] Market yield efficiency: weight of fruit on tree divided by TCSM (cm2)

[w] OMS: Organic Management System

[v] OMS-1: Use of sulfur fungicides except for the 3-4 week period of rapid shoot elongation following petal fall stage. Dates of application for 2013: 18 Apr; 8 May; 15 May; 20 June; 27 June; 5 July; 12 July. Dates for 2014: 21 Apr; 28 Apr; 2 May; 8 May; 13 May; 20 May; 24 May; 3 July; 17 July; 1 Aug.

[u] OMS-2: Replaces use of sulfur fungicides with a combination of agricultural biostimulants. Each application included 0.23 kg.ha-1 kelp meal, 0.5% unsulfured organic molasses and 0.03% yucca extract emulsifier. Dates of application for 2013: 26 Apr (¼ inch green); 2 May (early pink); 21 May (petal fall); 27 May (first cover); 5 June; 13 June; 20 June; 27 June; 5 July; 12 July; 25 July; 7 Aug. Dates for 2014: 2 May (¼ inch green); 13 May (early pink); 24 May (petal fall); 5 June (first cover); 11 June; 20 June; 3 July; 17 July; 1 Aug; 15 Aug.

[t] OMS-3: Use of sulfur fungicides throughout the season. Liquid lime sulfur (LLS) was applied on 22 May 2013 at 18.7 L.ha-1 to provide post-infection apple scab management. Dates of application for 2013: 18 Apr; 8 May; 15 May; 21 May; 27 May; 5 June; 13 June; 20 June; 27 June; 5 July; 12 July. Dates of application for 2014: 21 Apr; 28 Apr; 2 May; 8 May; 13 May; 20 May; 24 May; 29 May; 11 June; 3 July; 17 July; 1 Aug.

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Table 1.15. USDA apple fruit grade distribution of ‘Ginger Gold' (GG), 'Honeycrisp' (HC), and 'Liberty' (L) in 2013 and 2014

2013

	Percent Incidence [z]															
	US#1 Count				US#1 Bag				Utility				Cull			
Systems	GG	HC	L	All	GG	HC	L	All	GG	HC	L	All	GG	HC	L	All
OMS [y]-1 [x]	20.0 a	22.6 a	7.3 a	16.6 a [u]	21.3	16.7	34.0	24.0	34.7	20.1	10.7	21.8 b	24.0	40.7	48.0	37.6
OMS-2 [w]	16.3 a	2.0 b	4.7 a	7.7 b	17.0	11.0	20.7	16.2	48.0	38.5	35.3	40.6 a	18.7	48.6	39.3	35.5
OMS-3 [v]	35.3 a	25.3 a	4.5 a	21.7 a	32.2	20.0	31.1	27.8	15.8	22.8	7.8	15.5 b	16.7	31.9	56.5	35.1

2014

	Percent Incidence															
	US#1 Count				US#1 Bag				Utility				Cull			
Systems	GG	HC	L	All	GG	HC	L	All	GG	HC	L	All	GG	HC	L	All
OMS-1	42.9	16.3	2.7	20.6	3.3	22.2	38.4	21.3	14.3	25.0	5.3	14.9	39.5	36.6	53.6	43.2
OMS-2	11.8	0.0	9.3	7.6	5.4	14.8	32.5	17.8	19.1	7.5	4.5	10.6	63.7	77.7	53.7	64.1
OMS-3	45.0	18.2	0.7	21.3	3.7	9.8	25.4	13.0	25.3	15.0	1.7	14.0	26.0	57.1	72.2	51.8

[z] Assessment of 30 fruit from five three-tree replicates per cultivar per OMS. All fruit from each cultivar were harvested on the same date, dates of harvest varied by cultivar, grading assessment occurred within one week of harvest based on "United States Standards for Grades of Apples." USDA Marketing Service. 2002. Appendix A, Research Plot Map.

[y] OMS: Organic Management System

[x] OMS-1: Use of sulfur fungicides except for the 3-4 week period of rapid shoot elongation following petal fall stage. Dates of application for 2013: 18 Apr; 8 May; 15 May; 20 June; 27 June; 5 July; 12 July. Dates for 2014: 21 Apr; 28 Apr; 2 May; 8 May; 13 May; 20 May; 24 May; 3 July; 17 July; 1 Aug.

[w] OMS-2: Replaces use of sulfur fungicides with a combination of agricultural biostimulants. Each application included 0.23 kg.ha-1 kelp meal, 0.5% unsulfured organic molasses and 0.03% yucca extract emulsifier. Dates of application for 2013: 26 Apr (¼ inch green); 2 May (early pink); 21 May (petal fall); 27 May (first cover); 5 June; 13 June; 20 June; 27 June; 5 July; 12 July; 25 July; 7 Aug. Dates for 2014: 2 May (¼ inch green); 13 May (early pink); 24 May (petal fall); 5 June (first cover); 11 June; 20 June; 3 July; 17 July; 1 Aug; 15 Aug.

[v] OMS-3: Use of sulfur fungicides throughout the season. Liquid lime sulfur (LLS) was applied on 22 May 2013 at 18.7 L.ha-1 to provide post-infection apple scab management. Dates of application for 2013: 18 Apr; 8 May; 15 May; 21 May; 27 May; 5 June; 13 June; 20 June; 27 June; 5 July; 12 July. Dates of application for 2014: 21 Apr; 28 Apr; 2 May; 8 May; 13 May; 20 May; 24 May; 29 May; 11 June; 3 July; 17 July; 1 Aug.

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Table 1.16. Estimated gross income (US$) per hectare of 'Ginger Gold' (GG), 'Honeycrisp' (HC), and 'Liberty' (L) in 2013 and 2014

	Gross Income [z]							
	2013				2014			
Systems	GG	HC	L	All	GG	HC	L	All
OMS [y]-1 [x]	17,748 ab [u]	14,523 b	12,748 a	15,006 b	2,328 a	7,922 a	1,651 a	3,967 a
OMS-2 [w]	12,981 b	6,521 b	7,903 a	9,135 c	1,277 a	1,954 b	2,909 a	2,053 a
OMS-3 [v]	26,921 a	28,058 a	9,618 a	21,532 a	3,328 a	2,877 ab	605 a	2,270 a

[z] Gross income: yield per tree (kg fruit harvested per tree and does not include dropped fruit), percentage of fruit in each grade and the current standard market price for that grade based on 1435 trees per hectare

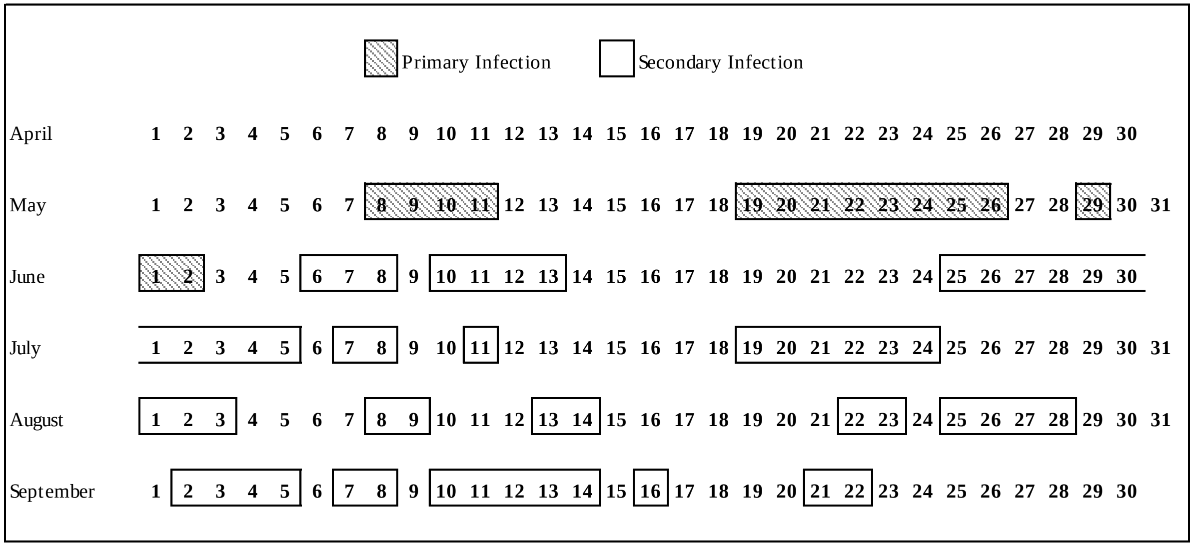
[y] OMS: Organic Management System

[x] OMS-1: Use of sulfur fungicides except for the 3-4 week period of rapid shoot elongation following petal fall stage. Dates of application for 2013: 18 Apr; 8 May; 15 May; 20 June; 27 June; 5 July; 12 July. Dates for 2014: 21 Apr; 28 Apr; 2 May; 8 May; 13 May; 20 May; 24 May; 3 July; 17 July; 1 Aug.

[w] OMS-2: Replaces use of sulfur fungicides with a combination of agricultural biostimulants. Each application included 0.23 $kg \cdot ha^{-1}$ kelp meal, 0.5% unsulfured organic molasses and 0.03% yucca extract emulsifier. Dates of application for 2013: 26 Apr (¼ inch green); 2 May (early pink); 21 May (petal fall); 27 May (first cover); 5 June; 13 June; 20 June; 27 June; 5 July; 12 July; 25 July; 7 Aug. Dates for 2014: 2 May (¼ inch green); 13 May (early pink); 24 May (petal fall); 5 June (first cover); 11 June; 20 June; 3 July; 17 July; 1 Aug; 15 Aug.

[v] OMS-3: Use of sulfur fungicides throughout the season. Liquid lime sulfur (LLS) was applied on 22 May 2013 at 18.7 $L \cdot ha^{-1}$ to provide post-infection apple scab management. Dates of application for 2013: 18 Apr; 8 May; 15 May; 21 May; 27 May; 5 June; 13 June; 20 June; 27 June; 5 July; 12 July. Dates of application for 2014: 21 Apr; 28 Apr; 2 May; 8 May; 13 May; 20 May; 24 May; 29 May; 11 June; 3 July; 17 July; 1 Aug.

[u] Means within columns followed by the same letter do not differ significantly at $p < 0.05$, Tukey-Kramer HSD; means in columns without letters are not significantly different from each other at $p < 0.05$, Oneway Analysis of Variance



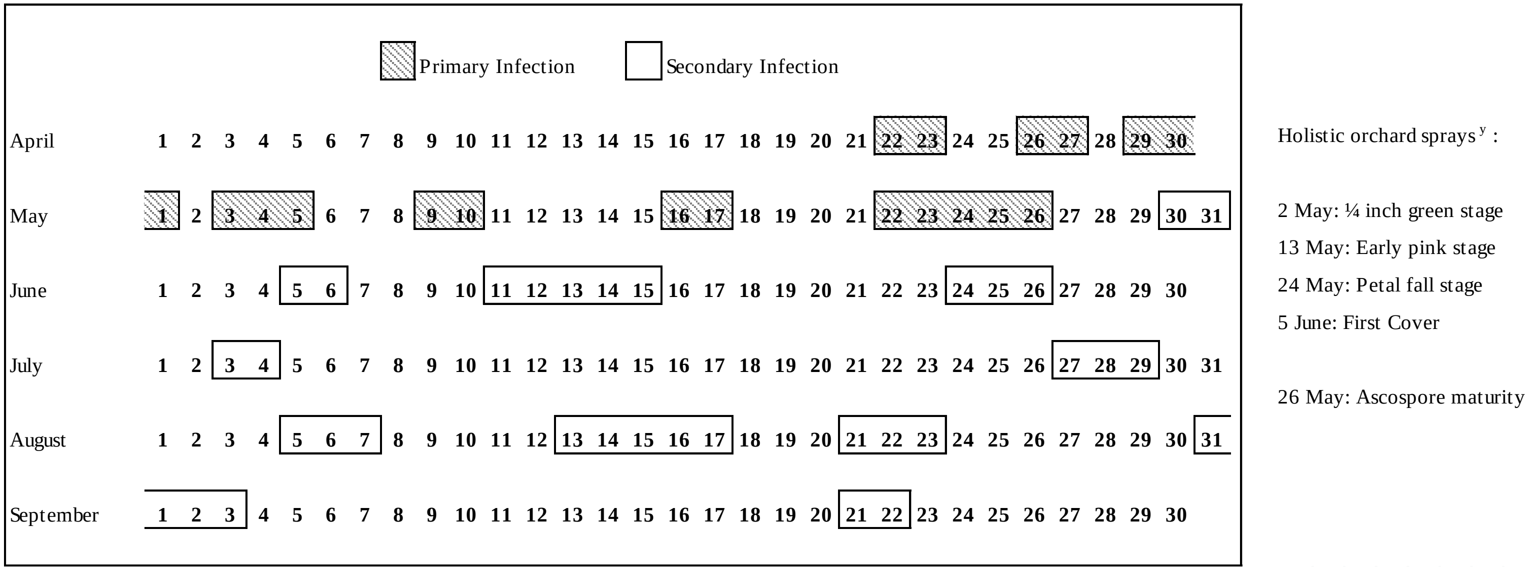
Holistic orchard sprays [y]:

26 Apr: ¼ inch green stage
2 May: Early pink stage
21 May: Petal fall stage
27 May: First cover

3 Jun: Ascospore maturity

[z] Infection events predicted by Cornell University - Network for Environment and Weather Applications (NEWA) according to data from South Burlington, VT weather station. Ascospores were essentially 100% matured and released on 2 June, 2013. The Ascospore Maturity degree day model begins at 50% green tip on McIntosh flower buds. Apple scab infection events are calculated beginning with 0.01 inch of rain. Two successive wetting periods are considered a single, uninterrupted wetting period if the intervening dry period is less than 24 hours.
[y] Four spring holistic orchard sprays. *The Holistic Orchard- Tree Fruits and Berries the Biological Way*. Phillips, M. 2011
Organic Management System (OMS) description and application dates:
OMS-1: Use of sulfur fungicides except for the 3-4 week period of rapid shoot elongation following petal fall stage. Dates of application for 2013: 18 Apr; 8 May; 15 May; 20 June; 27 June; 5 July; 12 July
OMS-2: Replaces use of sulfur fungicides with a combination of agricultural biostimulants. Each application included 0.23 $kg{\cdot}ha^{-1}$ kelp meal, 0.5% unsulfured organic molasses and 0.03% yucca extract emulsifier. Dates of application for 2013: 26 Apr (¼ inch green); 2 May (early pink); 21 May (petal fall); 27 May (first cover); 5 June; 13 June; 20 June; 27 June; 5 July; 12 July; 25 July; 7 Aug.
OMS-3: Use of sulfur fungicides throughout the season. Liquid lime sulfur (LLS) was applied on 22 May 2013 at 18.7 $L{\cdot}ha^{-1}$ to provide post-infection apple scab management. Dates of application for 2013: 18 Apr; 8 May; 15 May; 21 May; 27 May; 5 June; 13 June; 20 June; 27 June; 5 July; 12 July

Figure 1.1. Primary and secondary apple scab infection periods [z], 2013



[z] Infection events predicted by Cornell University - Network for Environment and Weather Applications (NEWA) according to data from South Burlington, VT weather station. Ascospores were essentially 100% mature and released on 26 May, 2014. The Ascospore Maturity degree day model begins at 50% green tip on McIntosh flower buds. Apple scab infection events are calculated beginning with 0.01 inch of rain. Two successive wetting periods are considered a single, uninterrupted wetting period if the intervening dry period is less than 24 hours.

[y] Four spring holistic orchard sprays. *The Holistic Orchard-Tree Fruits and Berries the Biological Way.* Phillips, M. 2011

Organic Management System (OMS) description and application dates:

OMS-1: Use of sulfur fungicides except for the 3-4 week period of rapid shoot elongation following petal fall stage. Dates of application for 2014: 21 Apr; 28 Apr; 2 May; 8 May; 13 May; 20 May; 24 May; 3 July; 17 July; 1Aug.

