Journal of the American Pomological Society 69(3): 118-136 2015

Management Strategies for *Phytophthora rubi* and *Pratylenchus penetrans* in Floricane Red Raspberry *(Rubus idaeus L.)*

Rachel E. Rudolph[1] and Lisa W. DeVetter[2, 3]

Additional index words: root lesion nematode, root rot, fumigation alternatives, replant disease, soilborne disease

Abstract

Red raspberry is a valuable crop throughout the world with the majority of production occurring in Russia, Poland, and the United States. In recent years, however, the longevity and health of red raspberry plantings have declined. *Phytophthora rubi* and *Pratylenchus penetrans* are common problematic organisms in red raspberry production and contribute to reduced plant vigor, yield, and overall survival. While chemical soil fumigation is a typical treatment for such organisms, there is growing awareness and interest in other soil management strategies among raspberry growers. Potential pre-plant and post-plant methods for managing *P. rubi* and *P. penetrans* include use of resistant cultivars, cover cropping and living mulches, brassicaceous seed meal and biofumigation, soil solarization, anaerobic soil disinfestation, antagonistic microorganisms, and removal of infected plant material. Many of these practices have been shown to be effective in the management of a diversity of soilborne pathogens and plant-parasitic nematodes. This review will discuss the current practices and new techniques that may have application in floricane red raspberry.

Red raspberry (*Rubus idaeus* L.) is a perennial crop that presents many unique production challenges to growers. On average, it takes three years after planting for raspberry to reach full production potential, making the crop a long-term investment (Hummer and Hall, 2013). Canes must be intensively managed in order to maximize yield and fruit quality, both during the growing season and during winter dormancy. When managed well and grown in the proper climate and soil conditions, raspberry plants may be productive for 12 years or longer (Hummer and Hall, 2013).

Raspberry is commercially produced in various regions around the world, including Russia, Eastern Europe, Mexico, United Kingdom, Canada, and the United States (FAO, 2013). The top three raspberry producing countries include Russia (143,000 t), Poland (121,000 t), and the United States (91,300 t; FAO, 2013). In the United States, California, Washington, and Oregon are the highest raspberry producing states, followed by Michigan, Pennsylvania, New York, and Ohio. In 2013, Oregon and Washington together produced over 33,000 t of red raspberry, which was valued at nearly $64 million (USDA-NASS, 2014). Washington alone produced over 93% of the red raspberry for processing in the United States (USDA-NASS, 2014). In Canada, British Columbia accounts for most of the commercial raspberry production in the country, with yields ranging from 11,000 t to 20,000 t depending on the hectares planted, growing conditions, and extent of winter injury (Province of B.C., 2013). Oregon, Washington, and British Columbia make up what is known as the Pacific Northwest (PNW), a major red raspberry producing area of the world. Although the total land area in raspberry production has increased in California, Washington, and Oregon, yields per hectare have shown a downward trend (USDA-ERS, 2014). In recent years, red raspberry plant survival in

[1] Graduate research assistant, Department of Horticulture, Washington State University
[2] Assistant professor, Department of Horticulture, Washington State University
[3] To whom reprint requests should be addressed; email lisa.devetter@wsu.edu

the PNW has declined. One possible explanation is replant disorder.

Replant disorder, also known as replant syndrome or replant disease, is of growing concern across the nation and the world for several crop species (Merwin et al., 2001). It is a term used to describe a combination of factors that affect the growth, development, yield, and general health of new plants that have been planted in sites shortly after removing the old crop of the same species. These factors may be both biotic and abiotic, including the presence of pathogenic fungi, bacteria, and nematodes, improper pH, moisture stress, and soil nutrient deficiency (Merwin et al., 2001). This disorder has been observed in many different perennial crops, such as apple, grape, strawberry, almond, and raspberry (Mazzola and Manici, 2012; Merwin et al., 2001; Seigies and Pritts, 2006; Szczygiel and Rebandel, 1988; Walters et al., 2011). Because replant disorder does not result from one single factor, there is no single, cure-all treatment (Merwin et al., 2001).

Severe pressure from soilborne pathogens and plant-parasitic nematodes, such as *Phytophthora rubi* Wilcox and Duncan and *Pratylenchus penetrans* (Cobb) Filipjev and Schuurmans Stekhoven, respectively, has been shown to contribute to reduced raspberry vigor, yield decline, and economic losses and are likely a significant part of the replant disorder complex (McElroy, 1977; Pinkerton et al., 2009). Infection by *P. rubi* begins with the zoospores, which are spores capable of moving in water that are produced in saturated, poorly draining soil. Zoospores attach to roots, leading to infection and colonization. Infected plants wilt and eventually may die due to reduced root function or root death (Funt, 2013). *Phytophthora rubi* has been shown to persist in raspberry fields as resting oospores or mycelia in infected plant material, limiting disease control options and efficacy (Pinkerton et al., 2002). *Phytophthora rubi* is genetically very similar to *Phytophthora fragariae* Hickman, which is a common pathogen of strawberry (*Fragaria* x *ananassa* Duch.; Wilcox et al., 1993). Therefore, many results related to *P. fragariae* in strawberry may be applicable to *P. rubi* in raspberry.

A survey of 10 representative raspberry fields in Whatcom and Skagit counties in Washington found *P. rubi* and *P. penetrans* in the sampled soil and roots at all locations (Gigot et al., 2013a). *Phytophthora rubi*, which causes Phytophthora root rot, is the most important known soilborne pathogen for Washington red raspberry (Walters et al., 2011) and the most serious pathogen affecting raspberry roots worldwide (Funt, 2013). In fact, field surveys and genetic analyses reveal that *P. rubi* may be an endemic pathogen to the PNW (Gigot et al., 2013a; Stewart et al., 2014). Additionally, *P. rubi* isolates were identified from 65% of the 20 New York farms that were surveyed with declining raspberry plants (Wilcox, 1989). In Chile, *P. rubi* was recovered from 50% of the 18 red raspberry plantations that were surveyed (Wilcox and Latorre, 2002).

Pratylenchus penetrans, also known as root lesion nematode (RLN), is another major pest of red raspberry (McElroy, 1992). This plant-parasitic nematode is an endoparasite that migrates between plant roots and the soil. Root lesion nematode feeds on raspberry roots, reducing uptake of nutrients and water (McElroy, 1992). Plants severely infected with RLN have been shown to decline rapidly, often causing growers to remove them only three or four years after being planted (Walters et al., 2009, 2011). Root rot problems can be intensified by RLN feeding, with wounded roots and weakened plants being more susceptible to other pathogens that contribute to replant disorder (Chitwood, 2003; Pscheidt and Ocamb, 2014). To date, the potential contribution of these nematodes to the replant disease complex has not been extensively characterized.

Although red raspberry can be found on every continent, except Antarctica, it remains a relatively minor crop in agriculture (Funt and Hall, 2013) and research addressing the effective management of soilborne pathogens and nematodes has been relatively limited. The purpose of this paper is to review the management strategies currently utilized for red raspberry and identify possible new methods of management of two problematic soilborne organisms, *P. rubi* and RLN.

Chemical Fumigants, Fungicides, and Nematicides

Soil fumigation is commonly used to manage soilborne pathogens and nematodes among raspberry growers (Walters, 2011). Most growers who decide to remove heavily infested raspberry plantings will typically mow and cultivate the plant residue into the soil and then fumigate fields in the fall or spring before replanting. Although fumigation can help delay disease onset for a few years, it cannot completely eliminate the causal pathogen or nematodes responsible for disease (PNW Extension, 2007). There are also restrictions associated with many fumigants, such as buffer zones, posting requirements, worker protective equipment, and fumigant management plans (Health Canada, 2012; US-EPA, 2014). Buffer zones, in particular, have proven to be challenging for growers near cities and other high population areas. The United States Environmental Protection Agency (EPA) mandates that buffers of at least 8 m be present in all directions from the application site in order to prevent possible exposure of residential areas to fumigants (US-EPA, 2012). Because certain fumigant products have larger buffer zones, growers often have limited options on the products that they may use because of the proximity of surrounding neighbors.

The use of methyl bromide, a soil fumigant, was completely phased-out in the U.S. in 2005 (except for critical use exemptions) and in the European Union (EU) in 2009 (Council of the EU, 2008; US-EPA, 2015). Metam sodium, another soil fumigant, is permitted for use in the U.S. and in 2012, the EU approved its use with an authorization that expires in 2022 (Council of the EU, 2012). Each Member State of the EU is responsible for registering and regulating its own plant protection products that are included on the list of substances allowed by the EU (European Commission, 2013). For example, dazomet and metam sodium are registered for use in Bulgaria, Poland, and Hungary, while oxamyl is registered for use in Poland and Hungary, but not in Bulgaria (Labrada, 2008).

For control of *P. rubi*, growers may also use post-plant fungicides. Both mefenoxam and fosetyl-aluminum are registered for use in Oregon, Washington, California, and Canada for the control of Phytophthora root rot in established red raspberry (CDPR, 2015a, d; HC-PMRA, 2015a, d; WSPRS, 2014d). In a Washington raspberry field naturally infested with *P. rubi*, mefenoxam was shown to significantly increase above ground 'Qualicum' biomass compared to the non-treated control and to solarization plots in the first year after treatment (Pinkerton et al., 2002). All other results, including total number of primocanes, healthy primocanes, and percent wilted primocanes were not significantly different between the mefenoxam treatment and the nontreated control.

