Expanding Cherry Production in British Columbia under Climate Change

Final Report

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Disclaimer

The Governments of Canada and British Columbia are committed to working with industry partners. Opinions expressed in this document are those of the authors and not necessarily those of the Governments of Canada and British Columbia, or the Investment Agriculture Foundation.

Executive Summary

Climate change has resulted in warmer average temperatures and is predicted to result in reduced water available for irrigation, even as growing season droughts are expected to increase. Climate models indicate that the area suitable for production of sweet cherries in the BC interior has already increased northward and in elevation. As opportunities arise for expanding production of perennial horticultural crops in the BC interior due to climate change, it is important to consider soil and water resources in site selection to optimize fruit production. Using sweet cherry as a key indicator crop, we assessed the impact of mulch, compost and postharvest deficit irrigation on water use efficiency, soil water holding capacity and crop production in two newly-planted north Okanagan orchards and one well-established south/central Okanagan orchard. Soil was collected from six sites newly designated as climatically suitable for cherry production and from twelve older orchards throughout the Valley. Using greenhouse bioassays of cherry seedlings in 'old' and 'new' soils, we determined whether soil chemistry and indigenous soil microbial populations (plant parasitic nematodes, mycorrhizal fungi, soil bacterial and fungal populations) placed any restrictions on expanding cherry production into the newly designated areas.

Surface application of compost increased soil and leaf nutrient status in both newly-cultivated and older orchard soils and showed potential to improve fruit quality. Compost application may also maintain soil health, and mitigate future soil-borne disease in newly established orchard soils that have never cropped sweet cherry or other tree fruits. Woodchip mulch had no effect on soil nutrient status and soil biology after three growing seasons, but increased foliar P at two sites. It may have benefits longer term in enhancing soil organic matter and improving soil water holding capacity. Cost/benefit analysis suggests that compost amendment has greater potential for benefits to be realized in the short term than mulch, but the costs may outweigh the benefits to be gained. Overall, we conclude that the use of organic amendments may be an effective tool to maintain and/or restore soil organic carbon in perennial horticulture and to enhance sweet cherry production.

Postharvest deficit irrigation with a 25% reduction in water application had no detrimental effects on soil physiochemical or biotic properties, on tree growth, tree water stress, foliar nutrient status, fruit yield or quality in the two years following its implementation. Water use efficiency increased with its implementation. Cost/benefit analysis suggests that adoption of postharvest irrigation would be beneficial as costs of implementation are minimal and water usage is decreased without loss of sweet cherry productivity. However, there is little incentive presently for growers to adopt this management practice as current water allocations are sufficient to meet grower needs.

The bioassay indicated that new orchard soils were more 'biologically suitable' for planting sweet cherry than old orchard soils, and the lower plant growth observed in old orchard soils may have been the result of detrimental changes in the microbial community, rather than from abiotic elements in the soil environment. Orchard management practices that maintain soil organic carbon levels, and stimulate an active microbial community will benefit growth of cherry trees in both new and old orchard soils.

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1.0 Introduction

Climate change has become a reality, making environmentally sound and sustainable crop production necessary to provide sufficient food for the increasing human population, which is expected to reach 9 billion by 2050 (FAO 2002). The altered amount and distribution of precipitation, heat, and atmospheric CO_2 concentrations are all expected to alter the suitability of specific locations for crops (Neilsen et al. 2013), and agricultural productivity patterns worldwide (Brouder and Volenec 2008). It is difficult to predict whether these factors will decrease or increase the current levels of agricultural production (Schimel 2006), as both the geographic range of crops, pests and diseases, and the frequency of extreme weather events are expected to change (Neilson et al. 2013). Therefore, crop management practices that conserve water, reduce soil erosion, and increase carbon (C) sequestration to enhance soil health, are necessary to help mitigate and adapt to climate change and contribute to the future food requirements for the world's growing population (Lal et al. 2011).

Sweet cherry (*Prunus avium*) is one of the economically important fruits produced in Canada. The market value for commercial production of this fruit has been increasing and sweet cherry has become one of the top ten marketed fruits grown in Canada (Agriculture and Agri-Food Canada, 2013). British Columbia (BC) is the top producer of sweet cherries, accounting for 89% of the total production in the country and the Okanagan Valley is the major production area (Neilsen et al., 2014; BC Ministry of Agriculture, 2014). For example, in 2014, about 14,000 tonnes of sweet cherries were produced out of 126,000 tonnes of total tree fruits produced in BC. In 2015 BC cherry exports increased 56% from the previous year to 13,600 metric tonnes, with a value of $91.7 million (70% increase) (BC Ministry of Agriculture, 2016). However, the cost of irrigation, spraying, labour, and propensity to damage and disease make cherry an expensive crop for growers, and the area of suitable land for cherry fruit production in BC has been limited (Utkhede and Thomas 1988). One way farmers are trying to increase cherry yields is by planting dwarfing rootstocks, which are smaller and can be planted closer together than conventional trees, in order to produce more fruit at a higher efficiency (Lang 2000). When young trees are replanted into orchard soils previously planted to fruit trees, stunted growth, low productivity, and a decline in tree vigour is often observed and this is known as replant disease (Mazzola 1998). Both biotic and abiotic factors may contribute to replant disease, but biotic factors are considered the most important and may involve the buildup of a complex of plant parasitic nematodes and soil fungal pathogens that stunt root and shoot growth (Mazzola 1998). Until recently, before replanting cherry, the primary means of mitigating replant stress has been to fumigate the soil. The lack of access to fumigants in agriculture, due to environmental and human health regulations, emphasizes the importance of developing alternative methods for mitigating and controlling replant stress of cherry, such as the application of organic amendments, which have been shown to improve early growth of cherry (Watson et al. 2017).

One adaptation to climate change in the British Columbia Interior will be to expand sweet cherry (*Prunus avium* L.) production into northern and higher elevation areas that now have warmer temperatures and a longer growing season (Quamme and Neilsen 2011). Crop suitability modelling for Sweetheart cherry in the Okanagan region over the past 50 years showed a significant expansion of land climatically suitable for

cherry growth (Fig. 1, Neilsen and Smith, unpublished data). However, in addition to suitable climate, it is important that soil chemical and microbiological conditions be suitable for cherry production (Forge et al. 2013, Neilsen et al. 2014).

The soil in the new areas has never been cultivated, and there is evidence to suggest that the soil microbial community in non-cultivated soils may be suppressive to soil-borne plant pathogens, and, in turn, beneficial to plant growth (Mazzola 1999). On the contrary, soil biological factors may influence cherry range expansion negatively, as the replacement of a native plant with a foreign species may change the selective pressures acting on the soil microbiome (Bakker et al. 2012; Brown and Vellend 2014). For instance, the foreign plant species may secrete exudates into the soil that serve as inefficient substrates for the native microbial community, causing this non-adapted microbiome to be less effective at preventing pathogen establishment, and thereby, increasing plant susceptibility to disease (Bakker et al. 2012; Brown and Vellend 2014). Ultimately, it will be important to implement proper land use practices with new orchard establishment to manage plant-soil feedbacks (Van der Putten et al. 2016). This could be accomplished by the use of organic amendments, cover crops, or reduced tillage, as such practices have been shown to foster microbiome characteristics that constrain disease, and increase soil health (Larkin et al. 2015).

Although new cherry orchards are being established in the higher latitude areas in the North Okanagan, the availability of adequate and regular water supply is a major concern due to climate change and competition for crop production and fresh water availability for a rapidly growing urban population (Neilsen et al., 2016, 2006). Based on the current and predicted future trends, there will be a requirement for stored water earlier in the growing season, which may potentially lead to water shortages. Thus, finding management options that increase water use efficiency of cherry trees would be useful for sustainable production of cherries in these new orchards.

The **long-term objective** of this project was to facilitate expansion of cherry production in the Okanagan Valley under current and projected climate conditions while improving soil health and water use efficiency. Two short-term objectives were also developed:
Objective 1: To determine the effect of orchard floor management (composts, mulches) and irrigation method on water use efficiency, water holding capacity, yield, and soil health in two new Okanagan cherry orchards at the northern limits for production, compared with one established orchard in the south/central Okanagan.

Five activities were defined under this objective:

1.1 Assess suitable sites for new and established cherry orchards.
1.2 Set up replicated orchard floor and irrigation treatments at each site.
1.3 Assess the impact of the orchard floor and irrigation treatments on water use efficiency, soil water holding capacity, crop yield and soil health.
1.4 Assess the economic cost/benefit of the orchard floor and irrigation treatments on cherry production.
1.5 Disseminate findings broadly.

Objective 2: To determine how soil biological and chemical factors will influence expansion of cherry orchards into new growing areas made available by warmer temperatures and a longer growing season.

Four activities were defined under this objective:

2.1 Assess suitable sites for soil and microbial analysis of old and new cherry production sites.
2.2 Collect soils for determination of chemical properties, indigenous microbial communities and for greenhouse assays.
2.3 Assess the contribution of indigenous soil microbial communities to cherry seedling growth in greenhouse bioassays.
2.4 Make recommendations regarding the suitability of new sites for cherry production and disseminate findings broadly.

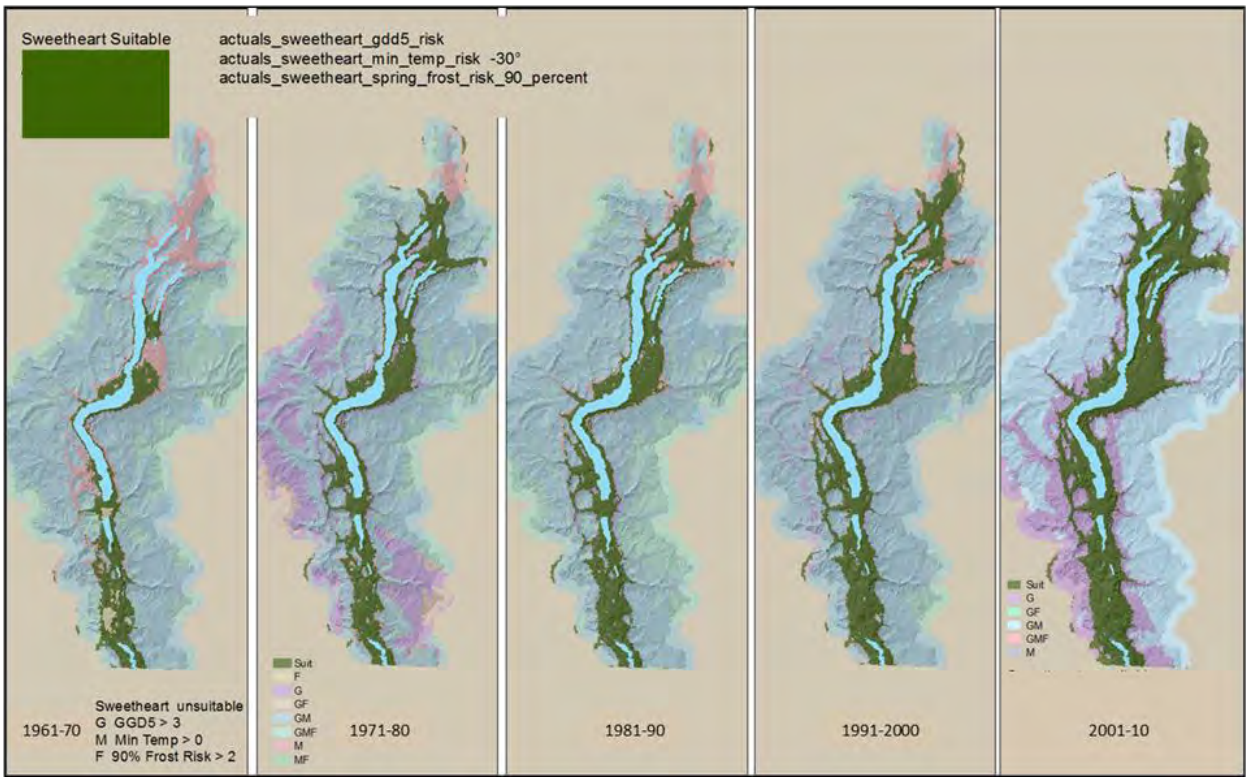

Figure 1. Crop suitability modelling for Sweetheart cherry in the Okanagan region over the past 50 years. Dark green areas are climatically suitable. Developed using the following combined criteria: chance of 90% blossom kill in spring, growing season length and absolute minimum winter temperature. (Denise Neilsen and Scott Smith, unpublished data).