OMS-2: Replaces use of sulfur fungicides with a combination of agricultural biostimulants. Each application included 0.23 $kg{\cdot}ha^{-1}$ kelp meal, 0.5% unsulfured organic molasses and 0.03% yucca extract emulsifier. Dates of application for 2014: 2 May (¼ inch green); 13 May (early pink); 24 May (petal fall); 5 June (first cover); 11 June; 20 June; 3 July; 17 July; 1 Aug; 15Aug.

OMS-3: Use of sulfur fungicides throughout the season. Liquid lime sulfur (LLS) was applied on 22 May 2013 at 18.7 $L{\cdot}ha^{-1}$ to provide post-infection apple scab management. Dates of application for 2014: 21 Apr; 28 Apr; 2 May; 8 May; 13 May; 20 May; 24 May; 29 May; 11 June; 3 July; 17 July; 1 Aug.

Figure 1.2. Primary and secondary apple scab infection periods [z], 2014

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CHAPTER 2. JOURNAL ARTICLE

The non-target impacts of an organic disease management system containing biostimulants compared with two sulfur-based systems on pest and beneficial arthropod populations on three apple cultivars in Vermont

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Abstract

Disease management in organic apple orchards in Vermont is focused on controlling diseases with sulfur fungicides. The objective of this two-year study was to evaluate the non-target effects of an organic disease management system containing agricultural biostimulants compared to two sulfur-based systems on pest and beneficial arthropod populations. Trees were arranged in a completely randomized design of five three-tree replications in a certified organic orchard. The two sulfur-based systems differed in the number of applications; in the third system, sulfur was replaced with biostimulants including pure neem oil, liquid fish, an activated microbial inoculant and equisetum and stinging nettle teas. Each biostimulant application also included kelp meal, unsulfured organic molasses and yucca extract emulsifier. Organically approved insecticides were applied uniformly to the whole orchard. The use of the agricultural biostimulants had very limited non-target effects and when present, they were beneficial in suppressing insect pest incidence and/or damage on foliage compared to one or both of the sulfur-based fungicide systems. However, many insect pests or their damage were not observed on the foliage or had incidence of less than 1% in any of the systems. The biostimulant system did appear to suppress European red mites in both years compared to both sulfur-based systems when data were averaged across cultivars. On fruit, no differences in non-target impacts among any of the three systems were observed except for surface-feeding Lepidoptera and San Jose scale damage. In summary, the organic disease management system containing biostimulants did not have different non-target impacts for almost all of the pest and beneficial arthropods evaluated in this study compared to the sulfur-based systems. Before this novel disease management approach in commercial orchards is adopted, the effects of the biostimulants on important diseases, in addition to the effects on tree growth and yield must be thoroughly evaluated.

Introduction

Apple scab [*Venturia inaequalis* (Cooke) Wint.] is the most challenging disease to manage in New England apple [*Malus sylvestris* (L.) Mill. var. *domestica* (Borkh.) Mansf.] orchards (MacHardy, 1996, 2000). Depending on weather and disease pressure, up to 15 protectant fungicide spray applications may be necessary to manage apple scab on susceptible apple cultivars (Ellis et al., 1998; Holb, 2005b; Jamar et al., 2010; MacHardy, 1996, 2000). Apple scab causes fruit and foliar lesions that when severe, can impact the health and vigor of the tree and lead to premature defoliation, decreased fruit yield and decreased fruit marketability (MacHardy, 1996; Sutton et al., 2014). Severe infections from this fungal disease can also increase susceptibility of the tree to winter injury and may impact fruit bud formation in the following season (MacHardy, 1996). Although the use of new scab-resistant cultivars can decrease the total number of fungicide sprays applied in the orchard during the growing season, many New England growers have been slow to replace 'McIntosh' trees (Berkett and Cooley, 1989). The lack of organic orchards in New England can be partially attributed to the high susceptibility of the widely planted cultivar 'McIntosh' to apple scab (MacHardy, 2000).

Although the use of scab-resistant cultivars can virtually eliminate the need for fungicide sprays for this pathogen, there are many other economically important fungal diseases in the orchard that require management such as powdery mildew [*Podosphaera leucotricha* (Ellis & Everh.) Salmon] and the complex of rust diseases including cedar apple rust [*Gymnosporangium juniper-virginianae* (Schwein)]; hawthorn rust [*G. globosum* (Farlow) Farlow]; quince rust [*G. clavipes* (Cooke and Peck)] and Japanese apple rust [*G. yamadae* (Miyabe ex Yamada)] (Gregory, et al., 2009; Yun, et al., 2009).

Fungal fruit rots (*Colletotrichum* spp. and *Botryosphaeria* spp.) as well as sooty blotch, which is caused by the complex of *Peltaster fruticola* (Johnson, Sutton, Hodges), *Geastrumia polystigmatus* (Batista & M.L. Farr), *Lepodontium elatus* (G. Mangenot) De Hoog and *Gleodes pomigena* (Schwein) Colby, and the disease flyspeck [*Zygophiala jamaicensis* (E. Mason)] can also cause economic losses in orchards (Cooley et al., 2014). All of these diseases would need to be successfully managed in organic apple orchards to produce a marketable crop of apples.

Disease management in organic apple orchards is currently reliant on OMRI-approved copper- and sulfur-based pesticides and although organic, these compounds are not without significant negative impacts (Ellis et al., 1998; Holb et al., 2003). In general, prolonged use of copper in various cropping systems has resulted in elevated levels in soils, affecting soil ecology and earthworm numbers (Paoletti et al., 1998; van Rhee, 1976). Since the traditional formulations of copper can increase chances of phytotoxicity after the phenological green tip stage in apple, these formulations are limited to the silver tip phenological stage where it is used as a bactericide for the management of overwintering fire blight inoculum (Brown et al., 1996). Unfortunately, the new lower rate copper formulations have label limitations that do not allow applications at adequate rates for control of fire blight later in the growing season so are not appropriate past the green tip spray (Rosenberger, Pers. comm., 2014). Although these new materials are labelled for use against many of the summer fruit rot diseases, the amount of available copper ions in the applied rates may be substantially less than the traditional copper formulations. As a result, these lower rate formulations vary in their effectiveness against scab and fruit rots and have been shown to increase fruit russet (Rosenberger, Pers. comm., 2014).

Sulfur and liquid lime sulfur remain the standard organic fungicides used to manage apple scab and other fungal diseases in the orchard (Ellis et al., 1991; Holb et al., 2003; MacHardy, 1996; Mills, 1947). Both are multi-site protectant fungicides, but liquid lime sulfur provides some activity against scab 48-72 hours post-infection (Hamilton and Keitt, 1928; Jamar and Lateur, 2006). Liquid lime sulfur, however, is highly caustic and its use can cause detrimental impacts on tree health, photosynthesis, pollen tube growth and can result in decreased fruit set and lowered yields. (Burrell, 1945; Holb et al., 2003; MacHardy, 1996; McArtney et al., 2006; Mills, 1947; Palmer et al., 2003). The use of this caustic material later in the season can result in russetting and burning of the fruit, especially under hot, humid conditions (Holb et al., 2003; Noordijk and Schupp, 2003; Stopar, 2004). For these reasons, use of liquid lime sulfur is limited to curative sprays for apple scab after weather conditions conducive for infection have occurred (MacHardy and Gadoury, 1989; Penrose, 1995). Although wettable sulfur lacks post-infection activity, is a weaker protectant than liquid lime sulfur and can also impact photosynthesis, this material causes less phytotoxicity and consequently is the primary fungicide used in organic apple orchards (Holb and Heijne, 2001; Jamar et al., 2008, Palmer et al., 2003).

Sulfur fungicides can impact mite populations and have long been identified as general acaricides (Collyer and Kirby, 1959; Garman and Townsend, 1938; Lord, 1949; MacPhee and Sanford, 1954). Sulfur can have non-target effects on both beneficial and phytophagous mite populations in orchards and can impact predator to prey ratios in orchards, causing phytophagous mite populations to flare (Beers and Hull, 1987; Beers et al., 2009; Blommers, 1994; Bower et al., 1995; Holdsworth, 1972; MacPhee and Sanford, 1954; van de Vrie, 1962).

Given the negative effects of sulfur and lime sulfur fungicides on tree health and the potential impacts to predatory mites, growers and researchers are searching for suitable alternatives for disease control in the orchard. Novel disease resistance elicitors, used alone or in combination with fungicides, may offer new, low environmental-impact options. Plant chemical defenses can be present in the plant all the time or can be "induced" by an elicitor. The term 'elicitor' was originally used for compounds that would induce production of phytoalexins, but now the definition of elictor has broadened to any compound that stimulates any plant defense. (Ebel and Cosio, 1994; Hahn, 1996; Thakur and Sohal, 2013.) The term 'agricultural biostimulant' is often substituted for 'elicitor' when used in a field or agricultural setting. There are several studies demonstrating the successful use of agricultural biostimulants for suppression of diseases caused by several genera of pathogens in a wide variety of crops (Cherif et al., 1992; Elmer and Reglinski, 2006; French-Monar, 2010; Germar, 1934; Gillman et al., 2003; Kunoh and Ishizaki, 1975; Leusch and Buchenauer, 1989; Renard-Merlier et al., 2007; Rodgers-Gray and Shaw, 2004; Sun et al., 1994, 2002). In addition to triggering plant defenses, agricultural biostimulants can also improve physiological responses in plants. Improved crop yields and quality, increased plant buffering capacities for temperature and drought extremes, and improvements in plant nutrition have been noted in various crops following applications of agricultural biostimulants (Botta, 2012; Calvo et al., 2014; Chen et al., 2003; Miller et al., 1990) and evidence of positive benefits of application is increasing (Chen et al., 2003; Lyon et al., 1995; Paul and Sharma, 2002). Agricultural biostimulants that show promise for organic production systems include humic acids, seaweed, silica and other plant extracts, chitinous products from fungal sources and oligiosaccharides (Aziz et al., 2006; Colavita et al., 2011; Craigie, 2010; French-Monar et al., 2010; Khan et al. 2009, Leusch and Buchenauer, 1989; Lyon et al., 1995; Norrie et al., 2002; Volk et al., 1958; Wu et al., 2005). Increased interest in using these materials may be partially driven by the loss of synthetic and/or organically acceptable products available for disease management.

The use of agricultural biostimulants for disease management in apples was introduced in a popular trade book authored by a New England orchardist called *The Holistic Orchard-Tree Fruits and Berries the Biological Way* (Phillips, 2011). Phillips' book promotes whole system health in the tree and orchard as a way to avoid "short term" solutions to disease management through the use of pesticides. Four holistic sprays in the spring are prescribed based on the phenological growth stage: ¼ green, early pink, petal fall and first cover, which is a week to ten days after petal fall (Phillips, 2011). These biostimulant sprays include a tank mix of pure neem oil, liquid fish, and a complex of diverse microbes that are applied to the foliage and trunk to "promote beneficial fungi and stimulate tree immunity to ward off disease." These early season sprays are timed to cover the primary infection periods for apple scab and infection by other pathogens. After the four spring applications, stinging nettle and horsetail teas are added to the applications and are made on a ten day to fourteen-day schedule throughout the rest of the growing season (Phillips, 2011).

This study was designed to test the non-target effects of this disease management approach, following Phillips' recommended application schedule, and compare the impacts of this novel approach with two sulfur-based systems on pest and beneficial arthropods on three apple cultivars in Vermont. This research is part of an overall evaluation of the target and non-target effects of these three organic disease management systems on foliar and fruit diseases, phytophagous mite populations, tree growth, yield and fruit quality which are reported in separate articles.

Materials and Methods

The study was conducted at the University of Vermont Horticulture Research Center in South Burlington, VT, USA. The research orchard was planted in 2006 and certified organic in 2008. The planting includes five cultivars: 'Ginger Gold', 'Liberty', 'Macoun', 'Honeycrisp' and 'Zestar!'. Three-tree plots of each cultivar were planted in a complete randomized design across eight rows at a tree spacing of 1.5 m X 4.6 m and trained to a vertical axis system. All cultivars were grafted on Budagovsky 9 (Bud. 9) dwarfing rootstock except 'Honeycrisp' that was on Malling 26 (M 26). The cultivars 'Ginger Gold', 'Honeycrisp' and 'Liberty' were used for this study (Appendix A, Research Plot Map).

Sprays were applied to five three-tree plots for each organic management system (OMS): OMS-1, OMS-2 and OMS-3. OMS-1 was based on the use of sulfur fungicides throughout the season except for the three to four week period of rapid shoot elongation following the petal fall phenological stage when no sulfur-based fungicides were applied. These were not applied due to sulfur's potential cumulative negative impact on photosynthesis during this critical period of growth (Palmer et al., 2003). Palmer et al.

found sulfur fungicides (lime sulfur and sulfur) had pronounced effects on leaf photosynthesis rate with the greatest effect noted after shoot growth had ended. The researchers hypothesized that several applications of sulfur over the course of the season or over several years may have a cumulative effect on leaf area and shoot growth. In OMS-2, the use of sulfur sprays was replaced with a combination of agricultural biostimulants throughout the growing season. OMS-3 was based on the use of sulfur fungicides throughout the season. Liquid lime sulfur was also a fungicide option in both OMS-1 and OMS-3 if its post-infection properties against apple scab infection were warranted. Because of limited orchard size, a 'non-treated' system could not be incorporated into the experimental design. OMS-3 is the standard organic management system applied by commercial organic apple growers in New England and serves as the control in this applied study. All materials used were OMRI-approved. The three systems were applied to the same trees over two consecutive growing seasons (2013, 2014) to assess multi-year effects of their target impacts on foliar and fruit diseases as well as non-target effects.

Weather was monitored with a RainWise MK-III Weather Station (RainWise, Inc.; Trenton, ME) and networked to the Cornell University Network for Environmental and Weather Applications (NEWA, http://newa.cornell.edu/). NEWA output was used to determine apple scab infection periods, fire blight (*Erwinia amylovora*) risk, and the risk of sooty blotch and flyspeck infection. This information, with apple phenological bud stages, was used to determine timing and frequency of spray applications.

Sprays were applied dilute to drip to the foliage with a 189-L hydraulic sprayer (Nifty Fifty; Rears Mfg. Co., Eugene, OR) with an attached handgun (Green Garde JD9-

C; H.D. Hudson Mfg. Co., Chicago, IL) with an L tip at a pressure of 6.8 atm. Cupric hydroxide (Champ WG; NuFarm Americas, Inc., Burr Ridge, IL) and cupric hydroxide/cupric oxychloride (Badge SC; Gowan Products, Yuma, AZ) were applied at the silver tip phenological stage for fire blight management in OMS-1 and OMS-3 in 2013 and 2014, respectively (Tables 2.1 and 2.2). The fungicide used in OMS-1 and OMS-3 was micronized wettable sulfur (Microthiol Disperss; United Phosphorus, Inc., King of Prussia, PA). In 2013, OMS-3 also included one application of liquid lime sulfur (Miller's Liquid Lime Sulfur; Waynesboro, MS) to provide post-infection apple scab management after a heavy rain event (Table 2.1). Agricultural biostimulants in OMS-2 included pure neem oil (Ahimsa Organics Neem Oil: The Ahimsa Alternative, Inc., Bloomington, MN**)**, liquid fish (OrganicGem Liquid Fish Fertilizer 3-3-0; Advanced Marine Technologies, New Bedford, MA), activated microbial inoculant (Dr. Higa's Original EM·1 Microbial Inoculant; TeraGanix, Alto, TX) plus equisetum (*Equisetum arvense*) tea and stinging nettle (*Urtica doica*) tea. Each of these applications also included kelp meal (SeaLife Kelp Meal; North American Kelp, Waldsboro, ME), unsulfured organic molasses and yucca extract emulsifier (Therm X-70; Cellu-Con, Inc., Strathmore, CA). Teas and activated EM·1 were prepared according to protocols described in *The Holistic Orchard-Tree fruits and Berries the Biological Way* (Phillips, 2011). The OMS-2 sprays at the ¼-½ inch green and early pink phenological stages were applied to thoroughly wet branches, trunk and ground while the later sprays were applied only to the foliage (Phillips, 2011). Tables 1 and 2 list dates of application and rates for 2013 and 2014, respectively, for the three management systems.