Mefenoxam is the active enantiomer of metalaxyl (Maloney et al., 2005). Metalaxyl has been shown to be effective at controlling root rot in both established 'Willamette' plantings with severe root rot and new 'Willamette' plantings in *P. rubi* infested soils in Washington (Bristow, 1980). In an experiment looking at raised versus flatbed production with and without metalaxyl in a field naturally infested with *P. rubi*, Maloney et al. (1993) found raised beds to have a stronger influence on plant mortality and yield relative to flatbed production. No significant differences were found between beds with and without metalaxyl. Additionally, *P. fragariae* isolates that are resistant to metalaxyl have been found in strawberry (Reeser and Pscheidt, 1996) and there is concern regarding the development of fungicide resistance by *P. rubi*.

There is a paucity of products specifically labeled and currently registered as nematicides in the U.S. Due to the life cycle and location (soil and plant roots) of endoparasitic nematodes, effective delivery of a chemical control can be challenging and has caused environmental and human health concerns, resulting in deregistration (Chitwood, 2003). Of the few nematicides that are registered in the U.S., only a limited number have shown to be effective at controlling RLN in raspberry. Products containing oxamyl and azadirachtin may be utilized in red raspberry production, but many states have restricted or prohibited the use of these products. Most of the restrictions pertain to whether the planting can be bearing or non-bearing when the products are applied (CDPR, 2015b, c; Cornell University, 2015a, b; WSPRS, 2014a, b, c). In Canada, oxamyl products are registered and available for use as nematicides, but not azadirachtin products (HC-PMRA, 2015b, c).

In a two year field study conducted by Walters et al. (2009), several nematicide treatments were applied in the fall and spring to established red raspberry fields. Spring applications of oxamyl, a downward-moving systemic carbamate, and fosthiazate, a systemic organophosphate, suppressed RLN soil populations four months after application. Only oxamyl was able to retain suppression through the end of the study. However, raspberry fruit yields were significantly lower in the oxamyl-treated plots compared to all other treatments in the first year. There were no significant differences in yield in the second year. Fall treatment applications showed no effects on RLN populations in the soil. Population densities of RLN in both the soil and raspberry roots were not suppressed by drip-applied 1,3-dichloropropene (1,3-D) and sampling of that treatment ceased after the first year. Pre-plant use of 1,3-D has been shown to reduce RLN densities in red raspberry in Quebec, Canada (Bélair, 1991). RLN densities were reduced by 1,3-D compared to nontreated soil for the first three years, but by the fourth year, RLN densities were similar in treated and nontreated plots. Berry yields were greater in the plots treated with 1,3-D compared to nontreated plots for only the first three years of the study. The same trend was true for plots treated with methyl isothiocyanate.

To evaluate the potential of other post-plant nematicides to manage RLN, two separate studies were conducted in a greenhouse (Zasada et al., 2010). The first study applied different nematicide treatments to naturally infested roots and soils. Fosthiazate was the only nematicide that resulted in consistently lower RLN recovery compared to the nontreated control 14 d after treatment (DAT). Fenamiphos (no longer registered in the U.S.) and oxamyl also significantly reduced RLN soil populations compared to the nontreated control 14 DAT. However, results were not consistent. Other nematicides were also evaluated, such as 1,3-D and soapbark saponins, but did not consistently reduce RLN recovery over sampling times (7 d and 14 d) or trials. The second study used potted soil inoculated with RLN and planted with 'Meeker' raspberry. Only oxamyl and fosthiazate reduced RLN numbers compared to the inoculated, nontreated control. None of the nematicides were able to reduce RLN population densities to those of the noninoculated, nontreated control.

Even though some of these conventional pesticides have been shown to effectively control pathogen and nematode populations, they do not address the issue of declining soil quality as related to soil biology. Fumigants are broad spectrum, non-selective treatments that can suppress beneficial microbial populations (Collins et al., 2006; Gamliel et al., 2000). Many soil microorganisms play an important role in soil quality by promoting soil structure formation, decomposing soil organic matter, cycling nutrients, and suppressing soilborne pathogens (Doran et al., 1996). In dealing with replant disorder and the limited number of effective products available for managing *P. rubi* and *P. penetrans*, many growers are looking for integrated management approaches that either combine fumigation with a biological and/or physical method or perhaps replace fumigation entirely. Several alternative methods of pathogen and nematode control are available, but their potential in red raspberry systems has not been fully explored. These alternatives will be discussed individually.

Resistant Cultivars/Germplasm

Host plant resistance or tolerance is an important factor in regard to integrated management of pathogens and nematodes (Zasada and Moore, 2014). A field study used integrated approaches to control Phytophthora root rot on red raspberry, including different cultivars, different bed heights, straw mulch applications, fungicide applications, and *Trichoderma* treatments (Wilcox et al., 1999). Cultivar was the most significant factor in disease severity and incidence.

Use of resistant cultivars or germplasm from certified planting stock is always recommended to avoid disease and pest problems in raspberry crops. Clean planting stock will help prevent many issues, but will be of limited use if the commercially-favored cultivars are susceptible to the prevalent soilborne pathogens and nematodes, as is the case with all the commercially-favored cultivars grown in Washington (Finn et al., 2014). A survey conducted of European and North American raspberry breeding programs concluded that one of the top objectives was to develop root rot resistant cultivars (Finn et al., 2008). Eleven different breeding programs throughout the world are currently developing new raspberry cultivars with various goals in mind, such as higher yields, better flavor, cold hardiness, and disease resistance or tolerance (Weber, 2012).

There are several fresh market floricane red raspberry cultivars currently available in different regions that are either resistant or tolerant to Phytophthora root rot. 'Boyne' from Manitoba is tolerant, while a related cultivar, 'Killarney', is moderately resistant (Weber, 2012). 'Prelude' and 'Titan' were both developed in New York. 'Prelude' is very resistant, while 'Titan' is susceptible, but still very productive (Weber, 2012). Of the current cultivars available to growers in the PNW, very few are resistant to Phytophthora root rot. The PNW industry standard, 'Meeker' raspberry, is considered to be "moderately resistant" to "susceptible" because young plants have shown to be susceptible while mature plants have demonstrated some tolerance in the field. 'Chilliwack', 'Fairview', and 'Summit' raspberry are three cultivars that are considered "moderately resistant", but are not currently grown commercially in the PNW (PNW Extension, 2007). 'Cascade Bounty', 'Cascade Dawn', and 'Cascade Delight' are new cultivars tolerant to root rot (Finn et al., 2008, 2014) whose adoption has been slow thus far and it remains to be seen what their future will be in commercial production. One barrier to adoption of several of these cultivars is that they are more suited for fresh market and, therefore, do not presently meet industry processing standards, such as Individually Quick Frozen (Finn et al., 2008). Individually Quick Frozen commands a higher premium relative to purees and juices in the processed red raspberry industry, but requires specific and higher fruit quality characteristics that new cultivar releases have not been demonstrated to possess.

Although work is underway to improve raspberry resistance to *P. rubi*, currently no breeding program has undertaken the task of identifying or developing sources of resistance to RLN (Zasada and Moore, 2014). Only a few studies have shown even moderate resistance to RLN in raspberry cultivars. Vrain and Daubeny (1986) screened 14 raspberry genotypes in greenhouse and microplot trials. In both, 'Nootka' supported the lowest RLN populations in the microplots, but differences were not significant among cultivars. This genotype also performed moderately well in an earlier study performed by Bristow et al. (1980). 'Chilcotin' raspberry supported high numbers of RLN in both the greenhouse and microplot studies, while 'Meeker', 'Skeena', and 'Willamette' had intermediate RLN counts (Vrain and Daubeny, 1986). These authors also screened other *Rubus* species and observed that *R. crataegifolius* Bge.'Jogkal' supported the lowest RLN numbers in the entire study. Conversely, Zasada and Moore (2014) also screened 'Jogkal' and observed inconsistent results across greenhouse trials with reproductive factors (RF) of 0.5 in 2010 and 1.2 in 2011. A RF value less than 1.0 is desirable because it means that RLN counts are less than they were at inoculation (Oostenbrink, 1966), most likely due to low reproduction. When plant-parasitic nematodes, such as RLN, are unable to reproduce in the presence of a certain plant, that plant is not considered a suitable host. In the Zasada and Moore trials, *R. leucodermis* Douglas ex Torrey & A. Gray and *R. niveus* Thunb. (PI 606461), non-red raspberry species, were the poorest hosts for RLN and had consistently low RF values (0.1 for both species) in both trials. These results indicate that resistance may be found outside of *R. idaeus* and perhaps that resistance can be incorporated into a commercial-quality cultivar. A better understanding of how resistance is inherited is necessary and future research should include field evaluations of other potential RLN-resistant species.

Cover Crops/Living Mulches

A cover crop is a densely-growing ground cover that is grown with, before, or after a main cash crop. It may be annual or perennial, and it is often terminated prematurely either by tillage or herbicide application before the main crop is planted. Cover crops may be grown for a variety of reasons, including increasing soil organic matter, adding nitrogen to the soil, reducing soil erosion, improving soil tilth, suppressing weeds, or providing a break in contact between host plants and soilborne pathogens in order to reduce pathogen populations (Hartwig and Ammon, 2002; Magdoff and Van Es, 2009). Although cover crops are commonly used in other cropping systems and can be effective at suppressing soilborne pathogens and nematodes, not all raspberry growers use this practice, particularly in the PNW. Because suitable farmland for red raspberry is limited due to the specific needs required by the crop, growers frequently replant raspberry in the same location and cultivate between the rows for weed control rather than practice cover cropping or crop rotation (PNW Extension, 2007; Walters, 2011). These practices can be detrimental to soil quality, which has been defined as the "capacity of the soil to function" (Karlen et al., 1997). From an agricultural perspective, soil quality refers to how good a particular soil is at promoting the growth of high-yielding, high-quality, and healthy crops (Magdoff and Van Es, 2009). Reduced soil quality can manifest into increased soil erosion, compaction, loss of soil physical structure, reductions in nutrient- and water-holding capacity, and low populations of beneficial soil microorganisms (Funt and Hall, 2013; Magdoff and Van Es, 2009; PNW Extension, 2007), all of which may exacerbate raspberry replant disorder.