2.0 Methods

2.1 Objective I

Site descriptions

The study sites were located at three newly-planted orchards in the Okanagan Valley of British Columbia: two were planted at sites never before used to grow tree fruits (Sites 1 and 2) and one was planted on a long-established, older orchard site (Site 3). A fourth older site was identified but will not be discussed

here as the previous history and experimental design were quite different from the first three sites.

Site 1 (50° 14' N 119° 8' W) and Site 2 (50° 14' N 119° 7' W) were located in Coldstream, BC and they both have sandy loam soils. Site 1 was former grazing pastureland that became an orchard in April 2015 when sweet cherry trees ['Stacatto' (*Prunus avium* L.) on Mazzard [(*P. avium*) rootstock] were planted here. Site 2 was formerly a dairy farm that became an established orchard in Spring 2014 when sweet cherry trees ['Skeena' *(P. avium*) on Giesela 6 (*Prunus ceras*us x *Prunus canescens*) rootstock] were planted here. The trees at Sites 1 and 2 were irrigated daily during the growing season, and on an as-needed basis after harvest, through 2 liter-per-hour (ph) ram line irrigation systems, or through 48 lph Maxijet microsprinker irrigation systems. Trees were fertigated in the 2015, 2016 and 2107 growing seasons with 163 g nitrogen tree^{-1} (as calcium nitrate) three times between mid-May and the end of June; 285 g N tree^{-1} (as urea) at the end of March; a 20-20-20 N-P-K (nitrogen-phosphorus-potassium) blend at 272 g tree^{-1} in mid-May; and two applications of magnesium (as magnesium sulphate) at a rate of 0.95 g tree^{-1} in May.

Site 3 (49° 51' N 119° 23' W) has loamy sand soil and it was planted with sweet cherry trees ['Sentennial' (*P. avium*) on Mazzard (*P. avium*) rootstock] in Spring 2013 on soil that previously cropped apple. Irrigation at Site 3 was supplied through a 72 lph micro sprinkler irrigation system every 1-2 h d^{-1} during the growing season, and 4-5 h wk^{-1} after harvest. Trees were fertigated in the 2015, 2016 and 2017 growing seasons with 150 g nitrogen tree^{-1} (as calcium nitrate) two times between mid-May and the end of June; 250 g tree^{-1} of a 20-20-20 N-P-K blend in mid-May; and two applications of magnesium (as magnesium sulphate) at a rate of 0.9 g m^{-2} in May.

The pest management regime at Site 1 was different from Sites 2 and 3, since Site 1 was a non-bearing orchard. However, rotating fungicides, herbicides, and insecticides of differing chemistries were sprayed for powdery mildew, weeds, and black cherry aphids at all orchard sites. At Sites 2 and 3, rotating insecticides and fungicides of differing chemistries were sprayed for spotted wing *Drosophila* and fungi *Monilinia*, *Alternaria*, and *Botrytis.*

Experimental design

Sites 1, 2, and 3 consisted of split-plot designs made of 36 plots; each plot had two measurement trees flanked by two guard trees (Table 1). Whole-plots consisted of two irrigation treatments: full irrigation and reduced deficit irrigation, each replicated 6 times. Within whole-plots, there were three soil amendment sub-plots: compost, mulch, and non-amended. Reduced deficit irrigation came into effect in August 2016 (after harvest) at Sites 2 and 3. The irrigation treatments included full irrigation (100%) and post-harvest deficit irrigation (a reduction of 25% and 28% of the full irrigation at Sites 2 and 3, respectively).

'Glengrow' compost (Glenmore Landfill, City of Kelowna, BC) and 'Douglas-fir' (*Pseudotsuga menziesi)* woodchip mulch were surface applied to plots at Sites 1, 2, and 3 in July 2015, and again in May 2016 and May 2017. Feedstocks for 'GlenGrow' compost consisted of yard trimmings, such as grass and plant debris. 'Douglas-fir' mulch was a by-product of the forest industry in the area, and was sourced from local distributers (Pryce Landscape Products, Vernon, BC for Sites 1 and 2; Better Earth Garden Centre, Kelowna, BC, for Site 3). Application rates of compost and woodchip mulch at all three sites are shown in Table 1. Analytical nutrient results for GlenGrow compost were supplied by the City of Kelowna. Nutrient analyses for the 'Douglas-fir' mulch were done by the BC Ministry of Environment Analytical Lab (Victoria, BC). The carbon-to-nitrogen (C:

N) ratios of the Better Earth and Pryce woodchip mulches were approximately 10-fold and 8-fold higher, respectively, than that of the GlenGrow compost. In addition, GlenGrow compost had 13-fold higher available P than that of the woodchip mulches. Nitrogen was applied by means of fertigation and <10% of the total nitrogen in the compost was assumed to be "available" (Gale et al. 2006). Nutrient additions from woodchip mulch were negligible, as only a small fraction of this material had been incorporated into the soil. Therefore, trees in the compost plots received ~ 10% more nitrogen than trees in bare and mulch plots.

Soil moisture and temperature probes, 5TM (moisture and temperature sensors; Decagon Devices, Pullman, WA) or 5TE (moisture, temperature and EC; Decagon Devices, Pullman, WA) were installed at all experimental sites, except Site 2, which received only soil moisture probes including Decagon EM50 or Em5b dataloggers (Decagon Devices, Pullman, WA) with EC-5 (moisture sensors; Decagon Devices, Pullman, WA). The probes were in triplicate for each irrigation treatment at each site. Automated data loggers were set to record soil moisture and temperature every four hours and the data were manually downloaded monthly.

Table 1. Orchard type, plot size, and compost and mulch application characteristics for all three sites. 'Glengrow' compost and the woodchip mulches ('Better Earth' and Pryce') were applied to Sites 1, 2, and 3 in Spring of 2015, 2016 and 2017.

					Compost			Mulch		
Site	**Orchard Type**	**Trees/ plot**	**Distance between trees in row (m)**	**Application area of amendment/ plot (m^2 $plot^{-1}$)**	**Type[a]**	**Compost required/ plot (m^3 $plot^{-1}$)[b]**	**Surface applied to soil, or incorporated into soil?**	**Type[c]**	**Mulch required/ plot (m^3 $plot^{-1}$)[b]**	**Surface applied to soil, or incorporated into soil?**
1	New	4	2.2	8.8	GG	0.44	Surface	DF - P	0.44	Surface
2	New	4	2.4	9.6	GG	0.48	Surface	DF - P	0.48	Surface
3	Replant	4	2.7	10.8	GG	0.54	Surface	DF - B	0.54	Surface

a = GG ('GlenGrow' compost)
b = Mulch and compost applied to each plot calculated assuming a 0.05 m application depth.
c = DF-P ('Douglas-fir' Pryce') or DF-B ('Douglas-fir' Better Earth)

Soil and root sampling

Soil was sampled in June 2015, before organic amendment addition, to provide a baseline measurement of the physicochemical status at each of the three orchards (hereafter referred to as baseline samples). Ten soil cores (2-cm diameter sampling tube to a depth of 30 cm) were taken from five of the rows destined to be rows included in the experimental treatment plots. Two cores were taken from each of the five rows. Electrical conductivity (EC) and pH of dried soil subsamples were measured in a 1: 2 soil: water suspension. Permanganate-oxidizable carbon (POXC), a measure of labile carbon in the soil, was measured using 0.25 g of dry soil according to Culman et al. (2012). Dried soil subsamples were analyzed for Bray I-extractable P, CEC, total C and N, exchangeable bases (Ca, Mg, K, Na, Ca, Mg, K, Na), and organic matter by

A&L Laboratories. Dissolved organic carbon (DOC) was extracted (0.5 M potassium sulphate), and extracts analyzed using persulphate oxidation. Organic matter (OM) content was determined gravimetrically by a loss on ignition procedure (%LOI).

Soil sampling was repeated within experimental plots at all three sites in October 2015, 2016 and 2017. Four soil cores were taken 30 cm from each measurement tree of each plot and combined to form a composite sample. Fine roots (~20 cm total length) were collected separately using a hand trowel. Roots were collected from three different locations at distances of 30 cm from each tree, and at a depth of 5 – 30 cm, roots were washed free of adhering soil and stored in 70% ethanol until analysis, and soil was sieved (5-mm sieve). Soil subsamples were taken from the soil composite samples from each plot at each site and were stored frozen (-20 °C), fresh (4 °C), or dried (at room temperature). Until further processing, frozen soil was stored for up to 3 months, fresh soil was stored for up to 2 months, and dried soil was stored for up to 4 months.

Soil biotic property analyses

Soil microbial activity was measured on sieved (<5 mm), fresh (stored at 4 °C) soil samples within 2 months after sampling in all sampling years using the fluorescein diacetate (FDA) hydrolysis method (Green et al. 2006; Zhai et al. 2009). Colorless FDA is hydrolyzed by both free and membrane-bound enzymes, of both fungi and bacteria, releasing fluorescein, a colored end product, which is measured by spectrophotometry (Adam and Duncun 2001).

Nematode extractions from soil and roots from each site were done in October 2015, 2016 and 2017. All root and soil extractions were completed within 2 wk of soil collection from each site, and all nematode counts were completed within 2 months of extraction from each site. sSoil from each plot was sieved (5-mm sieve) to remove debris and large roots. Fine roots (< 2 mm diameter) were washed with water and used for endoparasitic nematode extraction (*Pratylenchus* spp.) using the Petri-plate technique (Ravichandra 2014), while 50 g of soil were extracted using the Baermann-pan technique (Hackenberg et al. 2000). Nematodes were viewed (100x magnification) by direct examination under a microscope in a counting dish placed under an inverted microscope (Olympus CK2 Inverted Microscope) for identification based on morphological features. Individuals were identified as *Pratylenchus* on the basis of three lip annules, short stylet with basal knobs, pharynx overlapping the intestine ventrally, and rounded tail (Castillo and Vovlas 2007).

Percent root colonization by AMF was determined using the magnified intersections method (McGonigle et al. 1990).

Real-time PCR was used to quantify the abundance of bacterial and fungal DNA in a subsample of soil from each plot. DNA was isolated from 0.25 g of frozen soil (- 20 °C subsamples) per plot using a PowerSoil DNA Isolation Kit (Mo Bio Laboratories, Carlsbad, CA). The total abundance of bacteria was estimated using the primer set BACT1369F (5'-CGGTGAATACGTTCYCGG-3') / PROK1492R (5'-GGWTACCTTGTTACGACTT-3') to amplify a portion of the 16S rRNA region (Suzuki et al. 2000). The temperature profile was 95 °C for 2 min, 40 cycles of 95 °C for 30 s and 56 °C for 30 s, followed by one cycle of 65 °C for 5 s and 95 °C for 50 s. The abundance of total fungal DNA was determined by amplification of the 18S rRNA region using the primer set FR1 (5'-AICCATTCAATCGGTAIT-3') / FF390 (5'-CGATAACGAACGAGACCT-3') (Prevost-Boure et al., 2011). The

temperature profile was 95 °C for 2 min, 40 cycles of 95 °C for 15 s and 59 °C for 1 min, followed by one cycle of 70 °C for 60 s. Quantification of each gene region was determined by comparison of the C_T (cycle threshold) to a constructed standard curve. The abundance of total bacteria and fungi was reported as 16S and 18S copy number g^{-1} of soil, respectively.