Organic insecticides were applied following a standard integrated pest management approach based on phenological bud stages plus arthropod scouting and monitoring. Materials were applied with a 756 L airblast sprayer (Pul-Blast 200; Rears Mfg Co., Eugene, OR) calibrated to deliver 543 $L \cdot ha^{-1}$ at a pressure of 13.6 atm with a tractor driven at 3 km/hour. All materials were applied to the entire orchard and included: kaolin clay (Surround WP; Tessenderlo Kerley, Inc., Phoenix, AZ), azadiractin (Aza-Direct Biological Insecticide; Gowan Co., Yuma, AZ), pyrethrin (PyGanic Crop Protection EC 5.0; MGK Company, Minneapolis, MN), granulosis virus (CYD-X Biological Insecticide; Certis USA L.L.C., Columbia, MD), *Bacillus thuringiensis* (Dipel DF; Valent USA Corp., Walnut Creek, CA) and spinosad (Entrust; Dow AgroSciences, L.L.C., Indianapolis, IN). In addition, horticultural oil (JMS Stylet oil; JMS Flower Farms, Inc., Vero Beach, FL) was applied to OMS-1 and OMS-3 following standard organic management procedures for arthropod management.

The following assessments were used to evaluate the non-target impacts of the three organic disease management systems on pest and beneficial arthropods:

Foliar Assessment on 1, 2 August 2013 and 4, 5 August 2014

Two vegetative apical terminal shoots (six shoots per three-tree plot with five replications per cultivar) were selected at random around the tree canopy for evaluation. Bourse shoots were substituted when sufficient apical shoots were not available and only the leaves above the fruit cluster were assessed. Both sides of all leaves on each shoot were evaluated for presence of the following: spotted tentiform leafminer mines (STLM) [*Phyllonorycter blandcardella* (Fabr.)]; lyonetia mines (Lepidoptera: Lyonetiidae

[*Lyonetia prunifoliella* (Hubner)]; other leafminer mines; white apple leafhoppers (WALH) [*Typhlocyba pomaria* (McAtee)]; green aphids [*Aphis pomi* (De Geer) or *Aphis spiraecola* (Patch)]; European red mites [*Panonychus ulmi* (Koch)] and two-spotted spider mites [*Tetranychus urticae* (Koch)]. Foliar damage was evaluated for white apple leafhopper, Japanese beetle [*Popillia japonica* (Newman)] and potato leafhopper (PLH) [*Empoasca fabae* (Harris)]. Potato leafhopper damage data were not collected on the cultivar 'Honeycrisp' since the damage symptoms are difficult to distinguish from the cultivar's similar-appearing physiological characteristics. Both presence (incidence) and number per leaf (severity) were recorded for spotted tentiform leafminer mines. Beneficial arthropod incidence was also recorded and included: predacious mites [*Typhlodromus pyri* (Scheuten)]; ladybeetle (Coleoptera: Coccinellidae) eggs, larvae and adults; gall midge (Diptera: Cecidomyiidae) larvae; hover [Diptera: Syrphidae) fly eggs and larvae; green lacewing (Neuroptera: Chrysopidae) eggs and larvae; spider mite destroyer [*Stethorus punctum* (LeConte)] larvae and adults; black hunter thrips [*Leptothrips mali* (Fitch)]; spiders (Arachnida); minute pirate bugs [*Orius insidiousus* (Say)] and mullein plant bug [*Campylomma verbasci* (Meyer)] nymphs. The number of leaves with each arthropod present was tallied for each terminal. The number of leaves 'without arthropod pests or their damage' were recorded for each terminal. Headpiece magnifying glasses (10 X magnification) were used as aids in the assessments.

Fruit Damage Assessment at Harvest

All the fruit from each cultivar were picked on the same date but the dates of harvest for each cultivar varied: 'Ginger Gold' was harvested on 19 August 2013 and 28 August 2014; 'Honeycrisp' was harvested on 11 September 2013 and 10 September

2014; and ‘Liberty’ was harvested on 25 September 2013 and 22 September 2014. Harvested fruit was stored in regular cold air storage at 2^0 C until assessment, which occurred within one week of picking. Random samples of ten fruit for each tree in each of the five three-tree plots were assessed for injury from plum curculio [*Conotrachelus nenuphar* (Herbst)]; tarnished plant bug [*Lygus lineolaris* (Palisot de Beauvois)]; apple maggot [*Rhagoletis pomonella* (Walsh)]; internal Lepidoptera which includes damage from codling moth [*Cydia pomonella* (L.)], oriental fruit moth [*Grapholita molesta* (Busck)] and lesser appleworm [*Grapholita prunivora* (Walsh)]; surface Lepidoptera, including obliquebanded [*Choristoneura rosaceana* (Harris)] and red-banded [*Argyrotaenia velutinana* (Walker)] leafrollers; European apple sawfly [*Hoplcampa testudinea* (Klug)]; stink bug (Hemiptera: Pentomidae); rosy apple aphid [*Dysaphis plantaginea* (Passerini)] and San Jose scale [*Quadraspidiotus perniciosus* (Comstock)]. Fruit ‘without arthropod pests or damage’ was also noted. Fruit damage was identified using a standard field guide for the Northeast (Agnello et al., 2006).The same observer performed all the fruit damage assessments to minimize variation.

Statistical Analysis

The primary hypothesis of this research was that the organic agricultural biostimulant system would have non-target effects on pest and beneficial arthropod incidence and damage on three apple cultivars when compared with the sulfur-based fungicides. A second hypothesis was that the number of sulfur applications would impact pest and beneficial arthropod incidence and damage. The experimental design allowed for a two-way analysis of variance with independent cultivar and organic management system treatments. The statistical analyses of data were performed with SAS PROC

MIXED (SAS Institute; Cary, NC) using a two-way analysis of variance (ANOVA) with a significance level of $P < 0.05$. If the overall F-test for a main effect (cultivar or OMS) was significant, pairwise comparisons were performed using Tukey's HSD. If the interaction was significant then pairwise comparison of OMS was done within cultivar using Tukey's HSD. Data in the form of proportions were transformed using the arc sin square root transformation and the analyses were performed on the transformed data. The results are summarized in tables. Actual means are reported even though the analysis for some of the measures was conducted on the transformed data.

Results and Discussion

Foliar Pest and Beneficial Arthropods

Tables 2.3 and 2.4 include data on presence and/or damage of insect pests that were observed on foliage in August of each year. Many insect pests or their damage were not observed or had incidence of less than 1%. Of all the various insects or damage, significant differences among the systems were only detected for Japanese beetle damage in 2013, and for STLM damage incidence and severity in 2014 and then only when means were averaged across all cultivars. With both of these insects, OMS-2 had the least damage but the level was different from only one of the sulfur-based systems (i.e., OMS-2 was not different from OMS-1 in Japanese beetle damage nor from OMS-3 for STLM damage and severity). No differences were detected between the two sulfur-based systems.

Regarding phytophagous mites, European red mites were significantly lower in the OMS-2 system when compared to both sulfur-based systems in both years when averaged across cultivars (Table 2.5). OMS-2 did not receive an early season application of horticultural oil as in OMS-1 and OMS-3. Since sulfur has been reported to have general acaricidal properties, fewer phytophagous mites might be expected in the system having more sulfur sprays (Collyer and Kirby, 1959; Garman and Townsend, 1938; Lord, 1949; MacPhee and Sanford, 1954). However, there was no difference in European red mite or two-spotted spider mite incidence between the sulfur-based systems for any cultivar in any year. The results seen in OMS-2 corroborate those noted in a separate study on the cultivar 'Zestar' where, when there were differences among the systems, the biostimulant system had less mite incidence per leaf than one or both of the sulfur-based systems in both years (Hazelrigg, 2015). Several studies that have shown that sulfur fungicides can flare mite populations in orchards by disrupting predator to prey ratios (Beers and Hull, 1987; Beers et al., 2009; Blommers, 1994; Bower et al., 1995; Holdsworth, 1972; MacPhee and Sanford, 1954; van de Vrie, 1962). However, incidence of beneficial arthropods was very low or non-existent throughout the orchard in this study (Table 2.6 and 2.7), and they do not seem to be a major factor in explaining the difference between the sulfur-based systems and the biostimulant system. Of all the beneficial arthropods that were assessed in each year, there were only two data sets in 2014 where differences were detected among the systems: in the cultivar "Ginger Gold', where populations of *T. pyri* were significantly lower in OMS-2 when compared to the full sulfur system and when means for spider mite destroyer incidence were averaged across cultivars. OMS-2 had significantly less spider mite destroyer adults compared to the sulfur-based OMS-3 system (Table 2.7). Spider mite destroyers are an important mite predator and can consume up to 100 motile mites per day (Agnello et al., 2006). The reduced number of these predators might be expected to result in the flaring of mite populations in OMS-2, as opposed to the suppression that was noted. Thus, it appears other factors may be influencing the differences noted among the systems in phytophagous mite incidence.

The amount of foliar disease has been shown to influence mite populations. A study in Ireland found that a higher incidence of apple scab on the foliage resulted in lower populations of phytophagous mites, likely due to the lower palatability of the foliage (Cuthbertson and Murchie, 2003). In both years, apple scab was assessed on the foliage and when there were differences in incidence among the systems, more scab was observed in the biostimulant system (Hazelrigg, 2015).

Another consideration is that the lower incidence of ERM in OMS-2 compared with the sulfur-based systems may be due to the direct effects of the agricultural biostimulants. Components of OMS-2 have demonstrated mite suppression in other research. Neem-based products have shown miticidal effects and repellency of mites in several studies (Mansour et al., 1997; Sundarum and Sloane, 1995). However, a recent University of Vermont study examining the non-target effects of organic fungicides in apple orchards found the use of neem had no effect on populations of European red mites, but neem-treated trees had lower incidence of two-spotted spider mites per leaf in one year of the study (Cromwell et al., 2011). There are a limited number of studies showing suppression of mites with kelp meal or seaweed extracts in certain crops. One study in the U.K. showed applications reduced populations of two-spotted spider mites in high tunnel strawberries (Hankins and Hockey, 1990). A greenhouse study in West Virginia on bean plants showed seaweed extracts sprays reduced the predator to prey ratio of two-spotted spider mites and the predator mite, *A. fallacis* (Hamstead, 1970). However, a study in Vermont showed seaweed extracts had no effect on phytophagous or predacious mites in apples (Bradshaw et al., 2013).

An overarching assessment of "foliage without arthropod pests and damage" was calculated in both years by evaluating the incidence and damage of both insect pests and phytophagous mites (Table 2.8). No differences were detected among the systems for each cultivar in either year. However, when data were averaged across cultivars, OMS-2 had a higher percentage of leaves without pest arthropods or their damage compared to both sulfur-based systems in both years. There were no significant differences between sulfur systems in either year. The lower incidence of arthropod pests or their damage noted in OMS-2 may be related to the direct insecticidal activity of some of the components of the agricultural biostimulant system. Use of neem as an effective insecticide is widely documented for management of arthropods in several crops and is a potent insect anti- feedant (Isman, 2006; Dayan et al., 2009; Mansour, 1997). Neem also showed good control of mirid (Miridae) bug damage in apples and pears (*Pyrus* sp.) (Jaastad et al., 2009).

There is also some evidence suggesting silicon, a component of the stinging nettle and equisetum teas, may suppress some arthropods through systemic acquired resistance (SAR) by inducing resistance in the plant to attack (Baldwin, 1998; Gomes et al., 2005; Goussain et al., 2005). This may have occurred in the biostimulant system. However, given that many insect pests or their damage were not observed on foliage or had incidence of less than 1.0 %, the assessment of "foliage without arthropods or damage" may just be another reflection of the incidence of European red mites on the foliage.

Arthropod Damage on Fruit

Tables 2.9 and 2.10 show the incidence of arthropod damage to fruit at harvest for both years. Fruit injury caused by some of the major insect pests of apple such as plum curculio, tarnished plant bug, internal- and surface-feeding Lepidoptera was observed on all cultivars in both years. However, no differences among the systems within the cultivars were detected for these insects. When cultivar means were averaged, system differences were only detected for surface-feeding Lepidoptera. In 2013, OMS-2 was not different from either of the sulfur-based systems, but OMS-3 had less damage than OMS-1. In 2014, OMS-2 had less damage than OMS-3, and OMS-3 was not different from OMS-1. Regarding other insect pests, the only difference in injury that was detected within a specific cultivar was associated with San Jose scale in the cultivar ‘Honeycrisp’. This cultivar had more damage in the biostimulant system compared to both sulfur-based systems in 2013, and the full-sulfur system in 2014 (Table 2.9).

The percentages of fruit “without arthropod pests and their damage” for each year are contained in Table 2.11. This overarching assessment showed no significant differences among systems within or across cultivars in either year. Given these fruit data the type of system did not have a major non-target impact or influence on incidence.

Summary and Conclusions

The objective of this research was to evaluate the non-target effects of an organic disease management system containing biostimulants compared with two sulfur-based systems on pest and beneficial arthropods on three apple cultivars. Organically approved insecticides had been applied uniformly to the whole orchard; the purpose of collecting data on arthropod incidence and damage was to assess differences among the three systems to determine potential non-target impacts of the systems. The use of the agricultural biostimulants had very limited non-target effects and when present, they were beneficial in suppressing insect pest incidence and/or damage on foliage compared to one or both of the sulfur-based fungicide systems. However, many insect pests or their damage were not observed on the foliage or had incidence of less than 1.0% in any of the systems. A similar situation existed for most of beneficial arthropods that were neither observed or had an incidence of less than 1.0 %. Differences in incidence among the systems was detected only in *T. pyri* and the spider mite destroyers, with fewer of these beneficial arthropods observed in the biostimulant system compared to at least one of the sulfur-based systems. These negative impacts did not appear to have a major impact on European red mite populations since a distinct difference was observed in the incidence of European red mites among the systems when data were averaged across cultivars ; in both years, the biostimulant system had less European red mite incidence than both sulfur-based systems. On fruit, no differences in non-target impacts among any of the three systems were observed except for surface-feeding Lepidoptera damage, where the biostimulant system had less damage than at least one of the sulfur-based systems when data were averaged across cultivars in both years, and for San Jose scale damage, where the biostimulant system had greater damage than at one or both of the sulfur-based systems in each year on 'Honeycrsip' trees. In summary, the organic disease management system containing biostimulants did not have different non-target impacts for almost all of the pest and beneficial arthropods evaluated in this study compared to the sulfur-based systems, but some impacts were observed. Before further adoption of this novel disease management system in commercial orchards, the targeted effects of the agricultural biostimulants on apple scab and other important diseases, in addition to the non-target effects on tree vigor and yield must be thoroughly evaluated.