Cover cropping is often associated with the idea of removing the cash crop for at least one growing season, which may not be possible for many raspberry growers who cannot afford to have land out of production for an extended period of time due to the loss of income. Alleyway cover cropping is one post-plant option available to growers that can mitigate losses in soil quality and may have potential to suppress pathogens or nematodes in the soil. By seeding cover crops in the alleyways, growers may still experience many of the advantages of using cover crops without rotating out of raspberry and losing their primary source of income. The use of cover crops may lead to improved soil structure and the promotion of beneficial soil microbial populations (Magdoff and Van Es, 2009; Sarrantonio, 2007). Alleyway ground covers are widely utilized in other perennial cropping systems, such as vineyards and orchards (Hartwig and Ammon, 2002). Northern highbush blueberry (*Vaccinium corymbosum* L.) is usually grown with permanent alleyway ground covers containing a mixture of cool season turf grasses, native vegetation, and/or weeds (Julian et al., 2011). Red raspberry grown in the PNW, however, usually lacks alleyway ground covers and the soil is clean cultivated. Growers often cite two explanations for this. First, cover crops may complicate field management (e.g., prevent subsoiling) and secondly, that they may compete with raspberry for water and nutrients. There is limited information to support these claims.

There is evidence to support that certain alleyway cover crops may be beneficial, but not all cover crops are compatible with red raspberry production. Zebarth et al. (1993) observed that nitrogen (N) cycling improved and nitrate leaching was reduced with barley (*Hordeum vulgare* L.), sheep's fescue (*Festuca ovina* L.), perennial ryegrass (*Lolium perenne* L.), and white clover (*Trifolium repens* L.) cover crops in the alleyways of raspberry grown in Canada. This indicates overall N management was improved through these cover crops. In the same study, white clover had twice the mineralizable N compared to all other treatments in the study, while the nontreated bare soil control had half the mineralizable N. Cane diameter was reduced by the perennial grasses, but only a small reduction in raspberry yield was observed. In contrast, Bowen and Freyman (1995) reported no differences in raspberry yield when white clover was established in the alleyways compared to clean cultivation, but berry yield was significantly lower with perennial ryegrass in the alleyways compared to clean cultivation. It should be noted that white clover is susceptible to RLN and may serve as a host (Thies et al., 1995; Vrain et al., 1996). In a four-year study with alleyway cover crops in raspberry, plants grown in areas that were annually seeded with oats (*Avena* spp.) produced the same berry yield as plants in clean-cultivated plots (Sanderson and Cutcliffe, 1988). Freyman (1989) observed that fall-planted, winter-killed barley in raspberry alleyways formed a thick vegetative mat that effectively suppressed weeds through the summer, making alleyway cultivation unnecessary. However, barley is also a known host for RLN (Vrain et al., 1996), which further demonstrates the importance for proper cover crop selection. Perennial ryegrass and sheep's fescue, were also effective at suppressing weeds, although perennial ryegrass reduced primocane diameter, cane weight, and berry yield (Freyman, 1989). These results were not consistent across all three years of the study. Forge et al. (2000) reported 'Saia' oat (*Avena strigosa* Schreb) to be the most effective at reducing RLN populations under greenhouse conditions, but results were inconsistent in both greenhouse and field experiments. In the same study, 'Wheeler' rye (*Secale cereale* L.) was observed to be a host for RLN in greenhouse experiments, but supported low RLN populations in field experiments. However, Thies et al. (1995) found cereal rye and 'Starter' oat (*Avena sativa* L.) to be suitable hosts for RLN.

Certain cover crop species have the potential to suppress soilborne diseases and pests, which may be useful as a preventative measure in susceptible raspberry fields. Brassicaceous crops are commonly used as pre-plant green manures or biofumigants in Washington to manage nematodes and other soilborne diseases in potato (*Solanum tuberosum* L.; Clark, 2012; McGuire, 2003). Specific wheat (*Triticum* spp.) cultivars can induce disease suppression by enhancing antagonistic microbial populations that suppress soilborne plant pathogens in apple (*Malus domestica* Borkh.) orchard soils (Mazzola and Gu, 2002). Conversely, there is preliminary evidence that wheat grown prior to replanting raspberry may serve as a green bridge for RLN in the following season (Zasada et al., unpublished). Further investigation is required to elucidate how cover crops of different cultivars suppress or promote soilborne pathogens and nematodes in the raspberry production system.

Previous research demonstrates that there are many potential benefits of cover crops in perennial fruit systems, including increased soil quality and improved ability to suppress soilborne pathogens. Most commercially available cover crops have been bred for high yield and large seed production, rather than pathogen and nematode-suppression potential (Pritts, 2002). There may be crop cultivars already available that are not promising from an agronomic standpoint, but may be useful in an integrated approach to management of pathogens and nematodes and promotion of certain components of soil quality. A cover crop that is resistant, not tolerant, to RLN would prevent or discourage reproduction. It would be extremely beneficial to growers when trying to replant in soil with RLN infestations.

Biofumigation and Brassicaceous Seed Meals

Biofumigation is an approach to soilborne pest and pathogen management that involves the use of plants primarily from the Brassicaceae family in rotation with cash crops (Kirkegaard et al., 1993). Biofumigant crops contain glucosinolates (GSLs) and upon cellular disruption and hydrolysis, can release GSL-degradation products, specifically isothiocyanates (ITCs; Kirkegaard and Sarwar, 1998). Isothiocyanates have fungicidal and nematicidal properties (Brown and Morra, 1997), and can provide growers with an alternative to chemical fumigation that is less detrimental to the environment. Biofumigation can also improve worker safety by reducing their exposure to hazardous chemicals. However, concentration of GSLs and the hydrolysis products vary within species and cultivars. Therefore, not all Brassicaceous crops are well-suited as biofumigants (Kushad et al., 1999). Growers can attain maximum ITC release under field conditions by allowing the proper biofumigant crop to grow until flowering. Plants should be mowed and finely chopped in order to disrupt the plants cells as much as possible. Plant biomass must then be thoroughly incorporated into the soil followed by heavy irrigation and tarping, if possible (McGuire, 2003; Rudolph et al., 2015).

In some cases brassicaceous seed meal (BSM) may be more advantageous than a biofumigant cover crop. Brassicaceous seed meal is the material remaining after extracting the oil from mustard, canola, or rapeseed seeds. Application of BSM by incorporating it into the soil is quicker than growing a cover crop and the timing of application is flexible. Although BSM does require irrigation upon incorporation, much less water than a cover crop and no fertilizer are needed. A grower can also be certain that frost will not be a limiting factor as with a cover crop, nor will BSM serve as a host to a plant-parasitic nematode (Zasada et al., 2009). Additionally, BSM has been shown to alter the soil biology which then aids in the suppression of plant diseases (Cohen and Mazzola, 2006; Mazzola et al., 2015). However, BSM can be costly (~$2,000/t) and its availability is still currently limited. Recommended application rates of BSM vary between 1 and 6.7 $t \cdot ha^{-1}$ (Jonathan Winslow, manager of Farm Fuel Inc., personal communication; Mazzola et al., 2015). Brassicaceous seed meal may be a viable pre-plant biofumigant or an alternative to cover crops.

In a greenhouse study (Gigot et al., 2013b), tissue-cultured raspberry was transplanted into soil containing either *P. rubi* or RLN six weeks after BSM application. Both seed meals of *Brassica juncea* (L.) Czern. and *Sinapis alba* L. suppressed RLN populations and root rot caused by *P. rubi*. *Brassica juncea* seed meal was most effective at suppressing root rot at the 2.0% $v \cdot v^{-1}$ rate, but all rates (0.5%, 1.0%, and 2.0% $v \cdot v^{-1}$) were significantly effective. Similar results were observed for *S. alba* seed meal. All rates of *B. juncea* seed meal suppressed RLN to near zero while *S. alba* seed meal was only more effective than the control at 1.0% and 2.0% $v \cdot v^{-1}$.

Not all seed meals are equally effective at suppressing soilborne pathogens (Zasada et al., 2009). The suppression of the plant-parasitic nematode populations of *Meloidogyne incognita* (Kofoid & White) Chitwood and *P. penetrans* by different BSMs was evaluated and the authors observed that the type of seed meal, the rate of application, and the seed meal particle size all influenced the suppressive effects of the various seed meals. However, all rates of *B. juncea* 'Pacific Gold' seed meal resulted in nearly complete reduction in recovery of both nematode species compared to the non-amended control. A rate as low as 0.06% $w \cdot w^{-1}$ resulted in a reduction in nematode recovery. Other seed meals, such as *B. napus* L. 'Dwarf Essex', *B. napus* 'Sunrise', and *S. alba* 'Ida Gold', showed varying success at suppressing nematodes, but none were as effective as 'Pacific Gold' across all rates and both nematodes species. However, ground seed meal of *S. alba* that could pass through a 20 mm mesh sieve was the most effective at reducing RLN recovery. Different BSMs were applied to apple orchard soils infested with RLN in a greenhouse (Mazzola et al., 2009). *Brassica juncea* 'Pacific Gold' seed meal was more effective than *B. napus* or *S. alba* seed meals. Regardless of the rootstock tested, *B. juncea* seed meal significantly reduced RLN populations when applied to the soil before planting. 'Pacific Gold' also suppressed RLN populations pre-plant, three months post-plant, and six months post-plant in a commercial orchard with infested soils (Mazzola et al., 2007). None of the other seed meal treatments suppressed RLN six months after planting. Mazzola et al. (2015) applied special formulations of BSM to two field sites known to have the apple replant disease complex which included *Cylindrocarpon* spp., *Phytophthora cactorum* (Lebert & Cohn) J.Schröter, *Pythium* spp., *Rhizoctonia* spp., and RLN. Brassicaceous seed meal treated plots were not only equal to or better than 1,3-D/chloropicrin fumigated plots at suppressing disease in newly planted apple trees, but were also more resistant to reinfestation by RLN and *Pythium* spp. for the four years of the study. Although the initial pathogen suppression may have been due to the release of ITCs, the soil microbial community was shown to be responsible for long-term suppression. A distinct bacterial and fungal community was observed in the rhizosphere in BSM amended soil compared to fumigated soil or the control. The microbiome in the BSM treated soil included bacteria and fungi that have been reported to metabolize toxic organic compounds and suppress plant pathogens. In dealing with apple replant disease, Mazzola and Zhao (2010) reported that BSM particle size influenced ITC emission, concentration, and efficacy of disease suppression. Particles less than 1 mm in diameter were more effective than coarser particles at suppressing *Rhizoctonia solani*. However, both fine and coarse BSM particles were able to successfully suppress RLN populations.