Soil for next generation sequencing (NGS) of soil microbial populations was sampled in October 2016 at each orchard location. At each location, all treatments (bare, mulch, and compost) were sampled in triplicate. In each plot (representing one treatment), four cores (30 cm deep) were sampled from each of two trees (20 cm distance from tree) and the total of eight cores combined. Three sites located outside the orchard were randomly chosen and sampled to represent undisturbed soil. Soil was sieved and stored at -20^{o}C until further analysis. DNA was extracted from 10 g of soil using the DNeasy PowerMax Soil Kit (Qiagen, Carlsbad, CA), eluted in 5 ml of elution buffer and stored in aliquots at -20°C until use. Dual-barcoding was performed by a two-step PCR. During the first 'amplicon' PCR, the V3-V4 region of the 16S rRNA gene (bacterial and archaeal) was amplified using primers CS1-341F/CS1-341F-spacer and CS2-806R/CS2-806R-spacer (Frey et al., 2016). The fungal ITS2 region was amplified using primers CS1-ITS3ngsmix1-5/CS1-ITS3ngsmix1-5-spacer and CS2-ITS4ngsUni/CS2-ITS4ngsUni-spacer (Tedersoo et al., 2014; Tedersoo and Lindahl, 2016). Conditions for the bacterial 'amplicon' PCR were: 95°C for 10 min, 20 cycles at 95°C for 1 min, annealing at 56°C for 1 min, 68°C for 1 min, and a final extension at 68°C for 10 min. Fungal amplicon conditions were similar, except that an annealing temperature of 58°C and 28 cycles were used. The amplicon products were diluted 1:15 and 2 µl used as template for the 'index' PCR. 'Index'primers contained CS1/CS2 linker sequence, unique 8 nucleotide barcode sequences and the Illumina adapter sequences P5 and P7 that hybridize into the MiSeq® instrument flow cell. Cycling conditions were: 95°C for 1 min, 15 cycles at 95°C for 30 s, 60°C for 30 s, 68°C for 1 min, and final extension at 68°C for 5 min. Samples were submitted to the IBEST Genomics Resources Core facility at the University of Idaho, USA, for quantification, normalization, pooling, and sequencing. The QIIME2 next-generation microbiome bioinformatics platform was used to process the raw data and to assess α-diversities for the bacterial and fungal populations. Statistical analysis was performed using R.

Statistical analysis for soil and root analyses

To compare treatment differences at Sites 1, 2, and 3, the effect of treatment on the measured variables was analyzed using repeated measures, blocked, one-way analysis of variance (ANOVA). The repeated measure was sampling year, the main factor was treatment, and the random factor was site. To compare the effects of the amendments within each site over time, repeated measures, blocked, one-way ANOVAs were performed. Sampling year was the repeated measure, treatment was the fixed factor, and block was the random factor. In both cases, if there were significant main factor amendment, or year by amendment interactions, a Tukey's HSD test was used to test the significance of differences (at a 5% significance level).

Analysis of variance assumptions were tested for each measured variable at all sites. Abundance of *Pratylenchus* in soils and roots was log (x+1) transformed and percent AMF root colonization data were square-root transformed to correct for unequal variance and/ or non-normality. Other variables were log

transformed if they were of unequal variance and/ or not normal. All tests and test assumptions were performed using SPSS Statistics version 23.0 (IBM, Chicago, IL).

Plant analyses

Water potential has been reported as a sensitive physiological indicator of the water status of the plant (Jones, 2007; Remorini and Massai, 2003). Stem water potential *(Ψ_{stem})* is more sensitive and accurate than leaf water potential *(Ψ_{leaf})* in indicating the amount of stress experienced in the actual plant trunk at that moment (Naor, 2006). Thus, to evaluate the water status of the trees, mid-day (10 am - 12 pm) Ψ_{stem} was measured from two leaves located on the shaded side of each tree using a Scholander pressure chamber (Model 3005: Soilmoisture Equipment Corp., Santa Barbara, CA, USA). Four replicates at each site were measured every two weeks. In brief, the leaves were wrapped with black plastic and aluminum foil while attached to the tree, to reduce the effect of transpiration, and left for an hour to allow equilibration with the stem before excision. Then the leaves with their petioles were detached from the trees, the petioles were cut at an angle with a blade, rapidly placed in a pressure chamber, and pressurized with compressed nitrogen gas, until the cut surface became wet and shiny. The pressure was then quickly turned off, and the pressure indicated on the gauge was recorded as MPa.

WUE is a measure of how efficiently plants use a unit of available water. WUE at crop level considers the different water losses (transpired water, soil evaporation and runoff), and is the ratio of total harvested yield to total water consumed (water applied by irrigation) during the growing season.

Tree trunk cross sectional area (TCSA) and leaf area (LA) are important indicators of plant productivity. Every year of treatment, annual measurements of trunk diameter were made during the dormant season (November) at a permanently marked height which is 0.3 m above the graft union. Samples comprised of 25 leaves were collected from the mid third portion of extension shoots of the current-year's growth at the standard mid-summer sampling period (mid-July to early August). Then, LA was measured from 20 sub-sampled leaves with a leaf area meter (LI-3000, LI-COR Inc.). Dried ground samples of the leaf tissue were sent to BC Ministry of Environment Laboratory, Victoria for mineral analysis.

During the commercial harvest period, a randomly-harvested 100-fruit subsample from each plot was obtained to determine average fruit weight, the number of split fruits and other quality analysis methods as described by Neilsen et al., (2014). In brief, out of the 100 fruit subsamples, 20 split-free fruit were selected to measure fruit firmness, stem pull force, and fruit color. Then, the fruit was juiced by mashing in a plastic bag and squeezed out by hand with cheese cloth. Soluble solids concentration (SSC) and titratable acidity were was determined on this juice.

Greenhouse bioassay using amended orchard soil

Soil samples were taken from all three sites in August 2016. Two soil samples were taken with a shovel (30 cm depth) from both measurement trees within sub-plots (compost, mulch, or no amendment) of full irrigation main plots, until approximately 10 L of soil were collected from each treatment at each site (18 plots total). Surface mulch and compost were pushed aside before soil was sampled. The soil was brought back to the lab in coolers, thoroughly mixed, sieved (< 5 mm) to remove rocks and debris, and stored at 4°C for up to one week before further processing.

Half of the soil from each treatment was microwaved in 500-ml increments in autoclave bags (VWR® Autoclavable Polypropylene Bags, Radnor, PA) for 4 min, followed by shaking, as many times as required for the internal soil temperature to reach 121 °C. The internal temperature was checked by placing a thermometer into the centre of the soil sample. Microwaved soil was then stored at 4°C overnight. The next day, soil was microwaved again using the same protocol. Since sterilization requires the destruction of both viable cells, and microbial spores, microwaving the soil a second time ensured the destruction of any spores that may have germinated after the initial sterilization process (Trevors 1996). The soil was left to cool at 4.0°C before planting.

Seven-week-old micro-propagated 'Crimson' sour cherry (*Prunus cerasus*) explants were obtained in September 2016 from Agriforest Biotechnologies in Kelowna, BC, Canada. Pots (9.52 cm diameter and 10.73 cm height) were filled with 400 ml of sterilized or non-sterilized field soil (collected from Sites 1, 2, and 3) and plants were planted singly in each pot. The experiment was fully factorial (3 sites x 3 field soil treatments x 2 lab sterilization regimes x 12 replicates = 216). Plants were arranged in a completely randomized block design in a greenhouse (UBC Okanagan, Kelowna, BC, Canada) and grown at 24°C ± 10.0°C; 45-90% humidity (average daily minimum and maximum), irradiance of 524 µmol m^2 s^{-1} of PAR (photosynthetically active radiation) and a 16-h photoperiod. Plants were watered with distilled water every two days until water holding capacity was reached. Plants were monitored daily for powdery mildew and spider mites, and sprayed with 5 mL L^{-1} of Green-Earth® lime-sulphur, and 20 mL L^{-1} of Safer's® insecticidal soap, respectively, as needed. Plants were harvested November 14, after 10 weeks of growth.

At time of harvest, shoots were cut at soil level and total shoot height increment was measured, prior to determining oven-dried shoot weight. Root systems were scanned and the following parameters measured using WinRHIZO Regular software (Regent Instruments Inc., Quebec City, QC): total root length, total root area, and percent necrotic root surface area. A 'necrosis key' was calibrated with a range of root color classes. 'Necrotic roots' were assigned as those that were black to dark brown, while 'healthy roots' were assigned lighter shades of brown. After scanning, subsamples of fine root tissue were used for nematode colonization analysis. After nematode extractions were completed, roots were dried and weighed, and added to the earlier weight to calculate total root weight.

Pratylenchus spp. populations from the microwave and steam sterilizer treatments were determined on each sample prior to planting in order to confirm successful sterilization of test soil. At the time of harvest, nematodes were extracted from a subsample of soil (50 g) and a subsample of fine root tissue (~2 g) from each plant (section 2.3.5). The number of *Pratylenchus* spp. recovered in soil at harvest (*Pratylenchus* final, or Pf) was divided by the number of initial *Pratylenchus* spp. in soil at planting (*Pratylenchus* initial, or Pi) to determine multiplication rate of *Pratylenchus*.

To compare growth of plants among field soil amendment treatments and lab sterilization regimes across sites, plant growth data were analyzed using a blocked two-way Multiple Analysis of Variance (MANOVA) using general linear model (GLM). The main factors were field soil amendment treatment and lab sterilization regime, and the random factors were site and. To compare *Pratylenchus* abundance data among field soil amendment treatments, data were analyzed using a blocked one-way ANOVA using GLM. The main factor was field soil amendment, and the random factors were site and block. To compare the main factor

field soil amendment treatments and lab sterilization effects for each site, plant growth data were analyzed using a blocked two-way MANOVA using GLM. Field soil amendment treatment and lab sterilization regime were the main factors, and block was the random factor. When main factor effects of field soil amendment treatment, or their interaction with lab sterilization regime were significant, Tukey's HSD (honest significant difference) test was used to test the significance of differences (at a 5% significance level).

Cost/Benefit Methods

To perform the Cost-Benefit analyses and provide the economics conclusion included in this report, we followed the widely accepted methodology described in Boardman et al. (1996). The methodology includes the following nine steps:

1. Specify the set of alternative projects
2. Decide whose benefits and costs count
3. Identify the impacts categories, catalogue them, and select measurement indicators.
4. Predict the impacts quantitatively over the life of the project.
5. Monetize all impacts
6. Discount benefits and costs to obtain present values
7. Compute the net present value of each alternative
8. Perform sensitivity analysis
9. Make a recommendation

2.2 Objective II

Soil Sampling and Analysis

In October 2015, soil was collected from 18 orchard sites, which differed in land use history, soil type, geographic region within the Okanagan Valley of British Columbia, Canada, and orchard type (Figure 2; Table 2). The orchard type was defined as 'old' if it previously was cropped to sweet cherry (*Prunus* spp.) or apple (*Malus* spp.), 'new' if it was a recently established sweet cherry orchard (< 10 yr), or 'non-cultivated' if the soil was not previously cropped with any type of fruit tree. Soil samples were taken with a shovel to a depth of 0.24 m from several locations in a 5000 m^2 area until 8 L of soil were collected from each site. All soil collected from each site formed a composite sample. The soil was thoroughly mixed and passed through a 5-mm sieve to remove rocks and organic debris. Subsamples of soil from the composite sample from each site were used for preliminary analyses of soil physicochemical properties and initial populations of *Pratylenchus* spp. in soil.