Table 2.1. Organic management system (OMS) application materials, rates and timing in 2013

	Application materials and rates								
	OMS -1 [z]		OMS -2 [y]					OMS -3 [x]	
Application Timing	Cupric hydroxide kg·ha $^{-1}$	Micronized wettable sulfur kg·ha $^{-1}$	Pure Neem oil %	Liquid fish %	Activated microbial inoculant %	*Equisetum arvense* tea %	*Urtica dioica* tea %	Cupric hydroxide kg·ha $^{-1}$	Micronized wettable sulfur kg·ha $^{-1}$
18 Apr	11.2							11.2	
26 Apr			1.0	4.0	1.0				
2 May			0.5	2.0	1.0				
8 May		16.8							16.8
15 May		16.8							16.8
21 May			0.5	2.0	1.0				11.2
22 May									* LLS
27 May			0.5	2.0	1.0	5.0	5.0		11.2
5 Jun			0.5		1.0	5.0	5.0		11.2
13 Jun			0.5		1.0	5.0	5.0		11.2
20 Jun		11.2	0.5		1.0	5.0	5.0		11.2
27 Jun		11.2	0.5		1.0	5.0	5.0		11.2
5 Jul		11.2	0.5		1.0	5.0	5.0		11.2
12 Jul		11.2	0.5		1.0	5.0	5.0		11.2
25 Jul			0.5		1.0	5.0	5.0		
7 Aug			0.5		1.0	5.0	5.0		

[z] OMS-1: Use of sulfur fungicides except for the 3-4 week period of rapid shoot elongation following petal fall stage. Dates of application for 2013: 18 Apr; 8 May; 15 May; 20 June; 27 June; 5 July; 12 July

[y] OMS-2: Replaces use of sulfur fungicides with a combination of agricultural biostimulants. Each application included 0.23 kg·ha $^{-1}$ kelp meal, 0.5% unsulfured organic molasses and 0.03% yucca extract emulsifier. Dates of application for 2013: 26 Apr (¼-inch green); 2 May (early pink); 21 May (petal fall); 27 May (first cover); 5 June; 13 June; 20 June; 27 June; 5 July; 12 July; 25 July; 7 Aug.

[x] OMS-3: Use of sulfur fungicides throughout the season. Liquid lime sulfur (*LLS) was applied on 22 May 2013 at 18.7 L·ha $^{-1}$ to provide post-infection apple scab management. Dates of application for 2013: 18 Apr; 8 May; 15 May; 21 May; 27 May; 5 June; 13 June; 20 June; 27 June; 5 July; 12 July

Table 2.2. Organic management system (OMS) application materials, rates and timing in 2014

	Application materials and rates								
	OMS -1 [z]		OMS -2 [y]					OMS -3 [x]	
Application Timing	Cupric hydroxide/ oxychloride $kg \cdot ha^{-1}$	Micronized wettable sulfur $kg \cdot ha^{-1}$	Pure Neem oil %	Liquid fish %	Activated microbial inoculant %	*Equisetum arvense* tea %	*Urtica dioica* tea %	Cupric hydroxide/ oxychloride $kg \cdot ha^{-1}$	Micronized wettable sulfur $kg \cdot ha^{-1}$
21 Apr	7.9							7.9	
28 Apr		11.2							11.2
2 May		11.2	1.0	4.0	1.0				11.2
8 May		11.2							11.2
13 May		11.2	0.5	2.0	1.0				11.2
20 May		11.2							11.2
24 May		11.2	0.5	2.0	1.0				11.2
29 May									11.2
5 Jun			0.5	2.0	1.0	5.0	5.0		
11 Jun			0.5		1.0	5.0	5.0		11.2
20 Jun			0.5		1.0	5.0	5.0		
3 Jul		11.2	0.5		1.0	5.0	5.0		11.2
17 Jul		11.2	0.5		1.0	5.0	5.0		11.2
17 Jul		11.2	0.5		1.0	5.0	5.0		11.2
15 Aug			0.5		1.0	5.0	5.0		

[z] OMS-1: Use of sulfur fungicides except for the 3-4 week period of rapid shoot elongation following petal fall stage. Dates of application for 2014: 21 Apr; 28 Apr; 2 May; 8 May; 13 May; 20 May;24 May; 3 July; 17 July; 1 Aug.

[y] OMS-2: Replaces use of sulfur fungicides with a combination of agricultural biostimulants. Each application included 0.23 $kg \cdot ha^{-1}$ kelp meal, 0.5% unsulfured organic molasses and 0.03% yucca extract emulsifier. Dates of application for 2014: 2 May (¼-inch green); 13 May (early pink); 24 May (petal fall); 5 June (first cover); 11 June; 20 June; 3 July; 17 July; 1 Aug; 15 Aug.

[x] OMS-3: Use of sulfur fungicides throughout the season. Dates of application for 2014: 21 Apr; 28 Apr; 2 May; 8 May; 13 May; 20 May; 24 May; 29 May; 11 June; 3 July; 17 July; 1 Aug.

Table 2.3. Foliage with arthropod pest and/or damage on 'Ginger Gold' (GG), 'Honeycrisp' (HC), and 'Liberty' (L) in 2013 and 2014

	Percent Incidence																						
	Terminal leaves [z]																						
	1-2 Aug 2013																						
	WALH [y]				WALH damage				PLH [x]				PLH damage [w]			Japanese beetle damage				Green aphids			
Systems	GG	HC	L	All	GG	HC	L	All	GG	HC	L	All	GG	L	All	GG	HC	L	All	GG	HC	L	All
OMS [v]-1 [u]	0.0	0.0	0.1	0.0 [r]	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	2.6	1.7	2.2	1.1	14.1	2.3	5.8 ab	0.0	0.0	0.4	0.1
OMS-2 [t]	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.3	5.4	3.8	0.2	5.4	1.7	2.2 b	0.0	0.0	0.0	0.0
OMS-3 [s]	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.1	1.7	0.6	1.1	0.8	15.2	3.0	6.4 a	0.4	0.0	0.0	0.1

	Percent Incidence																						
	Terminal leaves																						
	4-5 Aug 2014																						
	WALH				WALH damge				PLH				PLH damage			Japanese beetle damage				Green aphids			
Systems	GG	HC	L	All	GG	HC	L	All	GG	HC	L	All	GG	L	All	GG	HC	L	All	GG	HC	L	All
OMS - 1	0.0	0.0	0.0	0.0	0.0	0.0	0.7	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	6.3	13.3	8.1	9.2	0.0	0.0	0.0	0.0
OMS-2	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.1	0.0	0.3	0.0	0.1	0.0	0.0	0.0	4.0	10.8	3.3	6.0	0.0	0.0	0.0	0.0
OMS-3	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.6	12.2	10.1	8.6	0.0	0.0	0.0	0.0

[z] Assessment of all leaves in six terminal shoots on five three-tree replicates per cultivar per OMS

[y] WALH: White apple leaf hopper

[x] PLH: Potato leaf hopper

[w] PLH damage: data were not collected on the cultivar ‘Honeycrisp’ since the damage symptoms are difficult to distinguish from the cultivar’s similar-appearing physiological characteristics

[v] OMS: Organic Management System

[u] OMS-1: Use of sulfur fungicides except for the 3-4 week period of rapid shoot elongation following petal fall stage. Dates of application for 2013: 18 Apr; 8 May; 15 May; 20 June; 27 June; 5 July; 12 July. Dates for 2014: 21 Apr; 28 Apr; 2 May; 8 May; 13 May; 20 May; 24 May; 3 July; 17 July; 1 Aug.

[t] OMS-2: Replaces use of sulfur fungicides with a combination of agricultural biostimulants. Each application included 0.23 $kg{\cdot}ha^{-1}$ kelp meal, 0.5% unsulfured organic molasses and 0.03% yucca extract emulsifier. Dates of application for 2013: 26 Apr (¼ inch green); 2 May (early pink); 21 May (petal fall); 27 May (first cover); 5 June; 13 June; 20 June; 27 June; 5 July; 12 July; 25 July; 7 Aug. Dates for 2014: 2 May (¼ inch green); 13 May (early pink); 24 May (petal fall); 5 June (first cover); 11 June; 20 June; 3 July; 17 July; 1 Aug; 15 Aug.

[s] OMS-3: Use of sulfur fungicides throughout the season. Liquid lime sulfur (LLS) was applied on 22 May 2013 at 18.7 $L{\cdot}ha^{-1}$ to provide post-infection apple scab management. Dates of application for 2013: 18 Apr; 8 May; 15 May; 21 May; 27 May; 5 June; 13 June; 20 June; 27 June; 5 July; 12 July. Dates of application for 2014: 21 Apr; 28 Apr; 2 May; 8 May; 13 May; 20 May; 24 May; 29 May; 11 June; 3 July; 17 July; 1 Aug.

[r] Means within columns followed by the same letter do not differ significantly at $p < 0.05$, Tukey-Kramer HSD; means in columns without letters are not significantly different from each other at $p < 0.05$, Oneway Analysis of Variance

Table 2.4. Foliage with spotted tentiform leafminer (STLM), Lyonetia and other mines on 'Ginger Gold' (GG), 'Honeycrisp' (HC), and 'Liberty' (L) in 2013 and 2014

	Terminal leaves [z]																															
	1-2 Aug 2013																4-5 Aug 2014															
	STLM								Lyonetia				Other mines				STLM								Lyonetia				Other mines			
	Incidence				Severity [y]				Incidence				Incidence				Incidence				Severity				Incidence				Incidence			
Systems	GG	HC	L	All	GG	HC	L	All	GG	HC	L	All	GG	HC	L	All	GG	HC	L	All	GG	HC	L	All	GG	HC	L	All	GG	HC	L	All
OMS [x]-1 [w]	1.2	1.0	0.8	1.0[t]	1.0	1.0	1.0	1.0	0.0	0.3	0.0	0.1	0.0	0.0	0.0	0.0	2.6	0.4	2.3	1.8 a	3.0	0.0	3.0	2.0 a	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
OMS-2 [v]	0.0	0.2	0.4	0.2	0.0	0.0	0.0	0.0	0.6	0.0	0.2	0.3	0.0	0.0	0.0	0.0	0.7	0.4	0.5	0.6 b	1.0	0.0	0.0	1.0 b	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
OMS-3 [u]	0.3	1.0	0.6	0.6	0.0	1.0	1.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5	1.7	1.4	1.2 ab	0.0	2.0	1.0	1.0 ab	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

[z] Assessment of all leaves in six terminal shoots on five three-tree replicates per cultivar per OMS

[y] Mean number of lesions per leaf

[x] OMS: Organic Management System

[w] OMS-1: Use of sulfur fungicides except for the 3-4 week period of rapid shoot elongation following petal fall stage. Dates of application for 2013: 18 Apr; 8 May; 15 May; 20 June; 27 June; 5 July; 12 July. Dates for 2014: 21 Apr; 28 Apr; 2 May; 8 May; 13 May; 20 May; 24 May; 3 July; 17 July; 1 Aug.

[v] OMS-2: Replaces use of sulfur fungicides with a combination of agricultural biostimulants. Each application included 0.23 $kg{\cdot}ha^{-1}$ kelp meal, 0.5% unsulfured organic molasses and 0.03% yucca extract emulsifier. Dates of application for 2013: 26 Apr (¼ inch green); 2 May (early pink); 21 May (petal fall); 27 May (first cover); 5 June; 13 June; 20 June; 27 June; 5 July; 12 July; 25 July; 7 Aug. Dates for 2014: 2 May (¼ inch green); 13 May (early pink); 24 May (petal fall); 5 June (first cover); 11 June; 20 June; 3 July; 17 July; 1 Aug; 15 Aug.

[u] OMS-3: Use of sulfur fungicides throughout the season. Liquid lime sulfur (LLS) was applied on 22 May 2013 at 18.7 $L{\cdot}ha^{-1}$ to provide post-infection apple scab management. Dates of application for 2013: 18 Apr; 8 May; 15 May; 21 May; 27 May; 5 June; 13 June; 20 June; 27 June; 5 July; 12 July. Dates of application for 2014: 21 Apr; 28 Apr; 2 May; 8 May; 13 May; 20 May; 24 May; 29 May; 11 June; 3 July; 17 July; 1 Aug.

[t] Means within columns followed by the same letter do not differ significantly at $p < 0.05$, Tukey-Kramer HSD; means in columns without letters are not significantly different from each other at $p < 0.05$, Oneway Analysis of Variance

Table 2.5. Foliage with European red mites (ERM) and two-spotted spider mites (TSSM) on 'Ginger Gold' (GG), 'Honeycrisp' (HC), and 'Liberty' (L) in 2013 and 2014

	Percent Incidence															
	Terminal leaves [z]															
	1-2 Aug 2013								4-5 Aug 2014							
	ERM				TSSM				ERM				TSSM			
Systems	GG	HC	L	All	GG	HC	L	All	GG	HC	L	All	GG	HC	L	All
OMS [y]-1 [x]	91.4	90.3	97.4	93.0 a [u]	1.9	0.9	2.0	1.6	90.0	88.7	77.9	85.5 a	2.6	10.4	8.3	7.1
OMS-2 [w]	55.8	74.4	76.7	68.6 b	1.2	1.0	0.5	0.9	51.9	52.6	44.1	49.5 b	1.1	7.0	7.0	5.0
OMS-3 [v]	94.1	76.9	88.8	86.6 a	3.5	0.0	1.2	1.6	94.2	83.7	93.5	90.5 a	5.9	3.0	19.8	9.5

[z] Assessment of all leaves in six terminal shoots on five three-tree replicates per cultivar per OMS

[y] OMS: Organic Management System

[x] OMS-1: Use of sulfur fungicides except for the 3-4 week period of rapid shoot elongation following petal fall stage. Dates of application for 2013: 18 Apr; 8 May; 15 May; 20 June; 27 June; 5 July; 12 July. Dates for 2014: 21 Apr; 28 Apr; 2 May; 8 May; 13 May; 20 May; 24 May; 3 July; 17 July; 1 Aug.

[w] OMS-2: Replaces use of sulfur fungicides with a combination of agricultural biostimulants. Each application included 0.23 $kg \cdot ha^{-1}$ kelp meal, 0.5% unsulfured organic molasses and 0.03% yucca extract emulsifier. Dates of application for 2013: 26 Apr (¼ inch green); 2 May (early pink); 21 May (petal fall); 27 May (first cover); 5 June; 13 June; 20 June; 27 June; 5 July; 12 July; 25 July; 7 Aug. Dates for 2014: 2 May (¼ inch green); 13 May (early pink); 24 May (petal fall); 5 June (first cover); 11 June; 20 June; 3 July; 17 July; 1 Aug; 15 Aug.

[v] OMS-3: Use of sulfur fungicides throughout the season. Liquid lime sulfur (LLS) was applied on 22 May 2013 at 18.7 $L \cdot ha^{-1}$ to provide post-infection apple scab management. Dates of application for 2013: 18 Apr; 8 May; 15 May; 21 May; 27 May; 5 June; 13 June; 20 June; 27 June; 5 July; 12 July. Dates of application for 2014: 21 Apr; 28 Apr; 2 May; 8 May; 13 May; 20 May; 24 May; 29 May; 11 June; 3 July; 17 July; 1 Aug.

[u] Means within columns followed by the same letter do not differ significantly at $p < 0.05$, Tukey-Kramer HSD; means in columns without letters are not significantly different from each other at $p < 0.05$, Oneway Analysis of Variance

Table 2.6. Foliage with beneficial arthropods on 'Ginger Gold' (GG), 'Honeycrisp' (HC), and 'Liberty' (L) in 2013 and 2014

	Percent Incidence [z]																							
	Terminal leaves [y]																							
	1-2 Aug 2013																							
	Lady beetle adults				*T. pyri*				Cecidomyid larvae				Syrphid fly larvae				Chrysopid eggs				Chrysopid larvae			
Systems	GG	HC	L	All	GG	HC	L	All	GG	HC	L	All	GG	HC	L	All	GG	HC	L	All	GG	HC	L	All
OMS [x]-1 [w]	0.0	0.3	0.0	0.1 [t]	0.5	0.3	0.0	0.3	0.2	0.0	0.2	0.1	0.0	0.2	0.4	0.2	0.0	0.0	0.3	0.1	0.0	0.0	0.0	0.0
OMS-2 [v]	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.7	0.2	1.3	0.7	0.0	0.0	0.0	0.0
OMS-3 [u]	0.0	0.0	0.0	0.0	0.0	0.2	0.7	0.3	0.0	0.0	0.0	0.0	0.3	0.2	0.0	0.2	0.3	0.0	0.0	0.1	0.0	0.0	0.0	0.0

	Percent Incidence																							
	Terminal leaves																							
	4-5 Aug 2014																							
	Lady beetle adults				*T. pyri*				Cecidomyid larvae				Syrphid fly larvae				Chrysopid eggs				Chrysopid larvae			
Systems	GG	HC	L	All	GG	HC	L	All	GG	HC	L	All	GG	HC	L	All	GG	HC	L	All	GG	HC	L	All
OMS-1	0.0	0.0	0.0	0.0	1.2 b	6.0 a	1.8 a	3.0 a	0.0	0.4	0.0	0.1	0.0	1.7	1.8	1.2	0.6	0.2	0.0	0.3	0.8	0.0	0.0	0.3
OMS-2	0.0	0.0	0.0	0.0	0.0 b	2.3 a	1.4 a	1.2 a	0.3	0.2	0.0	0.2	0.0	0.4	0.6	0.3	0.3	0.0	0.0	0.1	0.5	0.0	0.0	0.2
OMS-3	0.0	0.0	0.0	0.0	8.2 a	0.2 a	3.4 a	3.9 a	0.5	0.7	0.0	0.4	0.9	1.1	0.4	0.8	0.6	0.4	1.0	0.7	0.0	0.0	0.0	0.0

[z] Lady beetle eggs, larvae, syrphid fly eggs and mullein plan bug nymphs were not detected in either year

[y] Assessment of all leaves in six terminal shoots on five three-tree replicates per cultivar per OMS

[x] OMS: Organic Management System

[w] OMS-1: Use of sulfur fungicides except for the 3-4 week period of rapid shoot elongation following petal fall stage. Dates of application for 2013: 18 Apr; 8 May; 15 May; 20 June; 27 June; 5 July; 12 July. Dates for 2014: 21 Apr; 28 Apr; 2 May; 8 May; 13 May; 20 May; 24 May; 3 July; 17 July; 1 Aug.