While apple orchards are very different from raspberry production systems, the use of BSM for the treatment of apple replant disorder may also be applicable in red raspberry. Future development of BSM formulations specific to the management of soilborne pathogens and nematodes in this crop, as well as research pertaining to the economic viability of BSM should be encouraged.

Soil Solarization

Soil solarization is a management technique that uses passive solar heating of irrigated soil under transparent plastic tarping. The soil is heated to temperatures detrimental to soilborne pests, pathogens and weed seeds, and thus can be a nonchemical alternative to pesticide application. Soil moisture is an important factor in solarization because it helps transfer heat to the target organisms. It also encourages growth of soilborne microorganisms which would then make them more susceptible to the high soil temperatures created by solarization (Pokharel, 2011). Efficacy is dependent on both time and temperature. Exposure to temperatures of approximately 37°C for two to four weeks will kill most mesophilic fungi, which includes many plant pathogens and nematodes (Pokharel, 2011; Stapleton and DeVay, 1986). A similar result may be reached in only a few hours if temperatures rise above 45°C (Pokharel, 2011). It has been observed that growth of *P. rubi* ceases at 29°C or higher (Pinkerton et al., 2009). The higher the temperature, the less time necessary to kill *P. rubi*. For example, 222 h at 29°C were required to kill *P. rubi*, but only 52 h were necessary at 35°C (Pinkerton et al., 2009). Utilizing solarization to manage RLN has been shown to be effective, but may be more challenging than managing *P. rubi* because RLN is more mobile and may reside deeper in the soil profile than solarization treatments are able to penetrate (Elmore et al., 1997). Previous work has shown that soil temperatures over 30°C impede RLN reproduction (Mamiya, 1971), while 50 to 99% mortality has been shown to occur between 35 and 45°C (Lazarovits et al., 1991; Porter and Merriman, 1983).

Pinkerton et al. (2002) tested solarized plots against non-solarized plots, each with and without mefenoxam applications, in a red raspberry field naturally infested with *P. rubi*. Solarized treatments were applied for 2 months. Raspberry yield of 'Qualicum' and 'Skeena' were significantly higher in all the solarized treatments than the nontreated control and these differences were observed three years after solarization. Non-solarized, fungicide-treated plots had higher yields than the nontreated control, but the differences were not significant. Mean cane heights of 'Qualicum' increased with solarization, fungicide, and solarization plus fungicide treatments, but 'Skeena' mean cane heights only increased within the solarization plus fungicide treatment plots. In a three year study in Clark Co., WA (Pinkerton et al., 2009), raspberry plant growth and berry yield were evaluated in six different treatment combinations in a field naturally infested with *P. rubi* and a history of Phytophthora root rot. Treatments included raised or flat beds that were solarized or non-solarized followed by a gypsum or no gypsum amendment. Solarized treatments were applied for 2 months. Mean soil temperatures in solarized and non-solarized plots were above 28°C and lower than 23°C, respectively. 'Malahat' raspberry planted in raised, solarized beds amended with gypsum had significantly greater berry yield than all the other treatments. However, no yield differences were reported between treatments with 'Willamette' raspberry. Simultaneous field studies were conducted in Pierce Co. and Whatcom Co., WA with the same two cultivars in fields with a history of Phytophthora root rot (Pinkerton et al., 2009). Treatments included solarized plots, solarized plots with mefenoxam and fosetyl-aluminum applications, non-solarized plots, and non-solarized plots with mefenoxam and fosetyl-aluminum applications. In the first year at both locations, 'Malahat' cane length and cane weight were significantly greater in all solarized plots compared to non-solarized plots. 'Qualicum' cane length and cane weight were greater in solarized plots compared to non-solarized plots. Diseased canes were evaluated in the second year in both locations in both cultivars. In both locations, 'Malahat' canes in plots treated with fungicides had significantly lower disease percentage than the nontreated control, but solarized plots did not. Percent disease in 'Qualicum' canes was significantly lower in all treatments compared to the nontreated control in Pierce Co., but differences were not significant in Whatcom Co. Berry yield was only significant in 'Qualicum' planted in Pierce Co. Non-solarized plots treated with fungicides were significantly higher than the nontreated control, but not significantly different from the other two treatments. In the Whatcom Co. field trials, mean soil temperatures at 10 cm and 30 cm depths for solarized plots were 28°C and 25.7°C, respectively, while the mean temperature at both 10 cm and 30 cm in non-solarized plots were 18.7°C. In Pierce Co., mean soil temperatures were approximately 2-3°C higher in all plots compared to Whatcom Co. plots. Gigot et al. (2013b) reported that in both years of a field study, solarization alone was not significantly different from the nontreated control in affecting disease severity caused by *P. rubi*. However, plots that were solarized as well as amended with BSM had lower disease severity than the nontreated control and non-solarized BSM amended plots. All BSMs were applied at a rate of 1.0% $v \cdot v^{-1}$. Differences were only seen at 15 cm depth, not at 30 or 45 cm. A deep-rooted crop, such as raspberry, would still be at risk of infection at the lower depths. *Pratylenchus penetrans* populations were not different among the treatments. This study took place in Skagit Co., WA where non-solarized soil temperatures did not exceed 21°C at 5 or 20 cm depths (WSU AgWeatherNet, 2015a). The previously mentioned solarization field studies were performed in areas that are further south (with the exception of Whatcom Co.). In Pierce Co., for example, non-solarized soil temperatures approached 26°C at 20 cm depths (WSU AgWeatherNet, 2015b).

In a strawberry field study conducted in southwestern Spain from July to September, solarized plots reached mean soil temperatures of 46°C at 5 cm, 43°C at 10 cm, and 38°C at 20 cm depths (Porras et al., 2007a). Those temperatures were 13, 11, and 10°C higher, respectively, than soil temperatures at the same depths in the nontreated control. Solarization treatments reduced *Phytophthora cactorum* densities in the naturally infested field by 100% in year 1, 60% in year 2, and 68% in year 3, but only significantly reduced the percentage of leather rot caused by *P. cactorum* in year 2.

Southern locations that reported positive results were warmer and likely reached pathogen-killing temperatures earlier and maintained those temperatures longer, which may account for the difference in results among locations. While solarization has been shown to be an effective method under certain climatic conditions, it may not be an option for all growers in regions where temperatures remain too low to affect mesophilic pathogenic organisms. Additionally, soil characteristics play an important role in the efficacy of solarization. Soil color and moisture content will affect the amount of heat that can be generated and transferred, as well as bulk density and other physical soil properties (Smith, 1964).

Anaerobic Soil Disinfestation

Anaerobic soil disinfestation (ASD) is similar to solarization in that it performs best during the warmest months of the year and requires tarping and irrigation. However, ASD does not rely solely on high temperatures to kill pathogens and nematodes, but also utilizes organic amendments as a carbon source in order to encourage an anaerobic environment where anaerobic microorganisms flourish and problematic soil organisms cannot survive due to the lack of oxygen and the production of organic acids and volatile compounds (Blok et al., 2000). The tarps help maintain soil moisture above field capacity and sustain anaerobic conditions and high soil temperatures (Shennan et al., 2014). In order for ASD to be effective, soil temperatures need to reach approximately 30°C and be maintained for at least 10 to 20 days (Katase et al., 2009). It may also be effective at lower average soil temperatures for longer periods of time (Muramoto et al., 2014). The anaerobic by-products that build up are degraded quickly once the tarp is removed or holes are created for transplanting the crop (Shennan et al., 2014).

Anaerobic soil disinfestation has been shown to be effective at suppressing a wide range of pathogens and nematodes in different cropping systems in various regions of the world. Pathogenic populations that have been shown to be negatively affected by ASD include *Verticillium dahliae* Kleb. in strawberry in California, *M. incognita* in eggplant (*Solanum melongena* L.) in Florida, *Fusarium oxysporum* (Schlechtend.) emend. W.C. Snyder & H.N. Hans. f. sp. *asparagi* in asparagus (*Asparagus officinallis* L.) in the Netherlands, and *Pyrenochaeta lycopersici* Schneider & Gerlach in tomato (*Solanum lycopersicum* L.) in Japan (Blok et al., 2000; Butler et al., 2012; Muramoto et al., 2014;

Shennan et al., 2014). The carbon source used for ASD varies by cropping system and region. Rice bran, molasses, ethanol, green manure residues, and composted boiler litter have all been used as experimental carbon sources in field studies and commercial fields. The application rate, timing, and duration may vary depending on the carbon source, season, and growing region.