The day of soil sampling, a subsample of the sieved (<5 mm) soil from each site was transferred into labelled plastic drying boats and dried at room temperature for 48 h. The dried soil was ground using a mortar and pestle and sieved (<2 mm) directly into a labelled plastic bag. Soil analyses for EC and POXC were as described in Section 2.1. Dried soil subsamples were sent to A & L laboratories, London, Ontario for the following measurements: Bray I-extractable P, total C and N, CEC, Ca, Mg, K, Na, DOC and OM as described in Section 2.1.

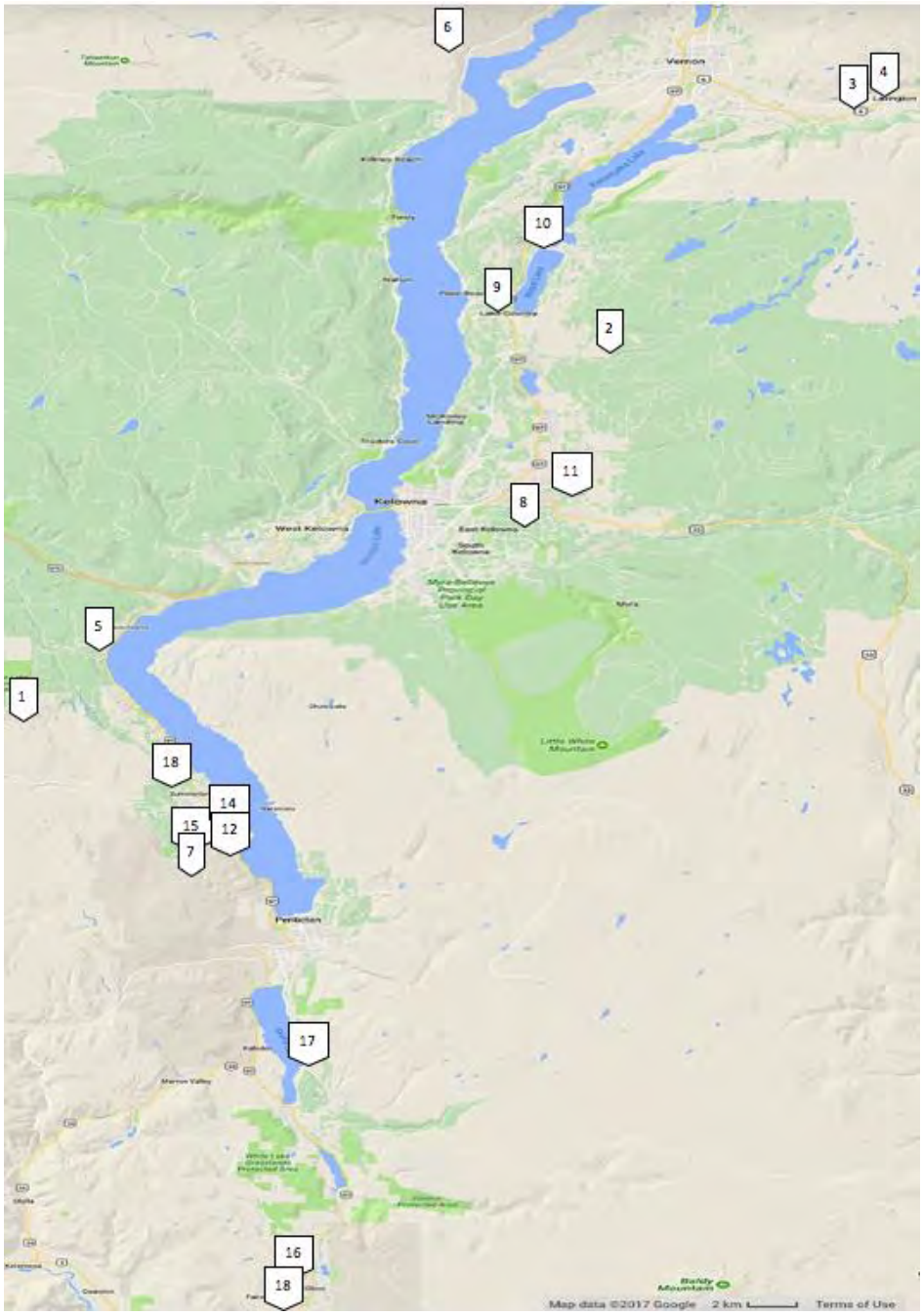

Figure 2. Location of each of the 18 orchard sites in the Okanagan Valley from which soil was collected (0.1 m = 50 m). Details of each site are shown in Table 2.

Table 2. Site information for all orchard soils used in this study, including: name, tree cultivar and rootstock planted, orchard type (old, new or non-cultivated), year current cherry trees were planted, land use history, soil type, and the latitude and longitude.

Site	Name	Cultivar[a]	Rootstock[a]	Orchard type[b]	Year current cherry trees were planted	Land use history	Soil type	Latitude/Longitude
1	Carlson	N/A[c]	N/A	NC[d]	N/A	Non-irrigated native grasses	Sandy loam	49° 40' N 119° 47' W
2	El Dorado	N/A	N/A	NC	N/A	Non-irrigated native grasses	Sandy clay	50° 2' N 119° 22' W
3	Coldstream	'Stacatto'	Mazzard	New	2015	Non-irrigated native grasses	Sandy loam	50° 14' N 119° 8' W
4	Lavington	'Skeena'	Giesela 6	New	2014	Dairy cow pastureland	Sandy loam	50° 14' N 119° 6' W
5	Sutherland	'Sweetheart'	Mazzard	New	2010	Non-irrigated native grasses	Sandy loam	49° 45' N 119° 46' W
6	Cholla	'Regina'	Mazzard	New	2005	Non-irrigated native grasses	Loamy sand	50° 17' N 119° 27' W
7	PARC	'Lapins'	Krymsk 5	Old	2015	Cherry orchard	Loamy sand	49° 33' N 119° 38' W
8	Dendy	'Sentennial'	Mazzard	Old	2013	Apple orchard	Loamy sand	49° 51' N 119° 23' W
9	Tangaro	'Sentennial'	Mazzard	Old	2012	Cherry orchard	Silty clay	50° 3' N 119° 25' W
10	Bailey	'Sweetheart'	Mazzard	Old	2010	Cherry orchard	Silty clay	50° 6' N 119° 23' W
11	Berry	'Sweetheart'	Mazzard	Old	2005	Cherry orchard	Sandy clay	49° 54' N 119° 21' W
12	Beulah	'Stacatto'	Mazzard	Old	2005	Cherry orchard	Loamy sand	49° 34' N 119° 39' W
13	Carlson	'Sweetheart'	Mazzard	Old	2005	Cherry orchard	Silty clay loam	49° 36' N 119° 41' W
14	Brown	'Stacatto'	Mazzard	Old	2004	Apple orchard	Silty clay	49° 34' N 119° 39' W
15	Norton	'Stacatto'	Mazzard	Old	2003	Cherry orchard	Sandy clay loam	49° 10' N 119° 34' W
16	Sidhu	'Lapins'	Mazzard	Old	2002	Cherry orchard	Sandy loam	49° 34' N 119° 39' W
17	Danninger	'Sweetheart'	Colt	Old	1999	Cherry orchard	Silty clay loam	49° 22' N 119° 33' W
18	Norton	'Sweetheart'	Mazzard	Old	1994	Cherry orchard	Sandy clay loam	49° 10' N 119° 34' W

a = All the cultivars listed are sweet cherry (*Prunus avium* L.) on Mazzard (*P. avium)*, Giesela 6 *(P. cerasus* x *P. canescens)*, Krymsk 5 (*P. fruticosa* x *P. lannesiana),* or Colt (*P. avium* x *P. pseudocerasus*) rootstocks.
b = Orchard type was classified as: 'old' if it previously cropped sweet cherry (*Prunus avium* L.), or a related species, 'new' if it was a recently established sweet cherry orchard (< 10 yr), or 'non-cultivated' if the soil was not previously cropped with any type of fruit tree. Non-cultivated sites were subsequently planted with sweet cherry.

c = No sweet cherry trees were planted at the time of soil sampling in October 2015.

d = 'NC' = Non-cultivated site

Experimental Treatments and Design

The remainder of the soil collected was stored at 4°C until time of planting. This stored soil from each site was either sterilized by means of microwaving (Section 2.1) or left untreated to assess the growth response of 'Crimson' sour cherry plants (Prunus ceraseus) to sterilization. Micro-propagated 'Crimson' sour cherry explants were obtained from Agriforest Biotechnologies (Kelowna, BC, Canada). The plants were moved into the greenhouse in September 2015, so they went through the dormancy stage over winter, and were approximately six months old at the time when the experiment was initiated, on March 23, 2016. At the start of the experiment, the initial shoot height of each plant was measured. Plants were planted singly in pots (9.52 cm diameter and 10.73 cm height) filled with 400 ml of soil. This was a fully factorial experiment (18 soil samples x 2 sterilization regimes x 6 replicates = 216 plants). Plants were arranged in a complete randomized block design in growth chambers (Percival Scientific Model AR36L3C8) set to the following conditions: 24°C ± 2.0°C, 35% humidity, and irradiance of 227 μmol m^{-2} s^{-1} of PAR (photosynthetically active radiation), with a 16-h photoperiod. Plants were watered to run-off as needed with distilled water and fertilized every 14 d with 3 g L^{-1} of Pro-Gro® 20-20-20 fertilizer blend (Pro-Gro Mixes & Materials, Sherwood, OR). Plants were monitored for powdery mildew and spider mites, and sprayed with 5 mL L^{-1} of Green-Earth® (Langley, BC, Canada) lime-sulphur, and 20 mL L^{-1} of Safer's® (Lititz, PA, USA) insecticidal soap, respectively, as needed. Plants were harvested June 1, 2017, after 10 weeks of growth.

Plant growth analyses

At time of harvest, shoots were cut at soil level and total shoot height increment was measured. Oven-dried shoot and root weights were determined after drying plant material at 65°C for 48 h. Since single replicate plants died in some soil by sterilization regime combinations, the smallest plant from all other treatments was removed and not used in further analyses, resulting in five replicates for each soil by sterilization regime combination.

Nematode extraction and quantification from soil and roots

In order to confirm successful sterilization, nematodes were extracted from a subsample of sterilized soil from each site. In addition, nematodes were extracted from non-sterile soil (stored at 4°C for 3 months) two weeks prior to planting to determine initial abundance of *Pratylenchus* in soil, and at harvest to determine the final abundance of *Pratylenchus* in soil. In all cases, nematodes were extracted, observed and identified as described in Section 2.1.

Microbial activity in soil of plants

*A*t harvest, ~10 g (fresh weight) of soil was subsampled from each of the five replicate pots from each non-sterile treatment, and stored at 4°C. Within one month of harvest, soil microbial activity was determined by the hydrolysis of fluorescein diacetate (FDA) from each stored sample as described in Section 2.1.

Statistical analyses

The initial shoot height was subtracted from the final shoot height to determine the total shoot height increment. The plant growth parameters statistically analyzed were shoot height increment, shoot weight,

root weight, and plant weight. The orchard types 'non-cultivated' (n=2) and 'new' (n=4) were pooled and the orchard types were subsequently defined as 'new' (n=6 orchards) and 'old' (n=12 orchards). The rationale for this was that 'new' and 'non-cultivated' soils had similar land use histories (i.e. un-irrigated native grasses, or dairy cow pastureland) before being converted to cherry orchards. The growth of plants planted in sterile relative to non-sterile soil from each orchard type was subjected to a blocked two-way ANOVA using GLM. The fixed factors in the model were 'orchard type' (old or new), and 'sterilization regime' (sterile or non-sterile), and the random factors were 'site' (18 orchard sites) and 'block' (six greenhouse blocks). When there was a significant orchard type by sterilization regime interaction, Tukey's HSD test was used to test the significance of differences (at a 5% significance level). Percent difference in growth (for each growth parameter) for plants grown in sterilized soil compared to plants grown in non-sterilized soil from each site was determined. If % growth was negative (i.e. % decrease in plant growth), plants responded negatively to sterilization, while if the % growth was positive (i.e. % increase in plant growth), plants responded positively to sterilization. The average percent difference in growth of five replicate plants grown in soil from each site was determined. A one-sample t-test was used to determine if the average percent difference in growth of plants from each orchard type was significantly different from zero at a 5% significance level.