[v] OMS-2: Replaces use of sulfur fungicides with a combination of agricultural biostimulants. Each application included 0.23 $kg\cdot ha^{-1}$ kelp meal, 0.5% unsulfured organic molasses and 0.03% yucca extract emulsifier. Dates of application for 2013: 26 Apr (¼ inch green); 2 May (early pink); 21 May (petal fall); 27 May (first cover); 5 June; 13 June; 20 June; 27 June; 5 July; 12 July; 25 July; 7 Aug. Dates for 2014: 2 May (¼ inch green); 13 May (early pink); 24 May (petal fall); 5 June (first cover); 11 June; 20 June; 3 July; 17 July; 1 Aug; 15 Aug.

[u] OMS-3: Use of sulfur fungicides throughout the season. Liquid lime sulfur (LLS) was applied on 22 May 2013 at 18.7 $L\cdot ha^{-1}$ to provide post-infection apple scab management. Dates of application for 2013: 18 Apr; 8 May; 15 May; 21 May; 27 May; 5 June; 13 June; 20 June; 27 June; 5 July; 12 July. Dates of application for 2014: 21 Apr; 28 Apr; 2 May; 8 May; 13 May; 20 May; 24 May; 29 May; 11 June; 3 July; 17 July; 1 Aug.

[t] Means within columns followed by the same letter do not differ significantly at $p < 0.05$, Tukey-Kramer HSD; means in columns without letters are not significantly different from each other at $p < 0.05$, Oneway Analysis of Variance

Table 2.7. Foliage with beneficial arthropods on 'Ginger Gold' (GG), 'Honeycrisp' (HC), and 'Liberty' (L) in 2013 and 2014 (continued)

	Percent Incidence																			
	Terminal leaves [z]																			
	1-2 Aug 2013																			
	Black killer thrips				Spiders				Minute pirate bug				SMD [y] larvae				SMD adult			
Systems	GG	HC	L	All	GG	HC	L	All	GG	HC	L	All	GG	HC	L	All	GG	HC	L	All
OMS [x]-1 [w]	0.2	0.0	0.0	0.1 [t]	0.3	0.3	0.1	0.2	0.0	0.0	0.3	0.1	0.0	1.7	0.0	0.6	0.0	0.0	0.0	0.0
OMS-2 [v]	0.0	0.0	0.4	0.2	0.4	0.1	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
OMS-3 [u]	0.0	0.4	0.0	0.1	0.0	0.2	0.0	0.1	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

	Percent Incidence																			
	Terminal leaves																			
	4-5 Aug 2014																			
	Black killer thrips				Spiders				Minute pirate bug				SMD larvae				SMD adult			
Systems	GG	HC	L	All	GG	HC	L	All	GG	HC	L	All	GG	HC	L	All	GG	HC	L	All
OMS-1	0.4	0.9	0.5	0.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.2	0.2	0.3 a	0.5 a	0.0 a	0.3 ab
OMS-2	0.0	0.0	0.3	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.1	0.0 a	0.0 a	0.2 a	0.1 b
OMS-3	0.2	0.5	0.7	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	3.3	1.2	1.6	0.5 a	1.1 a	0.4 a	0.7 a

[z] Assessment of all leaves in six terminal shoots on five three-tree replicates per cultivar per OMS

[y] SMD: Spider mite destroyer

[x] OMS: Organic Management System

[w] OMS-1: Use of sulfur fungicides except for the 3-4 week period of rapid shoot elongation following petal fall stage. Dates of application for 2013: 18 Apr; 8 May; 15 May; 20 June; 27 June; 5 July; 12 July. Dates for 2014: 21 Apr; 28 Apr; 2 May; 8 May; 13 May; 20 May; 24 May; 3 July; 17 July; 1 Aug.

[v] OMS-2: Replaces use of sulfur fungicides with a combination of agricultural biostimulants. Each application included 0.23 $kg \cdot ha^{-1}$ kelp meal, 0.5% unsulfured organic molasses and 0.03% yucca extract emulsifier. Dates of application for 2013: 26 Apr (¼ inch green); 2 May (early pink); 21 May (petal fall); 27 May (first cover); 5 June; 13 June; 20 June; 27 June; 5 July; 12 July; 25 July; 7 Aug. Dates for 2014: 2 May (¼ inch green); 13 May (early pink); 24 May (petal fall); 5 June (first cover); 11 June; 20 June; 3 July; 17 July; 1 Aug; 15 Aug.

[u] OMS-3: Use of sulfur fungicides throughout the season. Liquid lime sulfur (LLS) was applied on 22 May 2013 at 18.7 $L \cdot ha^{-1}$ to provide post-infection apple scab management. Dates of application for 2013: 18 Apr; 8 May; 15 May; 21 May; 27 May; 5 June; 13 June; 20 June; 27 June; 5 July; 12 July. Dates of application for 2014: 21 Apr; 28 Apr; 2 May; 8 May; 13 May; 20 May; 24 May; 29 May; 11 June; 3 July; 17 July; 1 Aug.

[t] Means within columns followed by the same letter do not differ significantly at $p < 0.05$, Tukey-Kramer HSD; means in columns without letters are not significantly different from each other at $p < 0.05$, Oneway Analysis of Variance

Table 2.8. Foliage without arthropod pests and their damage on ‘Ginger Gold' (GG), 'Honeycrisp' (HC), and 'Liberty' (L) in 2013 and 2014

	Percent Incidence							
	Terminal leaves [z]							
	1-2 Aug 2013				4-5 Aug 2014			
Systems	GG	HC	L	All	GG	HC	L	All
OMS[y]-1[x]	5.9	3.4	1.1	3.5 b[u]	5.9	3.1	7.8	5.6 b
OMS-2[w]	38.9	16.6	13.8	23.6 a	36.2	32.7	32.4	33.8 a
OMS-3[v]	3.8	11.9	3.5	6.4 b	2.4	3.3	1.1	2.3 b

[z] Assessment of all leaves in six terminal shoots on five three-tree replicates per cultivar per OMS

[y] OMS: Organic Management System

[x] OMS-1: Use of sulfur fungicides except for the 3-4 week period of rapid shoot elongation following petal fall stage. Dates of application for 2013: 18 Apr; 8 May; 15 May; 20 June; 27 June; 5 July; 12 July. Dates for 2014: 21 Apr; 28 Apr; 2 May; 8 May; 13 May; 20 May; 24 May; 3 July; 17 July; 1 Aug.

[w] OMS-2: Replaces use of sulfur fungicides with a combination of agricultural biostimulants. Each application included 0.23 kg·ha^{-1} kelp meal, 0.5% unsulfured organic molasses and 0.03% yucca extract emulsifier. Dates of application for 2013: 26 Apr (¼ inch green); 2 May (early pink); 21 May (petal fall); 27 May (first cover); 5 June; 13 June; 20 June; 27 June; 5 July; 12 July; 25 July; 7 Aug. Dates for 2014: 2 May (¼ inch green); 13 May (early pink); 24 May (petal fall); 5 June (first cover); 11 June; 20 June; 3 July; 17 July; 1 Aug; 15 Aug.

[v] OMS-3: Use of sulfur fungicides throughout the season. Liquid lime sulfur (LLS) was applied on 22 May 2013 at 18.7 L·ha^{-1} to provide post-infection apple scab management. Dates of application for 2013: 18 Apr; 8 May; 15 May; 21 May; 27 May; 5 June; 13 June; 20 June; 27 June; 5 July; 12 July. Dates of application for 2014: 21 Apr; 28 Apr; 2 May; 8 May; 13 May; 20 May; 24 May; 29 May; 11 June; 3 July; 17 July; 1 Aug.

[u] Means within columns followed by the same letter do not differ significantly at $p < 0.05$, Tukey-Kramer HSD; means in columns without letters are not significantly different from each other at $p < 0.05$, Oneway Analysis of Variance

Table 2.9. Fruit with arthropod damage at harvest on 'Ginger Gold' (GG), 'Honeycrisp' (HC), and 'Liberty' (L) in 2013 and 2014

2013 — Percent Incidence — Fruit [z]

	Plum curculio				Tarnished plant bug				San Jose scale				European apple sawfly			
Systems	GG	HC	L	All	GG	HC	L	All	GG	HC	L	All	GG	HC	L	All
OMS [y]-1 [x]	20.0	15.4	2.7	12.7 [u]	3.3	2.7	4.7	3.6	0.0 a	0.0 b	0.0 a	0.0 a	0.7	0.0	0.0	0.2
OMS-2 [w]	10.7	20.0	6.7	12.4	4.0	5.0	2.7	3.9	0.0 a	3.3 a	0.0 a	1.1 a	0.0	0.0	0.0	0.0
OMS-3 [v]	5.0	10.6	15.0	10.2	4.2	3.9	0.6	2.9	0.0 a	0.0 b	0.0 a	0.0 a	0.0	0.0	0.0	0.0

2014 — Percent Incidence — Fruit

	Plum curculio				Tarnished plant bug				San Jose scale				European apple sawfly			
Systems	GG	HC	L	All	GG	HC	L	All	GG	HC	L	All	GG	HC	L	All
OMS-1	25.3	42.3	8.9	25.5	3.6	9.5	3.3	5.5	0.0 a	3.0 ab	0.0 a	1.0 ab	0.0	0.7	0.0	0.2
OMS-2	15.7	43.6	14.8	23.3	17.1	5.0	5.7	9.6	0.0 a	18.6 a	0.7 a	5.6 a	0.7	0.0	0.0	0.2
OMS-3	38.1	19.1	2.7	19.9	17.6	4.7	2.3	8.2	0.0 a	0.0 b	0.0 a	0.0 b	0.0	1.0	0.0	0.3

[z] Assessment of 30 fruit from five three-tree replicates per cultivar per OMS. All fruit from each cultivar were harvested on the same date, dates of harvest varied by cultivar

[y] OMS: Organic Management System

[x] OMS-1: Use of sulfur fungicides except for the 3-4 week period of rapid shoot elongation following petal fall stage. Dates of application for 2013: 18 Apr; 8 May; 15 May; 20 June; 27 June; 5 July; 12 July. Dates for 2014: 21 Apr; 28 Apr; 2 May; 8 May; 13 May; 20 May; 24 May; 3 July; 17 July; 1 Aug.

[w] OMS-2: Replaces use of sulfur fungicides with a combination of agricultural biostimulants. Each application included 0.23 $kg \cdot ha^{-1}$ kelp meal, 0.5% unsulfured organic molasses and 0.03% yucca extract emulsifier. Dates of application for 2013: 26 Apr (¼ inch green); 2 May (early pink); 21 May (petal fall); 27 May (first cover); 5 June; 13 June; 20 June; 27 June; 5 July; 12 July; 25 July; 7 Aug. Dates for 2014: 2 May (¼ inch green); 13 May (early pink); 24 May (petal fall); 5 June (first cover); 11 June; 20 June; 3 July; 17 July; 1 Aug; 15 Aug.

[v] OMS-3: Use of sulfur fungicides throughout the season. Liquid lime sulfur (LLS) was applied on 22 May 2013 at 18.7 $L \cdot ha^{-1}$ to provide post-infection apple scab management. Dates of application for 2013: 18 Apr; 8 May; 15 May; 21 May; 27 May; 5 June; 13 June; 20 June; 27 June; 5 July; 12 July. Dates of application for 2014: 21 Apr; 28 Apr; 2 May; 8 May; 13 May; 20 May; 24 May; 29 May; 11 June; 3 July; 17 July; 1 Aug.

[u] Means within columns followed by the same letter do not differ significantly at $p < 0.05$, Tukey-Kramer HSD; means in columns without letters are not significantly different from each other at $p < 0.05$, Oneway Analysis of Variance

Table 2.10. Fruit with arthropod damage at harvest on 'Ginger Gold' (GG), 'Honeycrisp' (HC), and 'Liberty' (L) in 2013 and 2014 (continued)

	Percent Incidence[z]																				
	Fruit[y]																				
	Surface Lepidoptera					Internal Lepidoptera				Stink bug				RAA[x]				Apple maggot			
Systems	GG	HC	L	All		GG	HC	L	All	GG	HC	L	All	GG	HC	L	All	GG	HC	L	All
OMS[w]-1[v]	16.7	18.0	5.3	13.3	a[s]	0.7	5.6	1.3	2.5	1.3	0.7	0.0	0.7	0.7	0.0	0.0	0.2	0.0	0.0	0.0	0.0
OMS-2[u]	14.3	9.6	4.0	9.3	ab	2.0	1.3	1.3	1.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
OMS-3[t]	14.4	3.6	1.1	6.4	b	0.0	3.6	1.1	1.6	1.7	0.0	0.6	0.7	0.8	0.0	0.0	0.3	1.7	0.0	0.0	0.6

	2014																				
	Percent Incidence																				
	Fruit																				
	Surface Lepidoptera					Internal Lepidoptera				Stink bug				RAA				Apple maggot			
Systems	GG	HC	L	All		GG	HC	L	All	GG	HC	L	All	GG	HC	L	All	GG	HC	L	All
OMS-1	24.4	44.7	10.7	26.6	ab	10.2	2.0	7.6	6.6	0.0	0.7	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
OMS-2	22.4	18.7	3.3	14.5	b	9.0	2.5	0.7	4.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.7	0.2
OMS-3	21.6	64.8	20.0	35.5	a	20.4	1.7	7.9	10.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

[z] Oriental fruit moth was not detected in either year

[y] Assessment of 30 fruit from five three-tree replicates per cultivar per OMS. All fruit from each cultivar were harvested on the same date, dates of harvest varied by cultivar

[x] RAA: Rosy apple aphid

[w] OMS: Organic Management System

[v] OMS-1: Use of sulfur fungicides except for the 3-4 week period of rapid shoot elongation following petal fall stage. Dates of application for 2013: 18 Apr; 8 May; 15 May; 20 June; 27 June; 5 July; 12 July. Dates for 2014: 21 Apr; 28 Apr; 2 May; 8 May; 13 May; 20 May; 24 May; 3 July; 17 July; 1 Aug.

[u] OMS-2: Replaces use of sulfur fungicides with a combination of agricultural biostimulants. Each application included 0.23 $kg \cdot ha^{-1}$ kelp meal, 0.5% unsulfured organic molasses and 0.03% yucca extract emulsifier. Dates of application for 2013: 26 Apr (¼ inch green); 2 May (early pink); 21 May (petal fall); 27 May (first cover); 5 June; 13 June; 20 June; 27 June; 5 July; 12 July; 25 July; 7 Aug. Dates for 2014: 2 May (¼ inch green); 13 May (early pink); 24 May (petal fall); 5 June (first cover); 11 June; 20 June; 3 July; 17 July; 1 Aug; 15 Aug.