In four non-replicated field trials in central California, pre-plant ASD treatments of rice bran (20 t·ha^{-1}) and rice bran plus sugarcane molasses (10 t·ha^{-1} each) in strawberry fields have been shown to create longer lasting anaerobic conditions and higher marketable yields than sugarcane molasses alone (20 t·ha^{-1}). The rice bran ASD treatment was as effective at suppressing *V. dahliae* compared to the Pic-Clor 60 fumigant control (Muramoto et al., 2014). Nematicidal activity of wheat bran was evaluated in laboratory and greenhouse experiments using *M. incognita* (Katase et al., 2009). The volatile fatty acids, acetic and n-butyric acids, produced during the soil disinfestation process in the laboratory were effective at decreasing the number of surviving juvenile nematodes (J2 stage). In the greenhouse study using tomato plants in soil naturally infested with *M. incognita*, wheat bran was incorporated at soil depths from 0 to 40 cm for 24 d. Average J2 population densities were over 200 times greater in the nontreated control plot (1644/20 g of soil) compared to the wheat bran ASD plot (8/20 g of soil) at 0-20 cm soil depths. At 20-40 cm depths, average densities were over 35 times greater in the control plot than in the ASD plot. Tomato root galling was also much less in the ASD plot compared to the control.

Depending on the carbon source and the method of application, ASD can be more expensive than chemical fumigation (~$6,000/ha for ASD compared to ~$4,400/ha for Pic-Clor 60) and, therefore, should only be considered for use in high-value crops (Shennan et al., 2014). Fortunately, red raspberry is a high value crop. Although ASD has yet to be implemented in raspberry production, it may be an effective pre-plant treatment, particularly in fields that will be replanted with raspberry. However, northern regions may face challenges in achieving high enough temperatures, similar to solarization.

Antagonistic/Beneficial Microorganisms

Biological control of soilborne pathogens and nematodes has been shown to be effective in various crops. There are numerous organisms that have been employed as biological control agents, such as actinomycetes, arbuscular mycorrhizal fungi, and *Trichoderma*. Earlier studies have indicated the benefits of inoculating with these microorganisms, some of which are antagonistic to plant pathogens while others may enhance plant growth.

Actinomycetes are gram-positive bacteria commonly found in soil. They resemble fungi because their elongated cells form filaments and hyphae (McCarthy and Williams, 1992). Valois et al. (1996) tested 200 actinomycete strains, some isolated from raspberry roots and raspberry field soil, and observed 13 of those strains to be antagonistic to *P. rubi*. None of the strains from raspberry roots exhibited antagonistic properties, but three of the strains isolated from raspberry field soil did inhibit *P. rubi* growth. Toussaint et al. (1997) reported that 11 *Streptomyces* strains were able to inhibit *P. rubi* growth and break down their cell walls at 15°C and pH 7 under controlled laboratory conditions. Only seven of the strains were able to maintain this ability at 15°C and at pH 5 and pH 9. All 11 strains were also able to inhibit growth of *Pythium ultimum* Trow. Although raspberry is typically grown at soil pH between 5 and 9, it would not be unusual for the temperature to be well above or below 15°C which may affect efficacy in the field. Inoculation of susceptible and resistant alfalfa (*Medicago sativa* L.) with *Streptomyces* strains significantly reduced RLN populations compared to the control in greenhouse experiments (Samac and Kinkel, 2001). There is evidence of the ability of actinomycetes to induce plant systemic resistance to pathogens and nematodes. However, strains are not generally used for root rot biocontrol in red raspberry, perhaps due to the scarcity of commercial production, distribution, and advertisement for their use.

Arbuscular mycorrhizal (AM) fungi are root symbionts and can improve the growth and nutrient uptake of various crops. The name originates from the arbuscules, or branches, that are produced within the root cortical cells of plants (Bever et al., 2001). Arbuscular mycorrhizal fungi protect plants through secondary mechanisms, rather than interacting directly with pests and pathogens (Harrier and Watson, 2003). They may be beneficial to plants for several reasons, including enhancing host nutrient status (Harrier and Watson, 2003), altering plant root structure, size, and quantity (Norman et al., 1996), competing for root colonization with soilborne pathogens (Davis and Menge, 1980), and competing for the host's photosynthates on which the soilborne pathogens and nematodes might otherwise depend (Smith, 1988). Soil inoculation with certain AM fungi has been shown to reduce root rot caused by *P. fragariae* in certain strawberry cultivars (Norman et al., 1996) and improve perennial crop growth in soil infested with the migratory endoparasite nematode, *Pratylenchus vulnus* Allen and Jensen (Camprubi et al., 1993; Pinochet et al., 1993, 1995). In three greenhouse experiments, 'Ottawa 3' apple rootstock growth was greater in *Glomus mosseae* (T.H. Nicolson & Gerd.) Gerd. & Trappe-inoculated pots than in the non-inoculated control, regardless of whether RLN was present (Forge et al., 2001). In a two-year field study using 'Ottawa 3' apple, RLN populations were significantly lower in plants inoculated with *G. mosseae* than non-inoculated plants in fumigated soil (Forge et al., 2001).

Trichoderma spp. are free-living, imperfect fungi that are commonly found in soil. Forms of biocontrol by *Trichoderma* include mycoparasitism, production of fungitoxic enzymes, production of antibiotics, and competition for space and nutrients in the rhizosphere (Harman et al., 2004; Howell, 2003). Upon contact with other fungi, *Trichoderma* attaches to the host and may produce fungitoxic enzymes or antibiotics which contribute to the degradation of the cell walls of the host (Weindling, 1932, 1941). For these reasons, *Trichoderma* has been shown to be useful in the suppression of certain soilborne pathogen populations. In the previously mentioned three year strawberry field study conducted in Spain, *Trichoderma harzianum* Rifai and *Trichoderma viride* (A.S. Horne & H.S. Will.) Jaklitsch & Samuels were applied in a mix by drip irrigation and by dipping strawberry roots in the mix (Porras et al., 2007a). *Trichoderma* treatments significantly reduced *P. cactorum* soil populations and leather rot incidence compared to the control. However, solarization plus *Trichoderma* treatments were the most effective during all three years of the study at significantly reducing *P. cactorum* densities compared to the nontreated control. In a separate strawberry field study in which *P. cactorum* was not present, *Trichoderma* applications were similarly applied by drip irrigation and dipping plant roots in a mixture. *Trichoderma* treatments resulted in yield increases of 84.9% in year 2 and 17.6% in year 3 compared to the nontreated control (Porras et al., 2007b). In greenhouse experiments, 5-month old and 24-month old avocado (*Persea americana* Mill.) trees were inoculated with *Rosellina necatrix* Prill. 1902, the causal agent of white root rot of avocado, and different isolates of *Trichoderma* in order to evaluate the biological control activity by *Trichoderma* (Ruano Rosa and López Herrera, 2009). Isolate CH 304.1 of *T. atroviride* P. Karst. was shown to significantly reduce disease symptoms compared to other *Trichoderma* isolates, as well as the *R. necatrix* inoculated control. Inoculations that included isolate CH 304.1 in combination with other *Trichoderma* isolates had better disease control than when CH 304.1 was not included, possibly due to synergistic effects.

Inoculation with beneficial or antagonistic microorganisms in conjunction with other management approaches, such as BSM, may be applicable to red raspberry in cases of replanting in fields infested with soilborne pathogens or nematodes. However, proper pairing of microorganism species to plant species and cultivars would be needed given that specificity has been shown among different plants and cultivars (McGonigle and Miller, 2000).

Inoculum Removal

Previous studies have indicated that BSM and other alternatives to chemical fumigation have potential to suppress soilborne pathogens and plant-parasitic nematodes. However, many of the experiments showing efficacy were conducted using infested field soils or inoculated potting soils under more artificial conditions in controlled environments. These conditions are not comparable to those in commercial fields where the environment and soil conditions may be variable and less than optimal. When growers decide to replant a raspberry field, they mow the canes and incorporate all of the plant material, including infected plants, into the soil. This means that much of the original inoculum is still present in the field. Raspberry plants have large root systems where both RLN and *P. rubi* reside. Because these organisms can survive in field soil for years (Duncan, 1980), a few months elapsing between terminating old plants and replanting is likely inadequate to eliminate these organisms from the incorporated root material and prevent future infection. An additional step of removing as much old plant material, which possibly contains inoculum, from the field may improve management of these organisms. Raspberry root removal prior to either fumigation or BSM applications may increase treatment efficacy and perhaps also extend the life of new plantings, but there have been no reported results about this potential strategy to date.

Conclusions

Both *P. rubi* and RLN are detrimental organisms for red raspberry throughout the world and their persistence limits production and threatens the stability of the raspberry industry. Current management methods of fumigating and replanting are not long-term solutions or environmentally sustainable. An integrated approach using several promising strategies may help red raspberry growers more successfully manage these organisms, as similar practices have proven to aid in pathogen and nematode management in other cropping systems. The potential ability of these new practices to reduce soilborne pathogens and nematodes in red raspberry needs to be investigated further so that the knowledge of future promising strategies can promote the sustainability of the red raspberry industry.

Literature Cited

Bélair, G. 1991. Effects of preplant soil fumigation on nematode population densities, and on growth and yield of raspberry. Phytoprotection 72(1):21-25.

Bever, J.D., P.A. Schultz, A. Pringle, and J.B. Morton. 2001. Arbuscular mycorrhizal fungi: More diverse than meets the eye, and the ecological tale of why. BioScience 51(11):923-932.

Blok, W.J., J.G. Lamers, A.J. Termorshizen, and G.J. Bollen. 2000. Control of soilborne plant pathogens by incorporating fresh organic amendments followed by tarping. Phytopathology 90(3):253-259.