Fluorescein diacetate (FDA) hydrolysis, and *Pratylenchus* spp. abundance in soil and roots were subjected to a blocked one-way ANOVA because these assays were performed on only non-sterile soil. The fixed factor in each model was 'orchard type' (old or new), and the random factors were 'site' and 'block'. The terms in the model were fully factorial, however, the term 'orchard type by block by site' was not significant for any variables and was not included in any of the summary ANOVA tables. When there was a significant orchard type by site interaction, Tukey's HSD (honest significant difference) test was used to test the significance of differences (at a 5% significance level). Analysis of variance (ANOVA) and t-test assumptions were tested for each measured variable. Abundance of *Pratylenchus* in soils and roots was log (x+10) transformed and other variables that were not of equal variance and/ or from a normal distribution were log transformed. All statistical tests were conducted using SPSS Statistics version 23.0 (IBM, Chicago, IL), unless otherwise noted.

A Principal Components Analysis (PCA) was performed on all physicochemical variables (organic carbon, carbon-to-nitrogen ratio, total nitrogen , total organic carbon, phosphorus, potassium, magnesium, calcium, sodium, electrical conductivity, pH, cation exchange capacity, and permanganate oxidizable carbon); biological variables (FDA hydrolysis, *Pratylenchus* spp. 50 g^{-1} soil, and *Pratylenchus* spp. g^{-1} dry root), and topographic variables (elevation and latitude) with R. Loading values greater than or equal to the absolute value of 0.5 indicated significant interrelationships among variables within a principal component (Ownley et al. 2003), and any values less than this were eliminated before further analyses. Then, multivariate correlation coefficients were calculated to determine the strength of the relationships among variables. Only one variable was kept from each group of highly correlated variables, depending on which variable had the greatest collinearity tolerance level. The number of soil properties influencing shoot height increment were further narrowed using the step-wise regression analysis procedure to identify a model that included the lowest number of soil properties and that best described variation in the data. Significant predictors of shoot height increment were included in the model, and non-significant variables that did not contribute any additional information for explaining and predicting the dependent variable were eliminated.

3.0 Results

3.1 Objective I

Field Experiments

Organic amendments

Effect of soil amendments on soil abiotic and biotic properties

Across all sites and in both 2015 and 2016 compost treatment increased cation exchange capacity (CEC), soil phosphorus (P), calcium (Ca), potassium (K), magnesium (Mg), sodium, permanganate oxidizable carbon (POXC), total nitrogen (TN), total carbon (TC), organic carbon (OC), organic matter (OM), and pH compared to the other treatments (Tables 3 and 4). Results were similar in 2017 (data not shown). There was no effect of amendments on soil volumetric water content (data not shown).

Both organic amendments decreased AMF colonization of roots compared to bare soil across all sites (Table 5). Compost amendment tended to decrease the abundance of *Pratylenchus* in roots (Table 6) and soil and increase the abundance of total nematodes in soil (Table 6). There was no effect of amendments on total microbial activity (Table 5), total bacterial and total fungal abundance (data not shown). One year following application of organic amendments there were no significant differences in bacterial or fungal alpha diversity as measured by species evenness and species richness following next generation sequencing across all sites (Figures 3 and 4), but interestingly, they differed from soil sampled at adjacent undisturbed grass sites, which had lowest evenness and richness.

Effect of soil amendments on tree growth and foliar nutrients

Following three years of organic amendment application, compost and mulch had no effect on trunk cross sectional area compared to bare soil at any of the three sites, but leaf area was significantly greater with compost treatment than mulch or bare soil at Site 1, the youngest orchard (Table 7). Compost treatment increased foliar % N at Site 1 in 2017, % P at sites 1 and 3 in 2017, % K at sites 1, 2 and 3 in 2016 and 2017, and decreased % Mg at sites 1, 2 and 3 in both years relative to bare soil (Table 8). Mulch treatment enhanced foliar % P at Sites 1 and 3 in 2017 compared to bare soil.

Effect of soil amendments on cherry yield and quality

There was no effect of organic amendments on fruit yield or quality in 2016, but in 2017 compost increased fruit firmness at Site 3 and stem pull at Site 1 relative to bare soil (Table 9). Mulch decreased fruit firmness at Site 2 and increased colour at Site 2 and soluble solids at Site 3 compared to fruit grown in non-amemded soil. There was no effect of organic amendment on titratable acidity (data not shown).

Table 3. Effect of soil conductivity (EC), and elements phosphorus (P), calcium (Ca), potassium (K), magnesium (Mg), and sodium (Na) among Sites 1, 2, and, 3 in October 2015 and 2016 sampling year. Values represent means (n=72) and standard deviation (SD). Degrees of freedom (df), and P-and F-values for each variable from the ANOVA are given.

Amendment[a]	**CEC (meq 100 g^{-1} soil)**	**SD**	**P (mg kg^{-1})**	**SD**	**Ca (mg kg^{-1})**	**SD**	**K (mg kg^{-1})**	**SD**	**Mg (mg kg^{-1})**	**SD**	**Na (mg kg^{-1})**	**SD**
bare	19.9 b	2.0	150 b	34	2993 b	419	434 b	186	293 b	80	39.5 b	8.0
compost	22.4 a	1.9	203 a	43	3123 a	280	1030 a	283	383 a	105	69.2 a	12.0
mulch	17.6 b	2.7	148 b	30	2936 b	306	432 b	148	286 b	82	35.2 b	5.6
ANOVA[b]	**P**	**F**	**P**	**F**	**P**	**F**	**P**	**F**	**P**	**F**	**P**	**F**
Site	**<0.001**	318	**<0.001**	88	**<0.001**	384	**<0.001**	20	0.041	3.4	**<0.001**	194
Amendment	**<0.001**	39	**<0.001**	27	**0.018**	4.3	**<0.001**	172	**<0.001**	14	**<0.001**	186
Site * Amendment	**0.03**	2.8	0.2	1.6	0.27	1.3	**<0.001**	6.0	0.4	1.0	**<0.001**	6.1

a = Amendments sharing the same letter within a column do not differ significantly (P>0.05), according to Tukey's HSD test.
b = Values in bold were significant at a $P \leq 0.05$ significance level.

Table 4. Effect of soil amendment (bare, compost, or mulch) on permanganate-oxidizable carbon (POXC) content, total nitrogen (TN), total carbon (TC), organic carbon (OC), organic matter (OM), and pH among Sites 1, 2, and 3 in October 2015 and 2016 sampling years. Values represent means (n=72) and standard deviation (SD). Degrees of freedom (df), and P-and F-values for each variable from the ANOVA are given.

Amendment[a]	**mg POXC kg^{-1} soil**	**SD**	**TN (%)**	**SD**	**TC (%)**	**SD**	**OC (%)**	**SD**	**OM (%)**	**SD**	**pH**	**SD**
bare	1313 b	238	0.3 b	0.06	3.9 b	0.5	3.9 b	0.5	7.0 b	0.9	6.3 b	0.5
compost	1503 a	272	0.4 a	0.09	4.8 a	0.7	4.8 a	0.7	8.4 a	1.2	6.7 a	0.2
mulch	1324 b	224	0.3 b	0.06	4.1ab	0.5	4.0 b	0.	7.2 b	0.8	6.4 b	0.2
ANOVA[b]	**P**	**F**	**P**	**F**	**P**	**F**	**P**	**F**	**P**	**F**	**P**	**F**
Site	**<0.001**	17	**<0.001**	177	**<0.001**	339	**<0.001**	358	**<0.001**	353	**<0.001**	59
Amendment	**<0.001**	10	**<0.001**	26	**<0.001**	29	**<0.001**	36	**<0.001**	30	**<0.001**	10
Site * Amendment	0.9	0.3	0.10	2.1	0.1	2.0	0.19	1.6	0.3	1.3	0.2	1.5

a = Amendments sharing the same letter within a column do not differ significantly (P>0.05), according to Tukey's HSD test
b = Values in bold were significant at a $P \leq 0.05$ significance level.

Table 5. Effect of soil amendments (bare, compost, or mulch) on fluorescein diacetate (FDA) hydrolysis, and % arbuscular mycorrhizal fungi (AMF) colonization among Sites 1, 2, and 3 in October 2015 and 2016 sampling years. Values represent means (n=72) and standard deviation (SD). Degrees of freedom (df), and P-and F-values from the ANOVA are given.

Amendment[a]		**FDA hydrolysis ($\mu g\ g^{-1}$)**	**SD**	**% AMF Colonization**	**SD**
bare		3.7	1.2	27.9 a	9.8
compost		4.1	1.8	21.3 b	8.2
mulch		4.4	2.0	22.6 b	8.3
ANOVA Results[b, c]	**df**	**P**	**F**	**P**	**F**
Site	1	**<0.001**	35	**0.001**	7.7
Amendment	2	0.5	0.8	**<0.001**	10
Site * Amendment	4	0.6	0.7	**0.04**	2.7

a = Amendments sharing the same letter within a column do not differ significantly (P>0.05), according to Tukey's HSD test
b = Values in bold are significant at a $P \leq 0.05$ significance level.

Table 6. Effect of soil amendment (bare, compost, or mulch) on *Pratylenchus* spp. abundance in 1 g root and 50 g bulk soil, and total nematodes in 50 g bulk soil among Sites 1, 2, and 3 in October 2015 and 2016 sampling years. Values represent means (n=72) and standard deviation (SD). Degrees of freedom (df), and P-and F-values from the ANOVA are given.

Amendment	***Praty.* spp. g^{-1} root**	**SD**	***Praty.* spp. 50 g^{-1} soil**	**SD**	**Total Nematode 50 g^{-1} soil**	**SD**
bare	133	240	23	16	232	143
compost	103	132	18	13	289	162
mulch	161	352	21	14	251	127
ANOVA[a]	**P**	**F**	**P**	**F**	**P**	**F**
Site	**0.003**	6.3	**0.001**	8.1	**<0.001**	15.3
Amendment	0.052	2.3	0.055	2.3	0.054	3.1
Site * Amendment	0.2	1.6	0.3	1.3	0.2	1.3

a = Values are significant at a $P \leq 0.05$ significance level.