[t] OMS-3: Use of sulfur fungicides throughout the season. Liquid lime sulfur (LLS) was applied on 22 May 2013 at 18.7 $L \cdot ha^{-1}$ to provide post-infection apple scab management. Dates of application for 2013: 18 Apr; 8 May; 15 May; 21 May; 27 May; 5 June; 13 June; 20 June; 27 June; 5 July; 12 July. Dates of application for 2014: 21 Apr; 28 Apr; 2 May; 8 May; 13 May; 20 May; 24 May; 29 May; 11 June; 3 July; 17 July; 1 Aug.

[s] Means within columns followed by the same letter do not differ significantly at $p < 0.05$, Tukey-Kramer HSD; means in columns without letters are not significantly different from each other at $p < 0.05$, Oneway Analysis of Variance

Table 2.11. Fruit without arthropod pests and their damage on 'Ginger Gold' (GG), 'Honeycrisp' (HC), and 'Liberty' (L) at harvest in 2013 and 2014

	Percent Incidence							
	Fruit[z]							
	2013				2014			
Systems	GG	HC	L	All	GG	HC	L	All
OMS[y]-1[x]	64.0	63.2	86.0	71.1[u]	49.3	24.4	69.5	47.8
OMS-2[w]	73.3	65.7	87.3	75.5	42.5	29.1	79.6	51.9
OMS-3[v]	73.3	81.1	81.6	78.7	34.4	18.7	67.8	40.3

[z] Assessment of 30 fruit from five three-tree replicates per cultivar per OMS. All fruit from each cultivar were harvested on the same date, dates of harvest varied by cultivar

[y] OMS: Organic Management System

[x] OMS-1: Use of sulfur fungicides except for the 3-4 week period of rapid shoot elongation following petal fall stage. Dates of application for 2013: 18 Apr; 8 May; 15 May; 20 June; 27 June; 5 July; 12 July. Dates for 2014: 21 Apr; 28 Apr; 2 May; 8 May; 13 May; 20 May; 24 May; 3 July; 17 July; 1 Aug.

[w] OMS-2: Replaces use of sulfur fungicides with a combination of agricultural biostimulants. Each application included 0.23 $kg \cdot ha^{-1}$ kelp meal, 0.5% unsulfured organic molasses and 0.03% yucca extract emulsifier. Dates of application for 2013: 26 Apr (¼ inch green); 2 May (early pink); 21 May (petal fall); 27 May (first cover); 5 June; 13 June; 20 June; 27 June; 5 July; 12 July; 25 July; 7 Aug. Dates for 2014: 2 May (¼ inch green); 13 May (early pink); 24 May (petal fall); 5 June (first cover); 11 June; 20 June; 3 July; 17 July; 1 Aug; 15 Aug.

[v] OMS-3: Use of sulfur fungicides throughout the season. Liquid lime sulfur (LLS) was applied on 22 May 2013 at 18.7 $L \cdot ha^{-1}$ to provide post-infection apple scab management. Dates of application for 2013: 18 Apr; 8 May; 15 May; 21 May; 27 May; 5 June; 13 June; 20 June; 27 June; 5 July; 12 July. Dates of application for 2014: 21 Apr; 28 Apr; 2 May; 8 May; 13 May; 20 May; 24 May; 29 May; 11 June; 3 July; 17 July; 1 Aug.

[u] Means within columns followed by the same letter do not differ significantly at $p < 0.05$, Tukey-Kramer HSD; means in columns without letters are not significantly different from each other at $p < 0.05$, Oneway Analysis of Variance

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CHAPTER 3. JOURNAL ARTICLE

The non-target impacts of an organic disease management system containing biostimulants compared with two sulfur-based systems on phytophagous mite populations on the apple cultivar 'Zestar!' in Vermont

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Abstract

Disease management in organic apple orchards in Vermont is focused on controlling diseases with sulfur fungicides. The objective of this two year study was to evaluate the non-target effects of an organic disease management system containing agricultural biostimulants compared to two sulfur-based systems on phytophagous mite populations of the European red mite, *Panonychus ulmi* and two-spotted spider mite, *Tetranychus urticae*. Trees were arranged in a completely randomized design of five three-tree replications in a certified organic orchard. The two sulfur-based systems differed in the number of applications; in the third system, sulfur was replaced with biostimulants including pure neem oil, liquid fish, an activated microbial inoculant, and equisetum and stinging nettle teas. Each biostimulant application also included kelp meal, unsulfured organic molasses and yucca extract emulsifier. Leaf samples were evaluated for the number of motile phytophagous mites approximately every 14 days from 1 July through 26 August each year. Although not always significantly different from the sulfur-based systems, when there were differences, the biostimulant system had less mite incidence per leaf than one or both of the sulfur-based systems in both years. The difference in the number of sulfur sprays did not have a major effect on the mite populations. This research documents that the biostimulant system, which represents a novel management system for New England organic apple orchards, did not result in increased phytophagous mite populations and potentially may offer beneficial suppression compared to sulfur-based management systems. Before further adoption in commercial orchards, the targeted effects of the agricultural biostimulants on apple scab and other important diseases, in addition to the effects on insects, tree growth, yield, and fruit quality, must be evaluated.

Introduction

Apple scab [*Venturia inaequalis* (Cooke) Wint.] is the most challenging disease to manage in New England apple [*Malus sylvestris* (L.) Mill. var. *domestica* (Borkh.) Mansf.] orchards (MacHardy, 1996, 2000). Depending on weather and disease pressure, up to 15 protectant fungicide spray applications may be necessary to manage apple scab on susceptible apple cultivars (Ellis et al., 1998; Holb, 2005b; Jamar et al., 2010; MacHardy, 1996, 2000). Apple scab causes fruit and foliar lesions which when severe, can impact the health and vigor of the tree and lead to premature defoliation, decreased fruit yield and decreased fruit marketability (MacHardy, 1996; Sutton et al., 2014). Severe infections from this fungal disease can also increase susceptibility of the tree to winter injury and may impact fruit bud formation in the following season (MacHardy, 1996). Although the use of new scab-resistant cultivars can decrease the total number of fungicide sprays applied in the orchard during the growing season, many New England growers have been slow to replace 'McIntosh.' trees (Berkett and Cooley, 1989). The lack of organic orchards in New England can be partially attributed to the high susceptibility of the widely planted cultivar 'McIntosh' to apple scab (MacHardy, 2000). Although the use of scab-resistant cultivars can virtually eliminate the need for fungicide sprays for this pathogen, there are many other economically important fungal diseases in the orchard that require management. Disease management in organic apple orchards is currently reliant on OMRI-approved copper- and sulfur-based pesticides and although organic, these compounds are not without significant negative impacts (Ellis et al., 1998; Holb et al., 2003). In general, prolonged use of copper in various cropping systems has resulted in elevated levels in soils, impacting soil ecology and earthworm numbers

(Paoletti et al., 1998; Van Rhee, 1976). In apple, since the traditional formulations of copper can increase chances of phytoxicity after the phenological green tip stage, these formulations are limited to the silver tip phenological stage where it is used as a bactericide for the management of overwintering fire blight inoculum (Brown et al., 1996).

Sulfur and liquid lime sulfur remain the standard organic fungicides used to manage apple scab and other fungal diseases in the orchard (Ellis et al., 1991; Holb et al., 2003; MacHardy, 1996; Mills, 1947). Liquid lime sulfur, however, is highly caustic and its use can cause detrimental impacts on tree health, photosynthesis, pollen tube growth and can result in decreased fruit set and lowered yields (Burrell, 1945; Holb et al., 2003; MacHardy, 1996; McArtney et al., 2006; Mills, 1947; Palmer et al., 2003). The use of this caustic material later in the season can result in russetting and burning of the fruit, especially under hot, humid conditions (Holb et al., 2003; Noordijk and Schupp, 2003; Stopar, 2004). For these reasons, use of liquid lime sulfur is limited to curative sprays for apple scab after weather conditions conducive for infection have occurred (MacHardy and Gadoury, 1989; Penrose, 1995). Although wettable sulfur lacks post-infection activity, is a weaker protectant than liquid lime sulfur and can also impact photosynthesis, this material causes less phytotoxicity and consequently is the primary fungicide used in organic apple orchards (Holb and Heijne, 2001; Jamar et al., 2008, Palmer et al., 2003).

Sulfur fungicides can impact mite populations and have long been identified as general acaricides (Garman and Townsend, 1938; Lord, 1949; MacPhee and Sanford, 1954). Sulfur can have non-target effects on both beneficial and phytophagous mite populations in orchards and can impact predator to prey ratios in orchards. Since beneficial mites often occur in lower densities than phytophagous mites in orchards, the use of sulfur has a greater impact on the lower populations of predacious mites, causing the phytophagous mite numbers to flare (Beers and Hull, 1987; Beers et al., 2009; Blommers, 1994; Bower et al., 1995; Holdsworth, 1972; MacPhee and Sanford, 1954; van de Vrie, 1962).

Both the European red mite, *Panonychus ulmi* (Koch) and two-spotted spider mite, *Tetranychus uritcae* (Koch) are serious phytophagous mites in New England apple orchards and their feeding can cause off-color foliage and defoliation, reduce net photosynthesis and fruit quality and can impact future bud set and bloom (Beers and Hull, 1987, Beers et al., 2009; Hall and Ferree, 1975; Lienk, 1980; Nyrop et al., 1989). The European red mite is the most destructive mite species attacking New England apples and was listed as the second worst problem affecting apple production after apple scab in a recent survey of Northeast and Canadian researchers and crop consultants (Agnello, 2012). Studies have shown when populations of the predatory mite *Typhlodromus pyri* (Scheuten) are protected in orchards, the need for other acaricide controls can be eliminated (Agnello et al., 1994, 2003; Hardman et al., 1991; Prokopy et al., 1997).

Given the negative effects of sulfur fungicides on tree health and the potential impacts to predatory mites, growers and researchers are searching for suitable alternatives for disease control in the orchard. Novel disease resistance elicitors, used alone or in combination with fungicides, may offer new, low environmental-impact options for disease control. Plant chemical defenses can be present in the plant all the time or can be “induced” by an elicitor. The term ‘elicitor’ was originally used for compounds that would induce production of phytoalexins, but now the definition of elictor has broadened to any compound that stimulates any plant defense (Ebel and Cosio, 1994; Hahn, 1996; Thakur and Sohal, 2013). The term ‘agricultural biostimulant’ is often substituted for ‘elicitor’ when used in a field or agricultural setting. There are several studies demonstrating the successful use of agricultural biostimulants for suppression of diseases caused by several genera of pathogens in a wide variety of crops (Cherif et al., 1992; Elmer and Reglinski, 2006; French-Monar, 2010; Germar, 1934; Gillman et al., 2003; Kunoh and Ishizaki, 1975; Leusch and Buchenauer, 1989; Renard-Merlier et al., 2007; Rodgers-Gray and Shaw, 2004; Sun et al., 1994, 2002). In addition to triggering plant defenses, the use of agricultural biostimulants can also improve physiological responses in plants. Improved crop yields and quality, increased plant buffering capacities for temperature and drought extremes and improvements in plant nutrition have been noted in various crops following applications of various agricultural biostimulants (Botta, 2012; Calvo et al., 2014; Chen et al., 2003; Miller et al., 1990). The evidence showing positive benefits on a wide variety of crops continues to grow. (Chen et al., 2003; Lyon et al., 1995; Paul and Sharma, 2002). Agricultural biostimulants that show promise for organic production systems include humic acids, seaweed, silica and other plant extracts, chitinous products from fungal sources and oligiosaccharides (Aziz et al., 2006; Colavita et al., 2011; Craigie, 2010; French-Monar et al., 2010; Khan et al., 2009, Leusch and Buchenauer, 1989; Lyon et al., 1995; Norrie et al., 2002; Volk et al., 1958; Wu et al., 2005). Increased interest in using these materials may be partially driven by the loss of synthetic and/or organic chemical products available for arthropod and disease management.

The objective of this research was to evaluate the non-target effects of an organic disease management system containing biostiumulants compared with two sulfur-based systems on phytophagous mites on the apple cultivar ‘Zestar!’. The research is part of an overall evaluation of the target and non-target effects of these three organic management systems on diseases, pest and beneficial arthropods and tree growth, yield and fruit quality on three apple cultivars that are reported in separate articles.

Materials and Methods

The study was conducted at the University of Vermont Horticultural Research Center in South Burlington, VT, USA. The research orchard was planted in 2006 and certified organic in 2008. The planting includes five cultivars: ‘Ginger Gold’, ‘Liberty’, ‘Macoun’, ‘Honeycrisp’, and ‘Zestar!’. Three-tree plots of each cultivar were planted in a completely randomized design across eight rows at a tree spacing of 1.5 m X 4.6 m and trained to a vertical axis system. All cultivars were grafted on Budagovsky 9 (Bud. 9) dwarfing rootstock except ‘Honeycrisp’ which was on Malling 26 (M 26). The cultivar ‘Zestar!’ was used for this study (Figure 1. Research Plot Map).

Sprays were applied to five three-tree plots for each organic management system (OMS): OMS-1, OMS-2, and OMS-3. The OMS-1 treatment was based on the use of sulfur fungicides throughout the season except for the three to four week period of rapid shoot elongation following the petal fall phenological stage when no sulfur-based fungicides were applied. These were not applied due to sulfur’s potential cumulative negative effect on photosynthesis during this critical period of growth (Palmer et al., 2003). Palmer et al. found sulfur fungicides (lime sulfur and sulfur) had pronounced effects on leaf photosynthesis rate with the greatest effect after shoot growth had ended. The researchers hypothesized that several applications of sulfur over the course of the season or over several years may have a cumulative effect on leaf area and shoot growth. In OMS-2, the use of sulfur sprays was replaced with a combination of agricultural biostimulants throughout the growing season. OMS-3 was based on the use of sulfur fungicides throughout the season. Liquid lime sulfur was also a fungicide option in both OMS-1 and OMS-3 if its post-infection properties against apple scab infection were warranted. Because of limited orchard size, a 'non-treated' system could not be incorporated into the experimental design. OMS-3 is the standard organic management system applied by commercial organic apple growers in New England and serves as the control in this applied study. All materials used were OMRI-approved. The three systems were applied to the same trees over two consecutive growing seasons (2013, 2014) to assess multi-year non-target impacts on motile (all stages except egg) phytophagous mites.

Weather was monitored with a RainWise MK-III Weather Station (RainWise, Inc.; Trenton, ME) and networked to the Cornell University Network for Environmental and Weather Applications (NEWA, http://newa.cornell.edu/). NEWA output was used to determine apple scab infection periods, fire blight risk, and the risk of sooty blotch and flyspeck infection. This information, with apple phenological bud stages, was used to determine timing and frequency of spray applications.