Bowen, P. and S. Freyman. 1995. Ground covers affect raspberry yield, photosynthesis, and nitrogen nutrition of primocanes. HortScience 30(2):238-241.

Bristow, P.R. 1980. Raspberry root rots in the Pacific Northwest. Acta Hort. 112:33-38.

Bristow, P.R., B.H. Barritt, and F.D. McElroy. 1980. Reaction of red raspberry clones to the root lesion nematode. Acta Hort. 112:39-46.

Brown, P.D. and M.J. Morra. 1997. Control of soilborne plant pests using glucosinolate-containing plants. Adv. Agron. 61:167-231.

Butler, D.M., N. Kokalis-Burelle, J. Muramoto, C. Shennan, T.G. McCollum, and E.N. Rosskopf. 2012. Impact of anaerobic soil disinfestation combined with soil solarization on plant-parasitic nematodes and introduced inoculum of soilborne plant pathogens in raised-bed vegetable production. Crop Protection 39:33-40.

California Department of Pesticide Regulation (CDPR). 2015a. Aliette WDG Fungicide. 8 June 2015. <http://apps.cdpr.ca.gov/cgi-bin/label/label.pl?typ=pir&prodno=49455>.

CDPR. 2015b. Nematicides, active ingredients. <http://apps.cdpr.ca.gov/cgi-bin/label/labchemrep.pl>.

CDPR. 2015c. Oxamyl. 8 June 2015. <http://apps.cdpr.ca.gov/cgi-bin/label/labchemrep.pl>.

CDPR. 2015d. Ridomil Gold GR. 8 June 2015. <http://apps.cdpr.ca.gov/cgi-bin/label/label.pl?typ=pir&prodno=46770.

Camprubi, A., J. Pinochet, C. Calvet, and V. Estaun. 1993. Effects of the root-lesion nematode *Pratylenchus vulnus* and the vesicular-arbuscular mycorrhizal fungus *Glomus mosseae* on the growth of three plum rootstocks. Plant Soil 153(2):223-229.

Clark, A. 2012. Managing cover crops profitably. 3rd ed. SARE, College Park, MD.

Chitwood, D.J. 2003. Nematicides. 22 Oct. 2014. <http://www.ars.usda.gov/SP2UserFiles/person/990/Chitwood2003NematicideReview.pdf>.

Cohen, M.F. and M. Mazzola. 2006. Resident bacteria, nitric oxide emission and particle size modulate the effect of *Brassica napus* seed meal on disease incited by *Rhizoctonia solani* and *Pythium* spp. Plant Soil 286:75-86.

Collins, H.P., P.B. Hamm, A. McGuire, E. Riga, A. Alva, and R.A. Boydston. 2006. Soil microbial, fungal, and nematode responses to soil fumigation and cover crops under potato production. Biol. Fert. Soils 42(3):247-257.

Cornell University Pesticide Management Education Program (PMEP). 2015a. Azadirachtin. 8 June 2015. <http://pims.psur.cornell.edu/ProductResults.php?AICode=121701&SearchPage=AISearch.php&Set=current>.

Cornell University PMEP. 2015b. Oxamyl. 8 June 2015. <http://pims.psur.cornell.edu/ProductResults.php?AICode=103801&SearchPage=AISearch.php&Set=current>.

Council of the EU. 2008. 2008/753/EC: Commission Decision of 18 September 2008 concerning the non-inclusion of methyl bromide in Annex I to Council Directive 91/414/EEC and the withdrawal of authorisations for plant protection products containing that substance (notified under document number C(2008) 5076). Offic. J. European Union Document 32008D0753. 8 June 2015. <http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32008D0753&qid=1433797617255&from=EN>.

Council of the EU. 2012. Commission Implementing Regulation (EU) No 359/2012. Offic. J. European Union Document 32012R0359. 8 June 2015. <http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32012R0359&from=EN>.

Davis, R.M. and J.A. Menge. 1980. Influence of *Glomus fasciculatus* and soil phosphorus on Phytophthora root rot of citrus. Phytopathology 70(5):447-452.

Doran, J.W., M. Sarrantonio, and M.A. Liebig. 1996. Soil health and sustainability. Adv. Agron. 56:1-54.

Duncan, D.M. 1980. Persistence of mycelium of *Phytophthora fragariae* in soil. Trans. Brit. Mycol. Soc. 75(3):383-387.

Elmore, C.L., J.J. Stapleton, C.E. Bell, J.E. DeVay. 1997. Soil solarization: A nonpesticidal method for controlling diseases, nematodes, and weeds. Univ. Cali. Div. Agr. Natural Resources Publ. 21377.

European Commission. 2013. Plants, plant products and their protection. 17 June 2015. <http://www.exporthelp.europa.eu/thdapp/taxes/show2Files.htm?dir=/requirements&reporterId1=EU&file1=ehir_eu13_02v001/eu/main/req_heapestires_eu_010_1003.htm&reporterLabel1=EU&reporterId2=DE&file2=ehir_de13_02v001/de/main/req_heapestires_de_010_1003.htm&reporterLabel2=Germany&label=Control+of+pesticide+residues+in+plant+and+animal+products+intended+for+human+consumption&languageId=en&status=PROD>.

Finn, C.E., P.P. Moore, and C. Kempler. 2008. Raspberry cultivars: what's new? what's succeeding? where are breeding programs headed? IX Intl. Rubus and Ribes Symp.

Finn, C.E., B.C. Strik, and P.P. Moore. 2014. Raspberry cultivars for the Pacific Northwest. Pacific Northwest Ext. PNW 655.

Forge, T.A., R.E. Ingham, D. Kaufman, and J.N. Pinkerton. 2000. Population growth of Pratylenchus penetrans on winter cover crops grown in the Pacific Northwest. J. Nematol. 32(1):42-51.

Forge, T., A. Muehlchen, C. Hackenberg, G. Neilsen, and T. Vrain. 2001. Effects of preplant inoculation of apple (*Malus domestica* Borkh.) with arbuscular mycorrhizal fungi on population growth of the root-lesion nematode, *Pratylenchus penetrans*. Plant Soil 236:185-196.

Food and Agriculture Organization of the United Nations Statistics Division. 2013. Food and agriculture commodities production/countries by commodity—raspberry, 2013. 4 June 2015. <http://faostat3.fao.org/browse/rankings/countries_by_commodity/E>.

Freyman, S. 1989. Living mulch ground covers for weed control between raspberry rows. Acta Hort. 262:349-356.

Funt, R.C. 2013. Pest and Disease Management, p. 133-155. In: R.C. Funt and H.K. Hall (eds.). Raspberries. CAB International, Oxfordshire, UK.

Funt, R.C. and H.K. Hall. 2013. Raspberries. CAB International, Oxfordshire, UK.

Gamliel, A., M. Austerweil, and G. Kritzman. 2000. Non-chemical approach to soilborne pest management - organic amendments. Crop Protection 19:847-853.

Gigot, J.A., T.W. Walters, and I.A. Zasada. 2013a. Impact and occurrence of *Phytophthora rubi* and *Pratylenchus penetrans* in commercial red raspberry (*Rubus idaeus*) fields in Northwestern Washington. Intl. J. Fruit Sci. 13(4):357-372.

Gigot, J.A., I.A. Zasada, and T.W. Walters. 2013b. Integration of brassicaceous seed meals into red raspberry production systems. Appl. Soil Ecol. 64:23-31.

Harman, G.E., C.R. Howell, A. Viterbo, I. Chet, and M. Lorito. 2004. *Trichoderma* species - opportunistic, avirulent plant symbionts. Nature Rev. Microbiol. 2(1):43-56.

Harrier, L.A. and C.A. Watson. 2003. The potential role of arbuscular mycorrhizal (AM) fungi in the bioprotection of plants against soil-borne pathogens in organic and/or other sustainable farming systems. Pest Mgt. Sci. 60:149-157.

Hartwig, N.L. and H.U. Ammon. 2002. 50th anniversary - invited article: Cover crops and living mulches. Weed Science 50:688-699.

Health Canada (HC). 2012. Questions and answers - new label requirements for soil fumigant products containing certain active ingredients. 11 May 2015.<http://www.hc-sc.gc.ca/cps-spc/pubs/pest/_fact-fiche/soil-fumigant-fumigation-sol/soil-fumigant_qa_fumigation-sol-eng.php>.

Health Canada Pest Management Regulatory Agency (HC-PMRA). 2015a. Aliette. 11 May 2015. <http://pr-rp.hc-sc.gc.ca/pi-ip/result-eng.php?1=0&2=501&3=pr&4=n&5=1&6=ASC&7= A&8=E>.

HC-PMRA. 2015b. Azadirachtin. 12 May 2015. < http://pr-rp.hc-sc.gc.ca/pi-ip/rba-epa-eng.php?p_actv=AZADIRACHTIN>.

HC-PMRA. 2015c. Oxamyl. 12 May 2015. < http://pr-rp.hc-sc.gc.ca/pi-ip/rba-epa-eng.php?p_actv=OXAMYL>.

HC-PMRA. 2015d. Ridomil Gold. 11 May 2015.<http://pr-rp.hc-sc.gc.ca/pi-ip/result-eng.php?1=0&2=501&3=pr&4=n&5=1&6=ASC&7=R&8=E>.

Howell, C.R. 2003. Mechanisms employed by *Trichoderma* species in the biological control of plant diseases: the history and evolution of current concepts. Plant Dis. 87(1):4-10.

Hummer, K. and H.K. Hall. 2013. Raspberries, p. 1-19. In: R.C. Funt and H.K. Hall (eds.). Raspberries. CAB International, Oxfordshire, UK.