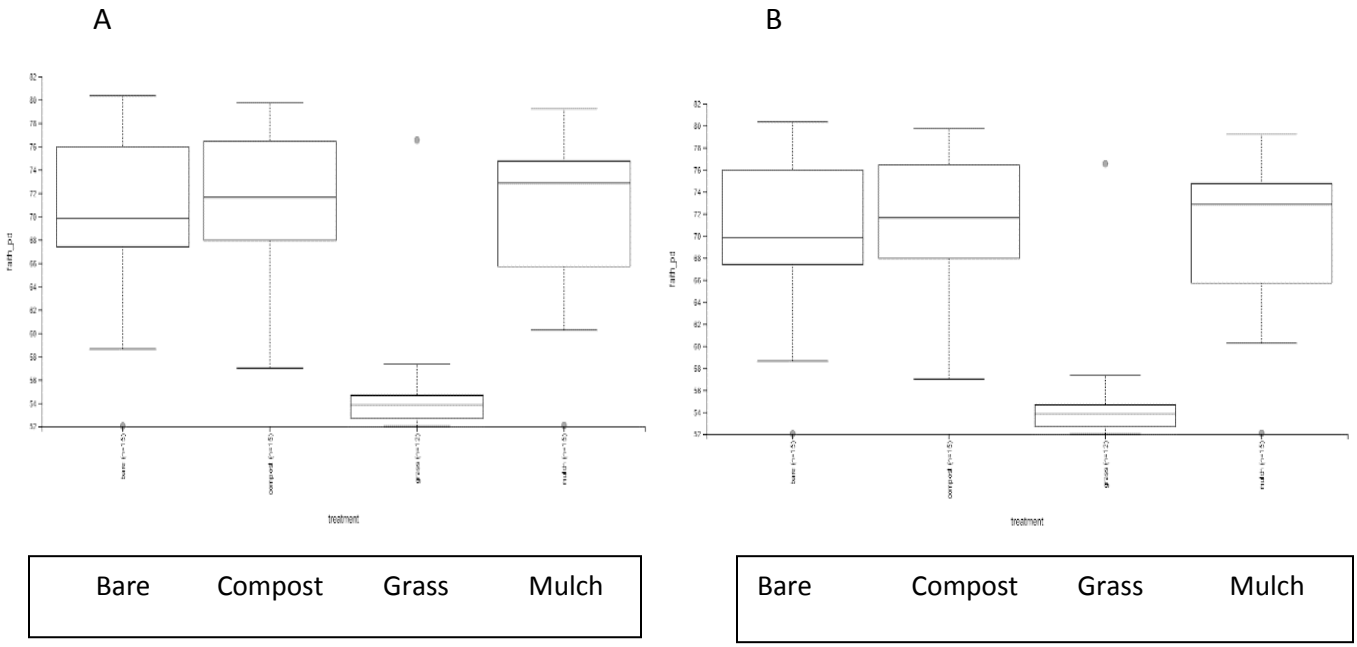

Fig. 3. Effect of organic soil amendments on bacterial species evenness (A) and species richness (B) across all sites in soil sampled one year following application of compost and mulch. Grass denotes a sample taken from an adjacent undisturbed site next to the study orchards.

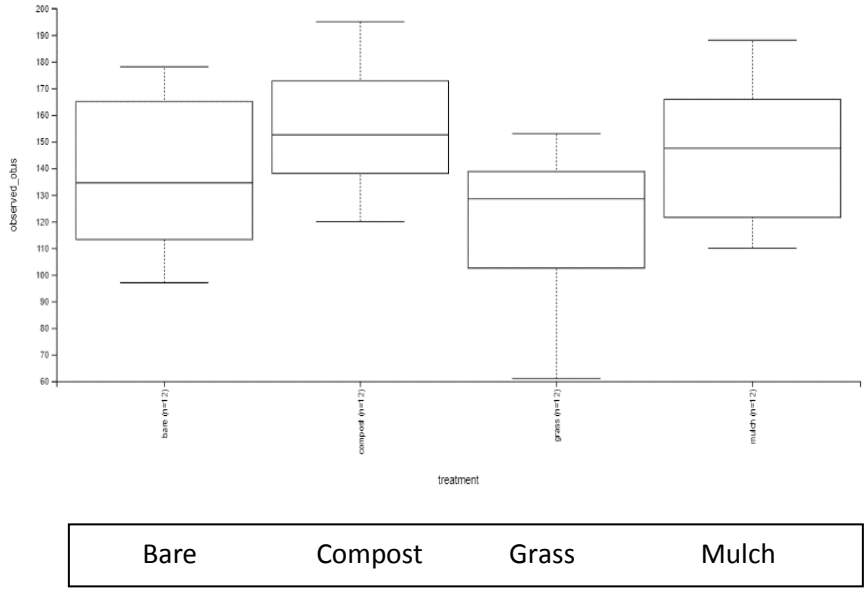

Fig. 4. Effect of organic amendments on fungal species richness across all sites sampled one year following application of compost and mulch. Grass denotes a sample taken from an adjacent undisturbed site next to the study orchards.

Table 7. Effect of soil amendments (bare, compost or mulch) on trunk cross sectional area (TCSA) and leaf area in 2017 at sites 1, 2 and 3. Values represent the means (n=6) at each site.

	Site 1		Site 2		Site 3	
Amendment	TCSA cm^2	Leaf Area cm^2	TCSA cm^2	Leaf Area cm^2	TCSA cm^2	Leaf Area cm^2
bare	43.5	1723 b	77.4	77.4	68.3	1653
compost	44.3	1907 a	80.3	80.3	66.1	1708
mulch	45.8	1751 b	77.6	77.6	71.9	1703
ANOVA	NS[a]	<0.05	NS	NS	NS	NS

[a]Not significant

Table 8. Effect of soil amendments (bare, compost or mulch) on cherry foliar percent N, P, K and Mg in 2016 and 2017 at sites 1, 2 and 3. Values represent the means (n=6) at each site.

Site	**Amendment**	**N(%)**		**P(%)**		**K(%)**		**Mg(%)**	
		2016	2017	2016	2017	2016	2017	2016	2017
1	bare	3.09	2.99	0.23	0.23 b	2.68	2.36 b	0.30	0.33 a
	compost	3.11	2.98	0.24	0.27 a	2.78	2.67 a	0.29	0.29 b
	mulch	2.90	2.92	0.24	0.26 a	2.71	2.38 b	0.30	0.33 a
	ANOVA	NS	NS	NS	<0.01	NS	<0.01	NS	<0.01
2	bare	2.89	2.95	0.21	0.25	2.63 b	2.24 b	0.33 a	0.36 a
	compost	2.92	2.91	0.22	0.24	2.82 a	2.50 a	0.30 b	0.32 b
	mulch	2.78	2.89	0.22	0.25	2.69 ab	2.32 b	0.34 a	0.36 a
	ANOVA	NS	NS	NS	NS	<0.05	<0.01	<0.05	<0.01
3	bare	2.89	2.76 b	0.19 b	0.22 b	2.27 b	1.85 c	0.29 a	0.42 a
	compost	3.03	2.91 a	0.21 a	0.26 a	2.89 a	2.43 a	0.24 b	0.33 b
	mulch	2.86	2.71 b	0.20 ab	0.25 a	2.30 b	1.96 b	0.29 a	0.41 a
	ANOVA	NS	<0.05	<0.05	<0.05	<0.001	<0.001	<0.05	<0.001

Table 9. Effect of organic amendments on fruit yield and fruit quality in 2017.

Site	Amendment	Yield (kg)	Firmness (g/mm)	Stem Pull (kg)	Colour	Soluble Solids(%)
1	bare	13.8	420	0.73 b	3.54	21.9
	compost	13.8	448	0.86 a	3.54	21.7
	mulch	13.0	429	0.72 b	3.47	21.2
	ANOVA	NS	NS	<0.05	NS	NS
2	bare	25.5	489 a	0.85	3.58 b	22.0
	compost	26.4	477 ab	0.85	3.99 a	22.1
	mulch	27.0	465 b	0.80	3.99 a	22.4
	ANOVA	NS	<0.05	NS	<0.001	NS
3	bare	7.2	410 ab	0.77	3.86	21.0 b
	compost	8.4	423 a	0.88	3.82	21.0 b
	mulch	6.7	395 b	0.83	3.92	21.9 a
	ANOVA	NS	<0.05	NS	NS	<0.05

Greenhouse Experiments

Field soil from each organic amendment treatment at Sites 1, 2 and 3 was collected for a greenhouse bioassay to determine if the orchard floor treatments affected soil health and sour cherry explant growth differentially when the soil was sterilized or left untreated. There were no sterilization or amendment effects for plant growth across the three sites (data not shown). However, at Sites 1 and 2 *Pratylenchus* abundance in roots was lower and root surface area was greater in plants grown in compost-amended soils than in bare soil and *Pratylenchus* abundance in roots was positively correlated with percent necrotic root surface area (Fig. 5). At Site 3 *Pratylenchus* abundance in soil and roots was also lower in compost-amended soil than in bare soil, but its abundance in roots was not correlated with percent root necrosis.

Cost/Benefit Analysis of Organic Amendments

An Okanagan region-focused perspective was assumed for this project. Impact categories considered for organic amendments included application cost, the quality of cherries, potential reductions in cost through reduced applications of pesticides or fertilizers and tree health. As part of the monetization process we developed a comprehensive pricing method that quantified the price variation based on the factors determining fruit quality. This method was developed in cooperation with David Geen and Julie McLachlan of Jealous Fruits. These factors are used in a weighted percentage, if the treatments show that they cause an increase in quality of the overall cherry. (Fig. 6). Impacts of costs of application of mulch or compost included the cost of materials, machinery, labour and frequency of application. As there is a potential for water to be saved to benefit society and the producer if organic amendments decrease water usage, two discount rates were selected and simulations run for each rate over a twenty year period. Discount rates of 3% (commonly

used for discounting environmental projects) and 10% (maximum expected return rate for most private investment) were selected. Data obtained from the three orchards in this study and from consultation with project stakeholders were used to select three base NPV outcomes: NPV with change in fruit quality for the bare soil treatment, NPV with change in fruit quality for the mulch treatment, and NPV with change in quality for the compost treatment. NPV was based on the average Canadian inflation rate of 2%. Sensitivity analysis included consideration of the uncertainties of the impacts of amendments on soil nutrient status and soil microbial activity due to the short duration of the current studies, of the weather, of the fruit quality weightings which may vary depending on the target markets and of inflation rates.

Based on the data obtained in the first three years of this study, there were small beneficial changes occurring with the amendment treatments, but the costs that would be incurred by growers in applying either compost or mulch to their orchards do not override the benefits. A longer study period may be required to see greater quantifiable changes among the treatments.

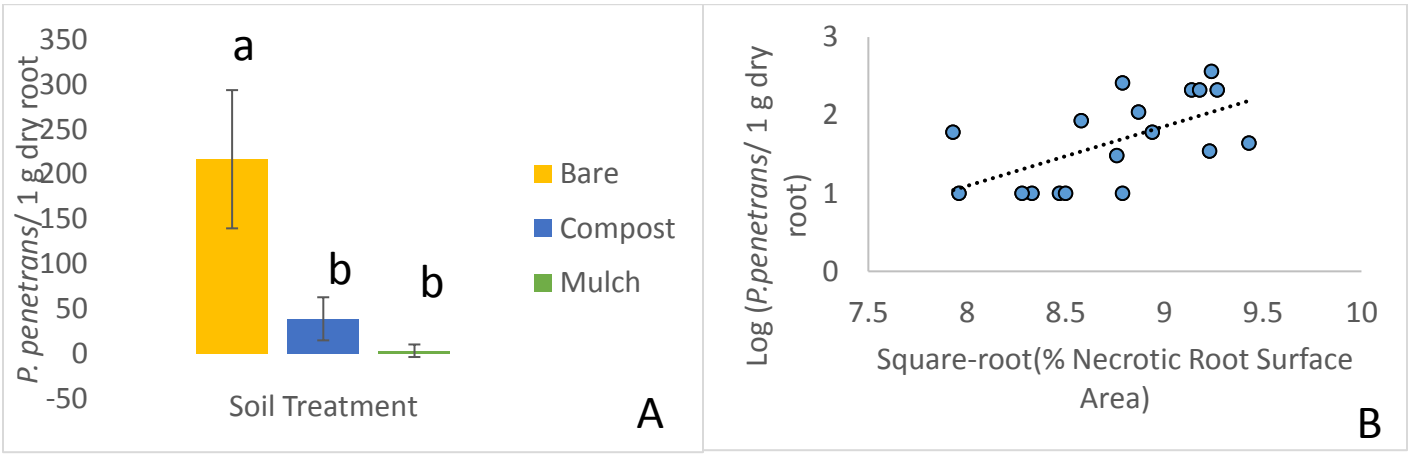

Fig. 5. Effect of soil amendment (bare, compost, mulch) on population density of *Pratylenchus* spp. in roots at site 1 (A) and the correlation between the population density of log of *Pratylenchus* spp./g dry root +1 with square root of % necrotic root surface area (n=6 for each treatment) (B). Pearson correlation; r=0.62; P=0.003.