Sprays were applied dilute to drip to the foliage with a 189-L hydraulic sprayer (Nifty Fifty; Rears Mfg. Co., Eugene, OR) with an attached handgun (Green Garde JD9-C; H.D. Hudson Mfg. Co., Chicago, IL) with an L tip at a pressure of 6.8 atm. Cupric hydroxide (Champ WG; NuFarm Americas, Inc., Burr Ridge, IL); and cupric hydroxide/cupric oxychloride (Badge SC; Gowan Products, Yuma, AZ) were applied at the silver tip phenological stage for fire blight management in OMS-1 and OMS-3 in 2013 and 2014, respectively (Tables 3.1 and 3.2). The fungicide used in OMS-1 and OMS-3 was micronized wettable sulfur (Microthiol Disperss; United Phosphorus, Inc., King of Prussia, PA). In 2013, OMS-3 also included one application of liquid lime sulfur (Miller's Liquid Lime Sulfur; Waynesboro, MS) to provide post-infection apple scab management after a heavy rain event (Table 3.1). Agricultural biostimulants in OMS-2 included pure neem oil (Ahimsa Organics Neem Oil: The Ahimsa Alternative, Inc., Bloomington, MN), liquid fish (OrganicGem Liquid Fish Fertilizer 3-3-0; Advanced Marine Technologies, New Bedford, MA), activated microbial inoculant (Dr. Higa's Original EM·1 Microbial Inoculant; TeraGanix, Alto, TX) plus equisetum (*Equisetum arvense*) and stinging nettle (*Urtica doica*) teas. Each of these applications also included kelp meal (SeaLife Kelp Meal; North American Kelp, Waldsboro, ME), unsulfured organic molasses and yucca extract emulsifier (Therm X-70; Cellu-Con, Inc., Strathmore, CA). Teas and the activated microbial inoculant were prepared according to protocols described in *The Holistic Orchard- Tree fruits and Berries the Biological Way* (Phillips, 2011). The OMS-2 sprays at ¼-½ inch green and early pink were applied to thoroughly wet branches, trunk and ground while the later sprays were applied only to the foliage

(Phillips, 2011). Tables 3.1 and 3.2 list dates of application and rates for 2013 and 2014, respectively, for the three management systems.

Organic insecticides were applied following a standard integrated pest management approach based on phenological bud stage plus arthropod scouting and monitoring. Materials were applied with a 756 L airblast sprayer (Pul-Blast 200; Rears Mfg Co., Eugene, OR) calibrated to deliver 543 $L \cdot ha^{-1}$ at a pressure of 13.6 atm with a tractor driven at 3 km/hour. All materials were applied to the entire orchard and included: kaolin clay (Surround WP; Tessenderlo Kerley, Inc., Phoenix, AZ), azadiractin (Aza-Direct Biological Insecticide; Gowan Co., Yuma, AZ), pyrethrin (PyGanic Crop Protection EC 5.0; MGK Company, Minneapolis, MN), granulosis virus (CYD-X Biological Insecticide; Certis USA L.L.C., Columbia, MD), *Bacillus thuringiensis* (Dipel DF; Valent USA Corp., Walnut Creek, CA) and spinosad (Entrust; Dow AgroSciences, L.L.C., Indianapolis, IN). In addition, horticultural oil (JMS Stylet oil; JMS Flower Farms, Inc., Vero Beach, FL) was applied to OMS-1 and OMS-3 following standard organic management procedures for arthropod management. OMS-2 did not receive an application of horticultural oil since it was not part of the Phillips program.

'Zestar!' leaf samples were evaluated for the number of motile phytophagous mites (combined numbers per leaf of European red mite and two-spotted spider mite) on five dates on a bi-weekly schedule throughout each growing season from 1 July through 26 August. Ten intermediate-age leaves were selected randomly from each of the trees in the five three-tree replicates at mid-canopy height encircling the tree. Leaves were immediately bagged, placed in a portable cooler in the field, refrigerated at 4^{o} C, and counted in the lab within two days (Bower et al., 1995; Nyrop, Pers. comm. 2013). The ten leaves collected from each tree in the five three-tree replicates were mite-brushed using the Leedom mite brusher (Leedom Enterprises; Mi Wuk Village, CA). The total number of motile (all stages except egg) phytophagous mites was counted for each tree.

Statistical Analysis

The primary hypothesis of this research was that the application of the organic agricultural biostimulant system would have non-target effects on the phytophagous mite populations on 'Zestar' when compared with the sulfur-based fungicides. A second hypothesis was that the number of sulfur applications would impact the phytophagous mite populations. Statistical analyses of data were performed with JMP 11 (SAS Institute; Cary, NC). Analysis of variance (ANOVA) was used to compare system effects. Significant differences between means were determined by using Tukey-Kramer HSD test ($P < 0.05$).

Results

On all except the first sampling date in 2013, OMS-2 had numerically the lowest mean number of mites per leaf and OMS-3 had the highest (Table 3.3). Although there was no significant difference among the systems on the first sampling date, on all subsequent dates OMS-2 had significantly less mites per leaf than one or both of the sulfur-based systems. Regarding the sulfur-based systems, only on the 29 July and 12 August sampling dates, were mite incidence significantly different between OMS-1 and OMS-3 with more mites observed on OMS-3. In general, mite numbers remained low in all systems until 29 July 2013, when the established economic threshold of five mites per leaf was exceeded in OMS-1 and OMS-3 (Cooley et al., 2014). The economic threshold represents the number of arthropods when the value of the crop destroyed equals the cost of controlling the pest (Stern et al., 1959). It is at this point the grower would intervene with a management tool, since exceeding this number results in crop losses. The following mite thresholds have been developed for use in New England apple orchards: 2.5 mites per leaf in June; 5 mites per leaf in July; and 7.5 mites per leaf for August (Cooley et al., 2014). The mite threshold was exceeded for all systems on 12 August.

In 2014, OMS-2 again had numerically the lowest mean number of mites per leaf across all sampling dates. However, depending on the sampling date, the incidence of mites was not significantly different from that observed in either OMS-1 or OMS-3No statistical differences in mite numbers were detected between OMS-1 and OMS-3 on any date. The established mite threshold was reached by the 29 July sampling date in OMS-1 and OMS-3 and then decreased below the threshold on the subsequent sampling dates. The number of mites in OMS-2 never exceeded the established mite thresholds in 2014.

Discussion

In both 2013 and 2014, there were differences in phytophagous mite incidence among the organic disease management systems. Although not always significantly different from the other two systems, OMS-2 had the lowest mean number of phytophagous mites per leaf on all except the first sampling date inthe first year. Research has shown that when there are high populations of phytophagous mites coupled with the absence of predatory mites, the cause is typically linked to use of pesticides that are toxic to the predator (Krieter et al., 1998; Nyrop et al., 1998). Since predatory mites were not assessed in this study conducted on 'Zestar' trees, it cannot be determined whether the lower population of phytophagous mites in OMS-2 is linked to the survival of higher numbers of predacious mites in that system when compared with the sulfur-based systems. However, in the larger orchard study when predacious mites were assessed on vegetative terminals of 'Ginger Gold', 'Honeycrisp' and Liberty', few predacious *T. pyri* were found on foliage in any of the three systems in either year which would indicate that predacious mite populations were not a significant factor in explaining the different levels of phytophagous mites among the systems. Because of limited orchard size and since it is not a 'realistic' system of orchard management, the experimental design did not include a system of 'non-treated' trees. Therefore, it cannot be determined if predacious mite populations would be higher on non-treated trees compared to the trees in the three management systems under investigation, and whether the subsequent phytophagous mite populations would be lower.

The lower levels of phytophagous mites in OMS-2 compared to OMS-1 and/or OMS-3 may be due to direct effects of the agricultural biostimulants. Components of OMS-2 have demonstrated mite suppression in other research. Neem-based products have shown miticidal effects and repellency of mites in several studies (Mansour et al., 1997; Sundarum and Sloane, 1995). However, a recent University of Vermont study examining the non-target effects of organic fungicides in apple orchards, found the use of neem had no effect on populations of European red mites or two-spotted spider mites in the first year of a two-year study, but two-spotted spider mites were lower in the second year on neem treated trees compared to sulfur/lime sulfur treated trees (Cromwell et al., 2011). There are a limited number of studies showing suppression of mites with kelp meal or seaweed extracts in certain crops. One study in the U.K. showed applications reduced populations of two-spotted spider mites in high tunnel strawberries (Hankins and Hockey, 1990). A greenhouse study in West Virginia on bean plants showed seaweed extracts sprays reduced the predator to prey ratio of two-spotted spider mites *T. urticae* and the predator mite, *A. fallacis* (Hamstead, 1970). However, a recent study in Vermont showed seaweed extracts had no effect on phytophagous or predacious mites in apples (Bradshaw et al., 2013).

Since sulfur has been reported to have general acaricidal properties, fewer phytophagous mites might be expected in the system having more sulfur sprays, especially in the absence of predatory mites in the orchard (Collyer and Kirby, 1959; Garman and Townsend, 1938; Lord, 1949; MacPhee and Sanford, 1954). In OMS-3, sulfur fungicides were applied throughout the growing season resulting in 10 sulfur applications in 2013 (plus one lime sulfur application) and 11 sulfur applications in 2014. OMS-1 included sulfur fungicides throughout the season except for the three to four week period of rapid shoot growth following the petal fall phenological stage when no sulfur-based fungicides were used. This resulted in OMS-1 having six sulfur applications in 2013 and nine sulfur applications in 2014. However, out of the total of 10 sampling dates across the two years, only two dates (i.e., 29 July 2013 and 12 Aug 2013) had statistical differences in mean number of phytophagous mites per leaf, with OMS-3 having a higher mean number. The difference in the number of sulfur sprays between the two systems did not appear to have a major effect on the phytophagous mite populations. Although horticultural orticultural oil was used to reduce overwintering mite populations in OMS-1 and OMS-3 resulting.

The agricultural biostimulants and the sulfur fungicides in the systems may have impacted foliar characteristics, rendering the leaves more or less suitable to sustain phytophagous mite populations. No phytotoxicity (non-specific, unidentified nectrotic areas not resembling frog-eye leafspot) to foliage was noted in any of the three management systems in either year and thus, was not a factor in the subsequent phytophagous mite populations that developed (Hazelrigg, 2015). The amount of foliar disease has been shown to influence mite populations. A study in Ireland found that a higher incidence of apple scab on the foliage resulted in lower populations of phytophagous mites, likely due to the lower palatability of the foliage (Cuthbertson and Murchie, 2003). In the larger, concurrent orchard study in 2013 and 2014 on different cultivars, significant difference in scab incidence among the systems was only observed on ‘Ginger Gold’ trees and when differences were detected, incidence and severity were higher in OMS-2 than on one or both of the sulfur-based systems. Since results were variable among cultivars in the larger orchard study and apple scab was not assessed in the cultivar used in this mite study, no conclusions can be drawn regarding the impact of scab on phytophagous mite populations (Hazelrigg, 2015).

Phytophagous mite populations can also be correlated to nitrogen content of the apple foliage (Hamstead and Gould, 1957; Papp et al., 2000; Rodriguez, 1952). Nitrogen deficiency in apple leaf disks was shown to affect oviposition, fecundity, and weight of female *T. urticae* mites (Wermelinger et al., 1985). The study noted a 50% reduction in nitrogen resulted in a tenfold decline in fecundity of *T. urticae*. Increased rate of reproduction of *P.ulmi* was also noted on apple with higher nitrogen levels (van de Vrie and Boersma, 1970). However, the foliar nitrogen in the orchard of each of the three systems was within the optimum range for nitrogen according to regional recommendations (Stiles and Reid, 1991).

Although there were design limitations in this study, the research documents OMS-2, comprised of agricultural biostimulants and representing a novel management system for New England organic apple orchards, did not result in increased phytophagous mite populations compared to more traditional sulfur-based management systems in either year and when differences among the systems were observed, incidence of phytophagous mites were lower in OMS-2 compared to the sulfur-based systems. It is also important to note that the difference in the number of sulfur sprays between the two sulfur-based systems did not appear to have a major effect on the phytophagous mite populations. Before further adoption in commercial orchards, the targeted effects of the agricultural biostimulants on apple scab and other important diseases, in addition to the non-target effects on pest and beneficial arthropods, tree growth, yield and fruit quality must be thoroughly evaluated.

Table 3.1. Organic management system (OMS) application materials, rates and timing in 2013

	Application materials and rates								
	OMS -1 [z]		OMS -2 [y]					OMS -3 [x]	
Application Timing	Cupric hydroxide $kg{\cdot}ha^{-1}$	Micronized wettable sulfur $kg{\cdot}ha^{-1}$	Pure Neem oil %	Liquid fish %	Activated microbial inoculant %	*Equisetum arvense* tea %	*Urtica dioica* tea %	Cupric hydroxide $kg{\cdot}ha^{-1}$	Micronized wettable sulfur $kg{\cdot}ha^{-1}$
18 Apr	11.2							11.2	
26 Apr			1.0	4.0	1.0				
2 May			0.5	2.0	1.0				
8 May		16.8							16.8
15 May		16.8							16.8
21 May			0.5	2.0	1.0				11.2
22 May									* LLS
27 May			0.5	2.0	1.0	5.0	5.0		11.2
5 Jun			0.5		1.0	5.0	5.0		11.2
13 Jun			0.5		1.0	5.0	5.0		11.2
20 Jun		11.2	0.5		1.0	5.0	5.0		11.2
27 Jun		11.2	0.5		1.0	5.0	5.0		11.2
5 Jul		11.2	0.5		1.0	5.0	5.0		11.2
12 Jul		11.2	0.5		1.0	5.0	5.0		11.2
25 Jul			0.5		1.0	5.0	5.0		
7 Aug			0.5		1.0	5.0	5.0		

[z] OMS-1: Use of sulfur fungicides except for the 3-4 week period of rapid shoot elongation following petal fall stage. Dates of application for 2013: 18 Apr; 8 May; 15 May; 20 June; 27 June; 5 July; 12 July

[y] OMS-2: Replaces use of sulfur fungicides with a combination of agricultural biostimulants. Each application included 0.23 $kg{\cdot}ha^{-1}$ kelp meal, 0.5% unsulfured organic molasses and 0.03% yucca extract emulsifier. Dates of application for 2013: 26 Apr (¼-inch green); 2 May (early pink); 21 May (petal fall); 27 May (first cover); 5 June; 13 June; 20 June; 27 June; 5 July; 12 July; 25 July; 7 Aug.

[x] OMS-3: Use of sulfur fungicides throughout the season. Liquid lime sulfur (*LLS) was applied on 22 May 2013 at 18.7 $L{\cdot}ha^{-1}$ to provide post-infection apple scab management. Dates of application for 2013: 18 Apr; 8 May; 15 May; 21 May; 27 May; 5 June; 13 June; 20 June; 27 June; 5 July; 12 July

Table 3.2. Organic management system (OMS) application materials, rates and timing in 2014

	Application materials and rates								
	OMS -1 [z]		OMS -2 [y]					OMS -3 [x]	
Application Timing	Cupric hydroxide/ oxychloride $kg{\cdot}ha^{-1}$	Micronized wettable sulfur $kg{\cdot}ha^{-1}$	Pure Neem oil %	Liquid fish %	Activated microbial inoculant %	*Equisetum arvense* tea %	*Urtica dioica* tea %	Cupric hydroxide/ oxychloride $kg{\cdot}ha^{-1}$	Micronized wettable sulfur $kg{\cdot}ha^{-1}$
21 Apr	7.9							7.9	
28 Apr		11.2							11.2
2 May		11.2	1.0	4.0	1.0				11.2
8 May		11.2							11.2
13 May		11.2	0.5	2.0	1.0				11.2
20 May		11.2							11.2
24 May		11.2	0.5	2.0	1.0				11.2
29 May									11.2
5 Jun			0.5	2.0	1.0	5.0	5.0		
11 Jun			0.5		1.0	5.0	5.0		11.2
20 Jun			0.5		1.0	5.0	5.0		
3 Jul		11.2	0.5		1.0	5.0	5.0		11.2
17 Jul		11.2	0.5		1.0	5.0	5.0		11.2
17 Jul		11.2	0.5		1.0	5.0	5.0		11.2
15 Aug			0.5		1.0	5.0	5.0		

[z] OMS-1: Use of sulfur fungicides except for the 3-4 week period of rapid shoot elongation following petal fall stage. Dates of application for 2014: 21 Apr; 28 Apr; 2 May; 8 May; 13 May; 20 May; 24 May; 3 July; 17 July; 1 Aug.

[y] OMS-2: Replaces use of sulfur fungicides with a combination of agricultural biostimulants. Each application included 0.23 $kg{\cdot}ha^{-1}$ kelp meal, 0.5% unsulfured organic molasses and 0.03% yucca extract emulsifier. Dates of application for 2014: 2 May (¼-inch green); 13 May (early pink); 24 May (petal fall); 5 June (first cover); 11 June; 20 June; 3 July; 17 July; 1 Aug; 15 Aug.