Julian, J.W., B.C. Strik, and W. Yang. 2011. Blueberry economics: the cost of establishing and producing blueberries in the Willamette Valley. OSU Extension, AEB 0022.

Karlen, D.L., M.J. Mausbach, J.W. Doran, R.G. Cline, R.F. Harris, and G.E. Schuman. 1997. Soil quality: A concept, definition, and framework for evaluation (a guest editorial). Soil Sci. Soc. Am. J. 61:4-10.

Katase, M., C. Kubo, S. Ushio, E. Ootsuka, T. Takeuchi, and T. Mizukubo. 2009. Nematicidal activity of volatile fatty acids generated from wheat bran in reductive soil disinfestation. Nematol. Res. 39(2):53-62.

Kirkegaard, J.A, P.A. Gardner, J.M. Desmarchelier, and J.F. Angus. 1993. Biofumigation - using Brassica species to control pests and diseases in horticulture and agriculture. Proc. 9th Australian Research Assembly on Brassica. p. 77-82.

Kirkegaard, J.A. and M. Sarwar. 1998. Biofumigation potential of brassicas. I. Variation in glucosinolate profiles of diverse field-grown brassicas. Plant Soil 201:71-89.

Kushad, M.M., B.P. Klein, M.A. Wallig, E.H. Jeffery, A.F. Brown, and A.C. Kurilich. 1999. Variation of glucosinolates in vegetable crops of *Brassica oleracea*. J. Agr. Food Chem. 47:1541–1548.

Labrada, R. 2008. Manual on alternatives to replace methyl bromide for soil-borne pest control in East and Central Europe. 20093015494.

Lazarovits, G., M.A. Hawke, Th.H.A. Olthof, and J. Coutu-Sundy. 1991. Influence of temperature on survival of *Pratylenchus penetrans* and of microsclerotia of *Verticillium dahliae* in soil. Can. J. Plant Pathol. 13(2):106-111.

Magdoff, F. and H. Van Es. 2009. Building soils for better crops: Sustainable soil management. Waldorf, M.D.: Sustainable Agriculture Research and Education.

Maloney, K., M. Pritts, W. Wilcox, and M.J. Kelly. 2005. Suppression of Phytophthora root rot in red raspberries with cultural practices and soil amendments. HortScience 40(6):1790-1795.

Maloney, K.E., W.F. Wilcox, and J.C. Sanford. 1993. Raised beds and metalaxyl for controlling Phytophthora root rot of raspberry. HortScience 28(11):1106-1108.

Mamiya, Y. 1971. Effect of temperature on the life cycle of *Pratylenchus penetrans* on *Cryptomeria* seedlings and observations on its reproduction. Nematologica 17:82-92.

Mazzola, M., D.M. Granastein, D.C. Elfving, K. Mullinix, and Y. Gu. 2002. Cultural management of microbial community structure to enhance growth of apple in replant soils. Phytopathology 92(12):1363-1366.

Mazzola, M., J. Brown, X. Zhao, X., A.D. Izzo, and M.F. Cohen. 2007. Mechanism of action and efficacy of seed meal-induced pathogen suppression differ in a Brassicaceae species and time-dependent

manner. Phytopathology 97(4):454-460.
Mazzola, M., J. Brown, X. Zhao, A.D. Izzo, and G. Fazio. 2009. Interaction of Brassicaceous seed meal and apple roots on recovery of *Pythium* spp. and *Pratylenchus penetrans* from roots grown in replant soils. Plant Dis. 93:51-57.
Mazzola, M. and L.M. Manici. 2012. Apple replant disease: role of microbial ecology in cause and control. Ann. Rev. Phytopathology 50:45-65.
Mazzola, M., S.S. Hewavitharana, and S.L. Strauss. 2015. Brassica seed meal soil amendments transform the rhizosphere microbiome and improve apple production through resistance to pathogen reinfestation. Phytopathology 105(4):460-469.
Mazzola, M. and X. Zhao. 2010. *Brassica juncea* seed meal particle size influences chemistry but not soil biology-based suppression of individual agents inciting apple replant disease. Plant Soil 337:313-324.
Mazzola, M. and Y. Gu. 2002. Wheat genotype-specific induction of soil microbial communities suppressive to disease incited by *Rhizoctonia solani* Anastomosis Group (AG)-5 and AG-8. Phytopathology 92(12):1300-1307.
McCarthy, A.J. and S.T. Williams. 1992. Actinomycetes are agents of biodegradation in the environment - a review. Gene 115(1):189-192.
McElroy, F.D. 1977. Effect of two nematode species on establishment, growth, and yield of raspberry. Plant Dis. Rptr. 61(4):277-279.
McElroy, F.D. 1992. A plant health care program for brambles in the Pacific Northwest. J. Nematol. 24(3):457-462.
McGonigle, T.P. and M.H. Miller. 2000. The inconsistent effect of soil disturbance on colonization of roots by arbuscular mycorrhizal fungi: a test of the inoculum density hypothesis. Appl. Soil Ecol. 14:147-155.
McGuire, A.M. 2003. Mustard green manures replace fumigant and improve infiltration in potato cropping system. Crop Mgt. 2(1) doi:10.1094/CM-2003-0822-01-RS.
Merwin, I.A., R. Byard, T.L. Robinson, S. Carpenter, S.A. Hoying, K.A. Iungerman, and M. Fargione. 2001. Developing an integrated program for diagnosis and control of replant problems in New York apple orchards. New York State Horticultural Society.
Muramoto, J., C. Shennan, G. Baird, M. Zavatta, S.T. Koike, M.P. Bolda, O. Daugovish, S.K. Dara, K. Klonsky, and M. Mazzola. 2014. Optimizing anaerobic soil disinfestation for California strawberries. Acta Hort. 1044:215-220.
Norman, J.R., D. Atkinson, and J.E. Hooker. 1996. Arbuscular mycorrhizal fungal-induced alteration of root architecture in strawberry and induced resistance to the root pathogen *Phytophthora fragariae*. Plant Soil 185:191-198.
Oostenbrink, M. 1966. Major characteristics between the relations between nematodes and plants. Meded. Landbouwhogesch. Wageningen 66-4.
Pacific Northwest Extension. 2007. Commercial red raspberry production in the Pacific Northwest. PNW 598.
Pinkerton, J.N., K.L. Ivors, P.W. Reeser, P.R. Bristow, and G.E. Windom. 2002. The use of soil solarization for the management of soilborne plant pathogens in strawberry and red raspberry production. Plant Dis. 86(6):645-651.
Pinkerton, J.N., P.R. Bristow, G.E. Windom, and T.W. Walters. 2009. Soil solarization as a component of an integrated program for control of raspberry root rot. Plant Dis. 93(5):452-458.
Pinochet, J., A. Camprubi, and C. Calvet. 1993. Effects of the root-lesion nematode *Pratylenchus vulnus* and the mycorrhizal fungus *Glomus mosseae* on the growth of EMLA-26 apple rootstock. Mycorrhiza 4(2):79-83.
Pinochet, J., C. Calvet, A. Camprubi, and C. Fernandez. 1995. Growth and nutritional response of Nemared peach rootstock infected with *Pratylenchus vulnus* and the mycorrhizal fungus *Glomus mosseae*. Fundamental Appl. Nematol. 18(3):205-210.
Pokharel, R. 2011. Soil solarization, an alternative to soil fumigants. Colo. St. Univ. Ext. Fact Sheet 0.505.
Porras, M., C. Barrau, F.T. Arroyo, B. Santos, C. Blanco, and F. Romero. 2007a. Reduction of *Phytophthora cactorum* in strawberry fields by *Trichoderma* spp. and soil solarization. Plant Dis. 91(2):142-146.
Porras, M., C. Barrau, and F. Romero. 2007b. Effect of soil solarization and *Trichoderma* on strawberry production. Crop Protection 26:782-787.
Porter, I.J. and P.R. Merriman. 1983. Effects of solarization of soil on nematode and fungal pathogens at two sites in Victoria. Soil Biol. Biochem. 15(1):39-44.
Pritts, M. P. 2002. From plant to plate: How can we redesign *Rubus* production systems to meet future expectations? Acta Hort. 585:537-543.
Province of British Columbia Ministry of Agriculture. 2013. Raspberries. 23 Oct. 2014. <http://www. agf. gov.bc.ca/aboutind/products/plant/raspberry.htm>.
Pscheidt, J.W. and C.M. Ocamb. 2014. Pacific Northwest plant disease management handbook. Oregon State University, Corvallis, OR.
Reeser, P.W. and J.W. Pscheidt. 1996. Insensitivity to metalaxyl in isolates of *Phytophthora fragariae* var. *fragariae* from strawberry in Oregon. Phytopathology 86(11):S111 (abstr).

Ruano Rosa, D. and C.J. López Herrera. 2009. Evaluation of *Trichoderma* spp. as biocontrol agents against avocado white root rot. Biological Control 51:66-71.

Rudolph, R.E., C. Sams, R. Steiner, S.H. Thomas, S. Walker, and M.E. Uchanski. 2015. Biofumigation performance of four *Brassica* crops in a green chile pepper (*Capsicum annuum*) rotation system in southern New Mexico. HortScience 50(2):247-253.

Samac, D.A. and L.L. Kinkel. 2001. Suppression of the root-lesion nematode (*Pratylenchus penetrans*) in alfalfa (*Medicago sativa*) by *Streptomyces* spp. Plant Soil 235:35-44.

Sanderson, K.R. and J.A. Cutcliffe. 1988. Effect of inter-row soil management on growth and yield of red raspberry. Can. J. Plant Sci. 68:283-285.