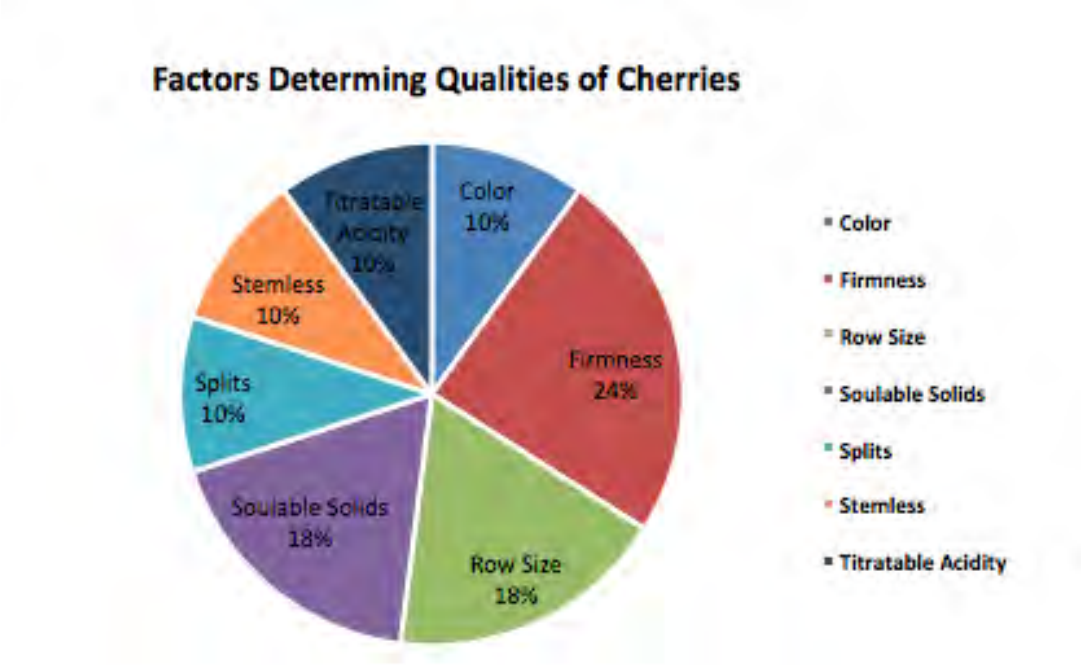

Fig. 6. Factors determining qualities of cherries and their weighting by percentage.

Irrigation Treatments

Effect of irrigation treatments on soil abiotic and biotic properties

Postharvest deficit irrigation (PDI) (25% reduction) was initiated at Sites 2 and 3 in August 2015. PDI had no effect on soil physiochemical or biotic properties compared to treatments receiving full irrigation at either site (data not shown). Volumetric water content, measured in mid-August, also did not differ between the two treatments.

Effect of postharvest deficit irrigation on plant properties and fruit quality and yield

Two years following initiation of PDI trunk cross sectional area, leaf area and leaf mineral content did not differ between the two irrigation treatments (data not shown). Stem water potential was not affected by a reduction in irrigation following harvest at either site in 2016 and 2017 (Fig. 7). Fruit yield and fruit quality attributes did not differ between the two irrigation treatments in 2016 or in 2017 (data not shown). Because yield was not affected by a 25% reduction in irrigation, water use efficiency increased under postharvest deficit irrigation.

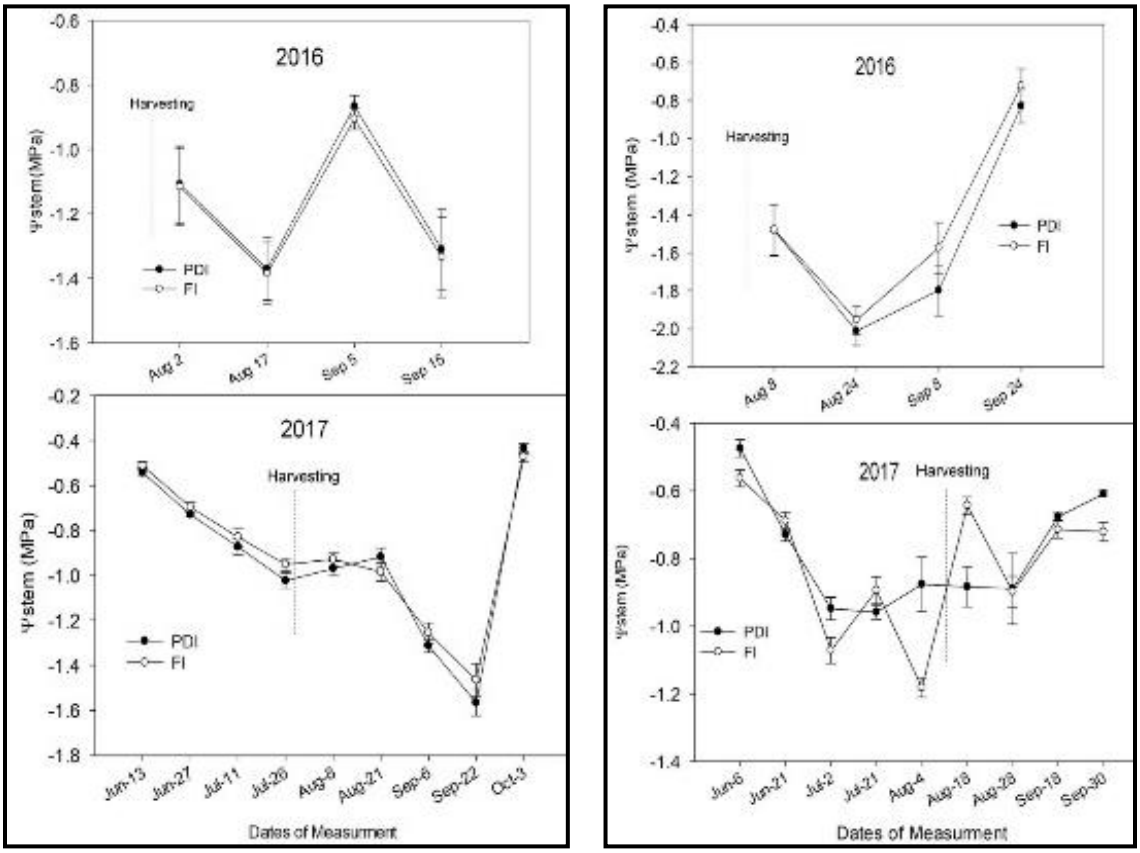

Fig. 7. Stem water potential (MPa) of sweet cherry trees at sites 2 and 3 following harvest in 2016 and and pre- and post-harvest in 2017 subjected to full irrigation (FI) or postharvest deficit irrigation (25% reduction). Each value is the mean +/- standard error (n=4).

Cost-Benefit Analysis of Irrigation Treatments

Four impact categories were considered in examining the cost- benefit analysis of a postharvest deficit irrigation that aims to maintain cherry quality and yield. These included implementation costs to apply deficit irrigation, verification that the quality of the cherry is maintained, estimation of the potential cost savings of reducing water usage for the growers and the social value of conserving water. The first two impacts were determined to have no influence on the cost-benefit analysis, based on the results of the current study. Data were obtained from regional districts on current water allocations to the growers and water pricing. Allocations to sites 1 and 2 are high and their current water usage is less than 25% of their annual allocation. The water use per tree, the irrigation system in place and the size of orchards in the study were taken into consideration in determining the potential water savings per orchard with implementation of the 25% reduction in water applied during the postharvest period in this study. These estimates were approximately 75,000 litres at site 1, 114,000 litres at site 2 and 52,000 litres at Site 3. Based on the expected allocation for Site 3, we estimate that there may be an incentive for PDI to be applied at this site. The value of alternative

use of water is difficult to evaluate, but regional climate change models, past history of flooding and drought and their impact on water reservoir filling were considered. We estimate that the benefits of saving water are larger in August and September than any other month in the Okanagan and that the value of water savings through RDI would be higher in years in which the reservoirs did not fill. Monetizing impact categories considered include benefits of not incurring over usage fees and of maintaining fruit quality, and the costs of implementation, which were thought to be insignificant.

Following consultation with stakeholders we decided the focus of the deficit irrigation net present value scenarios should be on fruit quality and yield. Two base NPV outcomes were selected: NPV with consistent filling of the Okanagan reservoirs with no effect on cherry quality and NPV with inconsistent filling of the Okanagan reservoirs with no effect on cherry quality. The NPV calculations were based on the average Canadian inflation rate of 2% and two real discount rate scenarios of 3% and 10% were used as for the organic amendment analysis. Sensitivity analysis included consideration of operation costs per orchard, fruit quality and alternative use/social benefit.

With the data gathered so far, we estimate water savings at all three orchards with Site 3 showing the most saving for the grower and Site 2 the most water saved per treatment period. We expect that in the future with more data collected that the NPV for the PDI treatment will be positive and higher than the NPV of the full irrigation treatment. As water supply decreases and demand remains the same or increases, water districts are expected to decrease annual allocations to orchard and this will increase the NPV of the PDI treatment. We recommend implementation of PDI as there appears to be negligible change in fruit quality and in implementation costs with overall saving of water.

3.2 Objective II

In the greenhouse bioassay of 6 soils from new orchards and 12 soils from established (“old”) orchards, plants grown in old orchard soils had a positive growth response to sterilization, meaning that soil biota was generally harmful to cherry explant growth at those sites (Fig. 8). Plants grown in new orchard soils grew less after sterilization than those in non-sterilized soil, meaning that soil biota generally stimulated growth. Non-sterilized new orchard soils (which included newly cultivated and non-cultivated sites) had nearly 2-fold greater microbial activity, as measured by FDA hydrolysis, relative to old orchard soils, and 4-fold lower abundance of root colonizing plant parasitic nematodes, *Pratylenchus* spp. (Table 10).

The physicochemical properties of the soils at the 18 sites were analysed and grouped into new and old orchard types. The mean values for the location (latitude and elevation) and some of the properties of these two major groups are shown in Table 11. On average new orchard soils were at higher latitude and elevation than old orchards and had higher cation exchange capacity, C:N ratios, organic matter, P and K, and lower pH, Ca and Na than old orchard soils.