[x] OMS-3: Use of sulfur fungicides throughout the season. Dates of application for 2014: 21 Apr; 28 Apr; 2 May; 8 May; 13 May; 20 May; 24 May; 29 May; 11 June; 3 July; 17 July; 1 Aug.

Table 3.3. Mean number of motile phytophagous mites (European red mite and two-spotted spider mite data combined) per leaf on 'Zestar' intermediate-age leaves on five dates in 2013 and 2014

	Mite incidence (mean number per leaf) [z]									
	Sampling Date									
	2013					2014				
Systems	1 Jul	15 Jul	29 Jul	12 Aug	26 Aug	1 Jul	15 Jul	29 Jul	12 Aug	26 Aug
OMS [y]-1 [x]	0.1 a	1.0 ab	6.1 b	20.8 b	18.4 a [u]	2.1 a	3.4 a	5.6 ab	4.6 a	7.2 a
OMS-2 [w]	0.1 a	0.6 b	4.4 b	9.2 b	5.2 b	0.4 b	1.5 a	2.2 b	2.0 a	2.1 b
OMS-3 [v]	0.1 a	1.7 a	11.2 a	27.9 a	20.9 a	1.5 ab	3.6 a	6.9 a	5.4 a	5.4 ab

[z] Assessment of ten leaves per tree on five three-tree replicates per system

[y] OMS: Organic Management System

[x] OMS-1: Use of sulfur fungicides except for the 3-4 week period of rapid shoot elongation following petal fall stage. Dates of application for 2013: 18 Apr; 8 May; 15 May; 20 June; 27 June; 5 July; 12 July. Dates for 2014: 21 Apr; 28 Apr; 2 May; 8 May; 13 May; 20 May; 24 May; 3 July; 17 July; 1 Aug.

[w] OMS-2: Replaces use of sulfur fungicides with a combination of agricultural biostimulants. Each application included 0.23 kg.ha-1 kelp meal, 0.5% unsulfured organic molasses and 0.03% yucca extract emulsifier. Dates of application for 2013: 26 Apr (¼ inch green); 2 May (early pink); 21 May (petal fall); 27 May (first cover); 5 June; 13 June; 20 June; 27 June; 5 July; 12 July; 25 July; 7 Aug. Dates for 2014: 2 May (¼ inch green); 13 May (early pink); 24 May (petal fall); 5 June (first cover); 11 June; 20 June; 3 July; 17 July; 1 Aug; 15 Aug.

[v] OMS-3: Use of sulfur fungicides throughout the season. Liquid lime sulfur (LLS) was applied on 22 May 2013 at 18.7 L.ha-1 to provide post-infection apple scab management. Dates of application for 2013: 18 Apr; 8 May; 15 May; 21 May; 27 May; 5 June; 13 June; 20 June; 27 June; 5 July; 12 July. Dates of application for 2014: 21 Apr; 28 Apr; 2 May; 8 May; 13 May; 20 May; 24 May; 29 May; 11 June; 3 July; 17 July; 1 Aug.

[u] Means within columns followed by the same letter do not differ significantly at $p < 0.05$, Tukey-Kramer HSD; means in columns without letters are not significantly different from each other at $p < 0.05$, Oneway Analysis of Variance

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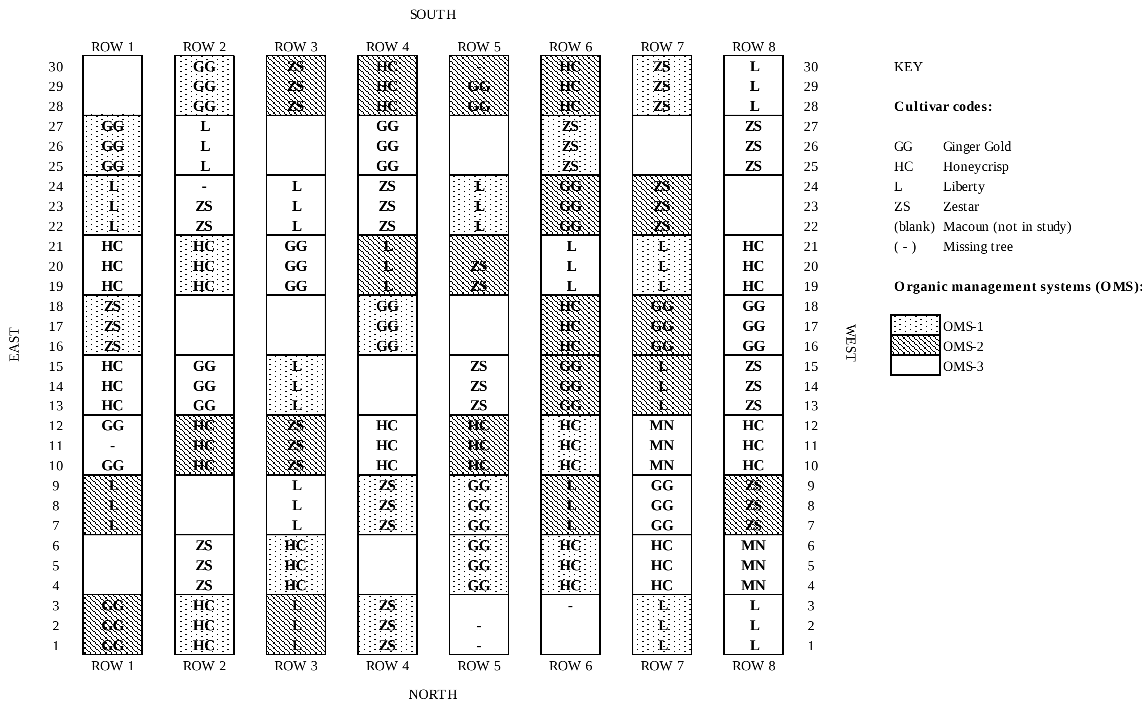
APPENDICES

Appendix A: Research Plot Map



2013 research plot map of cultivars and organic management systems (OMS) in OrganicA Orchard 1, University of Vermont Horticulture Research Center, South Burlington, VT

Appendix B: USDA Apple Grading Standards

United States Standards for Grades of Apples

Effective December 19, 2002

Compiled from:
http://www.ams.usda.gov/AMSv1.0/getfile?dDocName=STELPRDC5050339

Grades

§51.300 U.S. Extra Fancy.

"U.S. Extra Fancy" consists of apples of one variety (except when more than one variety is printed on the container) which are mature but not overripe, clean, fairly well formed, free from decay, internal browning, internal breakdown, soft scald, scab, freezing injury, visible water core, and broken skins. The apples are also free from injury caused by bruises, brown surface discoloration, smooth net-like russeting, sunburn or sprayburn, limb rubs, hail, drought spots, scars, disease, insects, or other means. The apples are free from damage caused by bitter pit or Jonathan spot and by smooth solid, slightly rough or rough russeting, or stem or calyx cracks, as well as damage by invisible water core after January 31st of the year following the year of production except for the Fuji variety of apples. Invisible water core shall not be scored against the Fuji variety of apples under any circumstances. For the apple varieties listed in Table I of §51.305, each apple of this grade has the amount of color specified for the variety. (See §§51.305 and 51.306.)

§51.301 U.S. Fancy.

"U.S. Fancy" consists of apples of one variety (except when more than one variety is printed on the container) which are mature but not overripe, clean, fairly well formed, and free from decay, internal browning, internal breakdown, soft scald, freezing injury, visible water core, and broken skins. The apples are also free from damage caused by bruises, brown surface discoloration, russeting, sunburn or sprayburn, limb rubs, hail, drought spots, scars, stem or calyx cracks, disease, insects, bitter pit, Jonathan spot, or damage by other means, or invisible water core after January 31st of the year following the year of production, except for the Fuji variety of apples. Invisible water core shall not be scored against the Fuji variety of apples under any circumstances. For the apple varieties listed in Table I of §51.305, each apple of this grade has the amount of color specified for the variety. (See §§51.305 and 51.306.)

§51.302 U.S. No. 1.

"U.S. No. 1" consists of apples which meet the requirements of U.S. Fancy grade except for color, russeting, and invisible water core. In this grade, less color is required for all varieties listed in Table I of §51.305. Apples of this grade are free from excessive damage caused by russeting which means that apples meet the russeting requirements for U.S. Fancy as defined under the definitions of "damage by russeting," except the aggregate area of an apple which may be covered by smooth net-like russeting shall not exceed 25 percent; and the aggregate area of an apple which may be covered by smooth solid russeting shall not exceed 10 percent: Provided, That, in the case of the Yellow Newtown or similar varieties, the aggregate area of an apple which may be covered with smooth solid russeting shall not exceed 20 percent. Each apple of this grade has the amount of color specified in §51.305 for the variety. Invisible water core shall not be scored in this grade. (See §§51.305 and 51.306.)

§51.303 U.S. Utility.

"U.S. Utility" consists of apples of one variety (except when more than one variety is printed on the container) which are mature but not overripe, not seriously deformed and free from decay, internal browning, internal breakdown, soft scald, and freezing injury. The apples are also free from serious damage caused by dirt or other foreign matter, broken skins, bruises, brown surface discoloration, russeting, sunburn or sprayburn, limb rubs, hail, drought spots, scars, stem or calyx cracks, visible water core, bitter pit or Jonathan spot, disease, insects, or other means. (See §51.306.)

§51.304 Combination grades.

(a) Combinations of the above grades may be used as follows:

(1) Combination U.S. Extra Fancy and U.S. Fancy;

(2) Combination U.S. Fancy and U.S. No. 1; and

(3) Combination U.S. No. 1 and U.S. Utility.

(b) Combinations other than these are not permitted in connection with the U.S. apple grades. When Combination grades are packed, at least 50 percent of the apples in any lot shall meet the requirements of the higher grade in the combination. (See §51.306.)

§51.305 Color requirements.

In addition to the requirements specified for the grades set forth in §§51.300 to 51.304, apples of these grades shall have the percentage of color specified for the variety in

Table I appearing in this Section (not included in this Appendix because no varieties in the study orchard were included in the table). All apple varieties other than those appearing in Table I shall have no color requirements pertaining to these grades. For the solid red varieties, the percentage stated refers to the area of the surface which must be covered with a good shade of solid red characteristic of the variety: Provided, That an apple having color of a lighter shade of solid red or striped red than that considered as a good shade of red characteristic of the variety may be admitted to a grade, provided it has sufficient additional area covered so that the apple has as good an appearance as one with the minimum percentage of good red characteristic of the variety required for the grade. For the striped red varieties, the percentage stated refers to the area of the surface in which the stripes of a good shade of red characteristic of the variety shall predominate over stripes of lighter red, green, or yellow. However, an apple having color of a lighter shade than that considered as a good shade of red characteristic of the variety may be admitted to a grade, provided it has sufficient additional area covered so that the apple has as good an appearance as one with the minimum percentage of stripes of a good red characteristic of the variety required for the grade. Faded brown stripes shall not be considered as color.

(A) Color standards USDA Visual Aid APL-CC-1 (Plates a - e) consists of a folder containing the color requirements for apples set forth in this section and five plates illustrating minimum good shade of solid red or striped red color, minimum compensating color and shade not considered color, for the following 12 varieties: Red Delicious, Red Rome, Empire, Idared, Winesap, Jonathan, Stayman, McIntosh, Cortland, Rome Beauty, Delicious, and York.

These color standards will be available for examination and purchasing information in the Fresh Products Branch, Fruit and Vegetable Programs, AMS, U.S. Department of Agriculture, South Building, Washington, D.C. 20250; in any field office of the Fresh Products Branch; or upon request of any authorized inspector of the Fresh Fruit and Vegetable Inspection Service.

§51.306 Tolerances.

In order to allow for variations incident to proper grading and handling in each of the grades in 51.300, 51.301, 51.302, 51.303, and 51.304 the following tolerances are provided as specified:

(a) Defects:

(1) U.S. Extra Fancy, U.S. Fancy, U.S. No. 1, and U.S. No. 1 Hail grades: 10 percent of the apples in any lot may fail to meet the requirements of the grade, but not more than one-half of this amount, or 5 percent, shall be allowed for apples which are seriously

damaged, including therein not more than 1 percent for apples affected by decay or internal breakdown.

(2) U.S. Utility grade: 10 percent of the apples in any lot may fail to meet the requirements of the grade, but not more than one-half of this amount, or 5 percent, shall be allowed for apples which are seriously damaged by insects, and including in the total tolerance not more than 1 percent for apples affected by decay or internal breakdown.

(b) When applying the foregoing tolerances to Combination grades, no part of any tolerance shall be allowed to reduce, for the lot as a whole, the 50 percent of apples of the higher grade required in the combination, but individual containers shall have not less than 40 percent of the higher grade.

(c) Size: When size is designated by the numerical count for a container, not more than 10 percent of packages in the lot may fail to be fairly uniform. When size is designated by minimum or maximum diameter, not more than 5 percent of the apples in any lot may be smaller than the designated minimum, and not more than 10 percent may be larger than the designated maximum. "Fairly uniform" means the size of the fruit within the container does not vary more than ½ inch diameter from the smallest to largest fruit.

Definitions

§51.312 Mature.

"Mature" means that the apples have reached the stage of development which will insure the proper completion of the ripening process. Before a mature apple becomes overripe it will show varying degrees of firmness, depending upon the stage of the ripening process. The following terms are used for describing different stages of firmness of apples:

(a) "Hard" means apples with a tenacious flesh and starchy flavor.

(b) "Firm" means apples with a tenacious flesh but which are becoming crisp with a slightly starchy flavor, except the Delicious variety.

(c) "Firm ripe" means apples with crisp flesh except that the flesh of the Gano, Ben Davis, and Rome Beauty varieties may be slightly mealy.

(d) "Ripe" means apples with mealy flesh and soon to become soft for the variety.

§51.313 Overripe.

"Overripe" means apples which have progressed beyond the stage of ripe, with flesh very mealy or soft, and past commercial utility.

§51.314 Clean.

“Clean” means that the apples are free from excessive dirt, dust, spray residue, and other foreign material.

§51.315 Fairly well formed.

“Fairly well formed” means that the apple may be slightly abnormal in shape but not to an extent which detracts materially from its appearance.

§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) Russeting 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 russeting. Smooth net-like russeting 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 russeting shows no very pronounced contrast with the background color of the apple, or lesser amounts of more conspicuous net-like russeting 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 russeting.

(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) Russeting 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 russeting, except that excessively rough or bark-like russeting 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 russeting outside of the stem cavity or calyx basin shall be considered as damage:

(1) Russeting which is excessively rough on Roxbury Russet and other similar varieties.

(2) Smooth net-like russeting, when an aggregate area of more than 15 percent of the surface is covered, and the color of the russeting shows no very pronounced contrast with the background color of the apple, or lesser amounts of more conspicuous net-like russeting when the appearance is affected to a greater extent than the amount permitted above.

(3) Smooth solid russeting, when an aggregate area of more than 5 percent of the surface is covered, and the pattern and color of the russeting shows no very pronounced contrast with the background color of the apple, or lesser amounts of more conspicuous solid russeting when the appearance is affected to a greater extent than the above amount permitted.

(4) Slightly rough russeting which covers an aggregate area of more than one-half inch in diameter.

(5) Rough russeting 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 russeting.

(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 russeting.

(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 russeting shall be considered as serious damage:

(1) Smooth solid russeting, when more than one-half of the surface in the aggregate is covered, including any russeting in the stem cavity or calyx basin, or slightly rough, or excessively rough or bark-like russeting, which detracts from the appearance of the fruit to a greater extent than the amount of smooth solid russeting permitted: Provided, That any amount of russeting shall be permitted on Roxbury Russet and other similar varieties.

(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 ⅛ 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 (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.

§51.319 Seriously deformed.

“Seriously deformed” means that the apple is so badly misshapen that its appearance is seriously affected.