Sarrantonio, M. 2007. Building soil fertility and tilth with cover crops, p.16-24. In: A. Clark (ed.) Managing cover crops profitably. 3rd ed. Sustainable Agriculture Research and Education, College Park, M.D.

Seigies, A.T. and M. Pritts. 2006. Cover crop rotations alter soil microbiology and reduce replant disorders in strawberry. HortScience 41(5):1303-1308.

Shennan, C., J. Muramoto, J. Lamers, M. Mazzola, E.N. Rosskopf, N. Kokalis-Burelle, N. Momma, D.M. Butler, and Y. Kobara. 2014. Anaerobic soil disinfestation for soil borne disease control in strawberry and vegetable systems: Current knowledge and future directions. Acta Hort. 1044:165-175.

Smith, E.M. 1964. Potential field for heat transfer in soil covered by different plastic mulches. Proc. Nat. Agr. Plastics Conf. 5:80-92.

Smith, G.S. 1988. The role of phosphorus nutrition in interactions of vesicular-arbuscular mycorrhizal fungi with soilborne nematodes and fungi. Phytopathology 78(3):371-374.

Stapleton, J.J. and J.E. DeVay. 1986. Soil solarization: a non-chemical approach for management of plant pathogens and pests. Crop Protection 5(3):190-198.

Stewart, J.E., D. Kroese, J.F. Tabima, V.J. Fieland, C.M. Press, I.A. Zasada, and N.J. Grünwald. 2014. Pathogenicity, fungicide resistance, and genetic variability of *Phytophthora rubi* isolates from raspberry (*Rubus idaeus*) in the western United States. Plant Dis. 98(12):1702-1708.

Szczygiel, A. and Z. Rebandel. 1988. Control of replanting problem in raspberry. Acta Hort. 233:81-84.

Thies, J.A., A.D. Petersen, and D.K. Barnes. 1995. Host suitability of forage grasses and legumes for root-lesion nematode *Pratylenchus penetrans*. Crop Sci. 35:1647-1651.

Toussaint, V., D. Valois, M. Dodier, E. Faucher, C. Déry, R. Brzezinkski, L. Ruest, and C. Beaulieu. 1997. Characterization of actinomycetes antagonistic to *Phytophthora fragariae* var. *rubi*, the causal agent of raspberry root rot. Phytoprotection 78(2):43-51.

United States Department of Agriculture, Economic Research Service. 2014. Table D-5—Red raspberries: Commercial acreage, yield per acre, utilized production, and season-average grower price, Oregon and Washington, 1980 to date. 13 Apr. 2014. <http://www.ers. usda.gov/data-products/fruit-and-tree-nut-data/yearbook-tables.aspx>.

United States Department of Agriculture, National Agriculture Statistics Service. 2014. Noncitrus fruits and nuts 2013 Summary. 4 Aug. 2014. <http://www.usda.gov/nass/PUBS/ TODAYRPT/ ncit0714.pdf>.

United States Environmental Protection Agency (US-EPA). 2012. Soil fumigant mitigation fact sheet: Buffer zones. 19 Nov. 2014. <http://www2.epa.gov/sites/production/files/2013-10/documents/sfm-buffer-zones-2012.pdf>.

US-EPA. 2014. Soil fumigants. 20 Oct. 2014. <http://www2.epa.gov/soil-fumigants>.

US-EPA. 2015. The phase-out of methyl bromide. 18 June 2015. <http://www.epa.gov/ ozone/mbr/>.

Valois, D., K. Fayad, T. Barasubiye, M. Garon, C. Déry, R. Brzezinski, and C. Beaulieu. 1996. Glucanolytic actinomycetes antagonistic to *Phytophthora fragariae* var. *rubi*, the causal agent of raspberry root rot. Appl. Environ. Microbiol. 62(5):1630-1635.

Vrain, T.C. and H.A. Daubeny. 1986. Relative resistance of red raspberry and related genotypes to the root lesion nematode. HortScience 21(6):1435-1437.

Vrain, T., R. DeYoung, J. Hall, and S. Freyman. 1996. Cover crops resistant to root-lesion nematodes in raspberry. HortScience 31(7):1195-1198.

Walters, T.W., J.N. Pinkerton, R. Ekaterini, I.A. Zasada, M. Particka, H.A. Yoshida, and C. Ishida. 2009. Managing plant-parasitic nematodes in established red raspberry fields. HortTechnology 19(4):762-768.

Walters, T., J. Gigot, and I. Zasada. 2011. Preplant soil fumigation and alternatives for berry production. WSU Ext. FS064E.

Washington State Pest Management Resource Service (WSPRS). 2014a. Oregon, non-bearing raspberry, nematode. 12 May 2015. <http://cru66.cahe.wsu.edu/labels/ViewLabels .php?radOutputType=standard&selFld1=none&selFld2=none&selFld3=none&selFld4=none&selFld5=none&selFld6=none&selFld7=none&selFld8=none&selFld9=none&view=View+Labels&SrchType=C>.

WSPRS. 2014b. Washington, non-bearing raspberry, nematode, 2014. 23 Oct. 2014. <http://cru66.cahe.wsu.edu/labels/ViewLabels.php?radOutputType=standard&selFld1=none&selFld2=none&selFld3=

none&selFld4=none&selFld5=none&selFld6=none&selFld7=none&selFld8=none&selFld9=none&view=View+Labels&SrchType=C>.

WSPRS. 2014c. Washington, Oregon, raspberry, nematode. 12 May 2015. <http://cru66.cahe.wsu.edu/labels/ViewLabels.php?radOutputType=standard&selFld1=none&selFld2=none&selFld3=none&selFld4=none&selFld5=none&selFld6=none&selFld7=none&selFld8=none&selFld9=none&view=View+Labels&SrchType=C>.

WSPRS. 2014d. Washington, Oregon, raspberry, Phytophthora root rot. 5 May 2015. <http://cru66.cahe.wsu.edu/labels/ViewLabels.php?radOutputType=standard&selFld1=none&selFld2=none&selFld3=none&selFld4=none&selFld5=none&selFld6=none&selFld7=none&selFld8=none&selFld9=none&view=View+Labels&SrchType=C>.

Washington State University (WSU) AgWeatherNet. 2015a. Washington State University Mount Vernon Historic Data. Subset Used: May 2008 to September 2010. 18 June 2015. <http://weather.wsu.edu/awn.php?page=historicData/>.

WSU AgWeatherNet. 2015b. Washington State University Puyallup Historic Data. Subset Used: July 2003 to September 2003. 18 June 2015. <http://weather.wsu.edu/awn.php ?page=historicData/>.

Weber, C. 2012. Raspberry variety review. Cornell Univ. Coop. Ext.

Weindling, R. 1932. *Trichoderma lignorum* as a parasite of other soil fungi. Phytopathology 22(8):837-845.

Weindling, R. 1941. Experimental consideration of the mold toxin of *Gliocladium* and *Trichoderma*. Phytopathology 31:991-1003.

Wilcox, W.F. 1989. Identity, virulence, and isolation frequency of seven *Phytophthora* spp. causing root rot of raspberry in New York. Phytopathology 79(1):93-101.

Wilcox, W.F. and B.A. Latorre. 2002. Identities and geographic distributions of *Phytophthora* spp. causing root rot of red raspberry in Chile. Plant Dis. 86(12):1357-1362.

Wilcox, W.F., M.P. Pritts, and M.J. Kelly. 1999. Integrated control of Phytophthora root rot of red raspberry. Plant Dis. 83(12):1149-1154.

Wilcox, W.F., P.H. Scott, P.B. Hamm, D.M. Kennedy, J.M. Duncan, C.M. Brasier, and E.M. Hansen. 1993. Identity of a *Phytophthora* species attacking raspberry in Europe and North America. Mycol. Res. 97(7):817-831.

Zasada, I.A., S.L.F. Meyer, and M.J. Morra. 2009. Brassicaceous seed meals as soil amendments to suppress the plant-parasitic nematodes *Pratylenchus penetrans* and *Meloidogyne incognita*. J. Nematol. 41(3):221-227.

Zasada, I.A. and P.P. Moore. 2014. Host status of *Rubus* species and hybrids for the root lesion nematode, *Pratylenchus penetrans*. HortScience 49(9):1128-1131.

Zasada, I.A., T.W. Walters, and J.N. Pinkerton. 2010. Post-plant nematicides for the control of root lesion nematode in red raspberry. HortTechnology 20(5):856-862.

Zebarth, B.J., S. Freyman, and C.G. Kowalenko. 1993. Effect of ground covers and tillage between raspberry rows on selected soil physical and chemical parameters and crop response. Can. J. Soil Sci. 73:481-488.

❖ ❖ ❖ ❖

Texture phenotyping in fresh fleshy fruit

After the visual appearance, the texture of fresh fleshy fruit (FFF) is the most relevant factor that determines its acceptability. Therefore, texture should be a priority on fruit quality research. Sensory evaluation and rheological analysis have been the classical approaches used to study texture of foods. However, the relevance of texture on describing a FFF has normally been underestimated. The flesh firmness instead has been the most commonly assessed trait in most researches on fruit quality. Even though flesh firmness is a relevant component of texture, it does not help for segregating two samples possessing different textures. A deeper study of texture on FFF would allow us to discover and to annotate new phenotypic attributes. These data will help to reduce the imbalance between the scarce data obtained through traditional phenotyping and the huge amount of data obtained via high output genotyping platforms. The aim of this review was to analyze critically the literature concerning sensory evaluation and the rheological studies on FFF, looking to reach a better comprehension of texture, and consequently to reach a deeper characterization of phenotypes in genetic and descriptive studies on FFF species. Abstract from: Loreto Contador, Paulina Shinya, and Rodrigo Infante. Scientia Horticulturae 193:40-46.