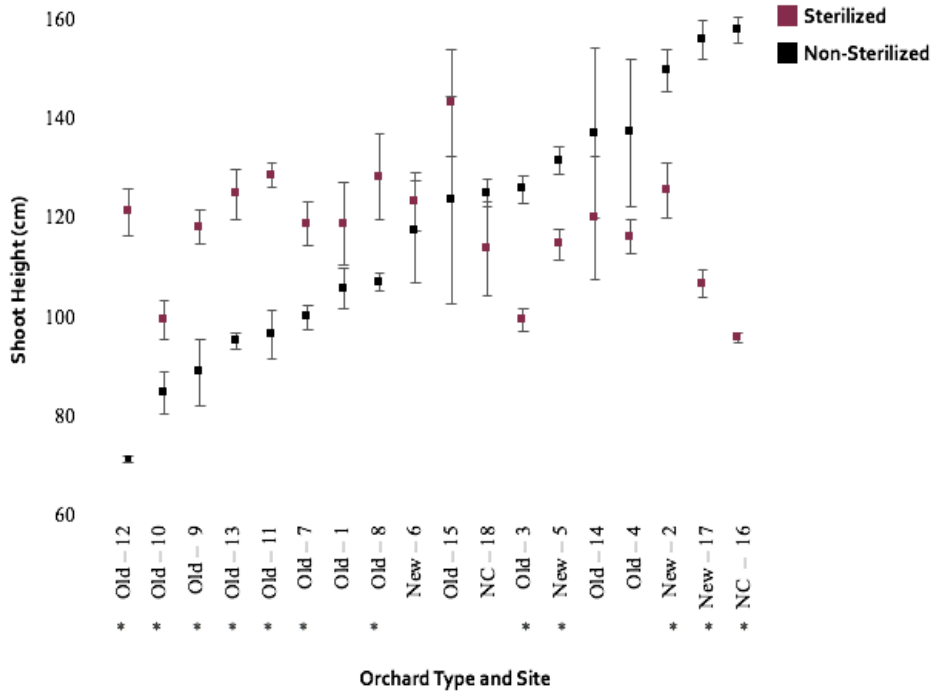

Fig. 8. Shoot height (cm) of plants grown in sterilized (solid box) and non-sterilized (open box) soil collected from 18 sites that were either 'old' (black label), 'new' (red label), or 'non-cultivated' (NC) (green) orchard types. The asterisk (*) indicates that the mean shoot height was significantly different (P≤0.003) between sterilized and non-sterilized soil from the same site. Squares indicate mean of five plants, and bars indicate mean ± one standard deviation.

Table 10. Effect of orchard type (new, old) on mean FDA hydrolysis of non-sterile soil and abundance of *Pratylenchus* spp. in roots of cherry explants grown in non-sterile soil from each site +/- standard deviation. There were 5 replicate pots for each site (N=6 for new orchards and 12 for old orchards).

Orchard Type	FDA Hydrolysis (μg/g)	*Pratylenchus* spp./g root
New	2.7 ± 0.02	15 ± 13.2
Old	1.5 ± 0.01	64 ± 55
P value	0.003	0.01

Table 11. Effect of orchard type (new, old) on mean latitude, elevation, electrical conductivity (EC), cation exchange capacity CEC), pH, C:N ratio, organic carbon (OC), total N (TN), P and K. Values are the means of 6 sites for new orchard soils and 12 sites for old orchard soils.

Site Location or Soil Property	New Orchard Soil	Old Orchard Soil
Latitude (^{o})	50.0	49.7
Elevation (m)	681	444
EC (S/m)	0.06	0.025
CEC (meq/100 g)	16.4	14.4
pH	6.1	6.8
C:N	10.1	9.7
OC (%)	3.2	2.3
TN (%)	0.3	0.2
P (mg/kg)	134	100
K (mg/kg)	431	378
Mg (mg/kg)	223	260
Ca (mg/kg)	1906	2011
Na (mg/kg)	18	28

The physicochemical variables (organic carbon (OC), carbon-to-nitrogen (C: N) ratio, total nitrogen N), total organic carbon (OC), phosphorus (P), potassium (K), magnesium (Mg), calcium (Ca), sodium (Na), electrical conductivity (EC), pH, cation exchange capacity (CEC), and permanganate oxidizable carbon (POXC)), biological variables (FDA hydrolysis, *Pratylenchus* spp. 50 g^{-1} soil, and *Pratylenchus* spp. g^{-1} dry root), and topographic variables (elevation and latitude) were used for principal components analysis (PCA.) The first axis of the PCA (PC1) accounted for 39.6% of the variation, and the second axis (PC2) accounted for an additional 21.3% of the variation (Fig. 9). Latitude, POXC, and FDA hydrolysis were positively correlated in the upper left quadrant of the bi-plot, and these variables were negatively correlated with *Pratylenchus* g^{-1} root, which was the variable most correlated with PC1 and tended towards the right half of the bi-plot. In addition, elevation was negatively correlated with soil pH. The variables POXC, P, K, and total N had less influence than variables such as pH, FDA, and OM on site separation in the ordination plane. Data for new orchards clustered in the upper left quadrant of the bi-plot, along with vectors for POXC and FDA hydrolysis. The old orchards tended to be located throughout the other three quadrants. The variables total N, *Pratylenchus* spp. 50 g^{-1} soil, P, POXC, and (C: N) ratio were eliminated before further analyses (i.e. multiple regression analyses), as they had loading values less than the absolute value of 0.5 (Ownley et al. 2003).

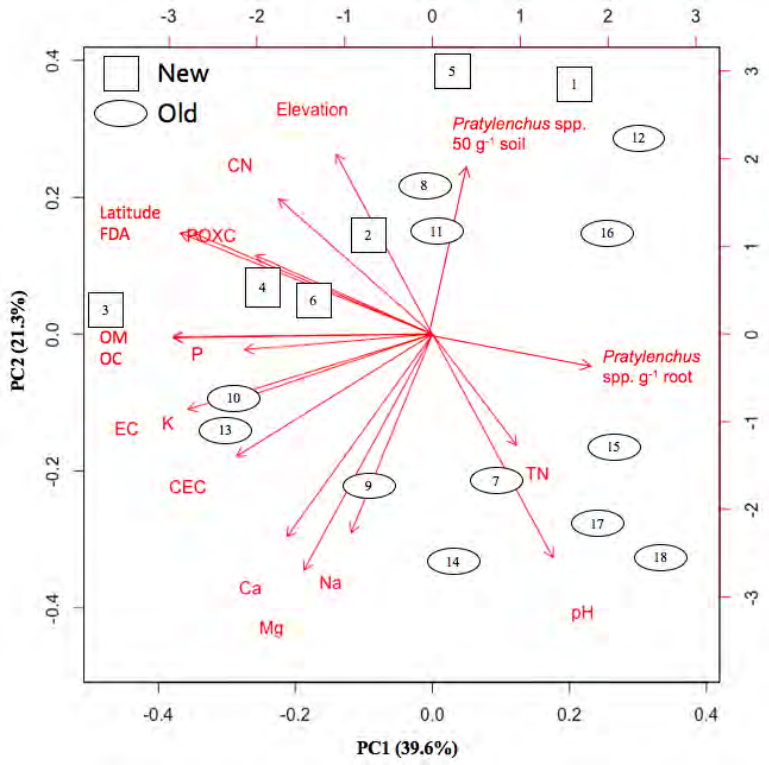

Figure 9. Vector loading plot of all separate variables in a two-dimensional principal components analysis (PCA) ordination of abiotic soil variables (C: N ratio, organic carbon (OC), total nitrogen (TN), POXC, phosphorus (P), potassium (K), magnesium (Mg), calcium (Ca), sodium (Na), electrical conductivity (EC), pH), biotic soil variables (FDA hydrolysis, *Pratylenchus* 50 g^{-1} soil and g^{-1} root), and topographic variables (elevation and latitude) for all 18 sampling sites (numbered 1 to 18). The first two axes of the PCA explained 60.9% of the variation in the variables measured. The first axis of the PCA (PC1) accounted for 39.6% of the variation. The second axis (PC2) explained an additional 21.3% of the variation.

The number of soil properties influencing shoot height increment in the new and old orchards were further narrowed using the step-wise regression procedure to identify a model that included the least number of soil properties and that best described variation in the data. Positive predictors of shoot height increment were sodium, FDA hydrolysis, and total organic carbon (Table 12). Calcium and magnesium were negative predictors of shoot height increment (Table 12). The categorical variable 'orchard type' was a significant predictor of shoot height increment, suggesting that the effect of the explanatory variables (i.e. sodium, FDA hydrolysis, organic carbon, calcium, and magnesium) on shoot height increment depended on whether the soils were from new or old orchard soils (Table 12).

Table 12. The variables that predicted shoot height increment in new and old orchard soils after conducting stepwise regression analyses.

Model Variables	Beta[b]	Standard Error	T-value	Significance Level[c]
Orchard type[a]	35.6	5.7	6.2	<0.001
Organic carbon (OC)	5.4	2.1	2.4	0.01
FDA hydrolysis	15.8	7.1	2.2	.03
Na	0.79	0.2	3.1	.003
Mg	-0.09	0.3	-2.7	0.008
Ca	-0.008	-3.2	-3.2	0.002
Constant[d]	67.1	9.7	6.8	<0.001
ANOVA Summary	**Degrees of Freedom**	**F-value**	**Significance Level[e]**	
	6	36	<0.001	

a = Categorical variable in model. Groups were 'new orchard soil' and 'old orchard soil'.
b = The beta coefficient is the degree of change in the outcome variable for every 1-unit of change in the predictor variable.
c = Variables significantly predicted shoot height increment at P≤0.05 significance level.
d = The constant is the y-value in which x=0 in the equation on the regression line.
e = ANOVA results are significant at a P≤0.05 significance level

4.0 Discussion

4.1 Objective I

Organic amendments

The effect of compost and mulch application on soil physical, chemical, and biological properties was assessed through three growing seasons at two newly-established cherry orchards, and one old orchard, that had been replanted to cherry in 2013. Several studies have demonstrated the benefits of organic amendments with regard to physical, chemical, and biological soil properties (Ferreras et al. 2006; Tejada et al. 2009; Torres et al. 2015). Our results agree with these findings, as the compost treatment increased soil phosphorus, POXC, total nitrogen, total carbon, organic carbon, and organic matter compared to woodchip mulched or bare plots. This effect was more noticeable in newly-cultivated orchard soils (Sites 1 and 2), than in established orchard soil (Site 3). Other studies have shown that the quantity and quality of soil organic carbon inputs affect the activity of decomposer organisms within the soil food web, which, in turn, influences nutrient cycling, biological suppressiveness, and crop growth (Hoitink and Boehm 1999; Westphal and Becker 1999).

There were few effects of the amendments on soil biological properties at Sites 1, 2, and 3. Although there were differences in means among soil amendment treatments for some of the biological data, there were no significant differences for most variables due to the very high variability of the data. Amendments were surface applied for three consecutive years in this study, and after this short amount of time the amendments may have influenced soil biological properties in only the top few centimeters of soil (Yang et al. 2003). Soil samples were taken from a 0-30 cm depth profile, which may have diluted any effects that were present. The method of soil sampling is important as soil biological properties vary at a very fine scale (Yang et

al. 2003). It can be concluded that the spatial and temporal variability of microbial abundance and activity in the experimental plots at Sites 1, 2, and 3 was very high, and the effect of the soil amendments was not quite strong enough after three years to produce significant differences.

One consistent result in this study was that at Sites 1, 2, and 3 the percent AMF root colonization was lower in compost- and mulch- amended soil, relative to non-amended soil. In this study, compost was applied generously, at a rate of 0.05 m^3/ m^2, for two consecutive years, and there was an increase in total P and N in compost-amended soils at all three sites. Although organic sources of nutrients, such as composts, have been shown to promote AMF root colonization (Meyer et al. 2015), the excessive use of organic amendments, which are a source of P and N, can result in a decrease in AMF colonization (Jordan et al. 2000; Cavagnaro 2014). However, this does not explain the decreased AMF colonization in mulch-amended soil, as the P and N contents were not different between the bare and mulch plots. One possible explanation is that organic amendments, such as woodchip mulch, cause increased root growth, as was observed by Kumar and Dey (2011) and Jindo et al. (2012). Since percent root colonization depends on both the standing root length of the plant and AMF abundance, changes in percent root length could have resulted from changes in standing root length, and may not have been related to AMF abundance (Treseder 2013). Although root growth was not directly measured in the field experiments, upon qualitative observation during root sampling each year, fine root growth appeared to be greater in compost- and mulch- amended plots than in the bare plots. In the greenhouse experiment, many root growth parameters were measured (i.e. root weight, root length, and root surface area), and at Site 1 root surface area and root weight were greater in amended soil than non-amended soil, and at Site 2, root length was greater in amended soil than non-amended soil.

Although the amendments did not cause a reduction in *Pratylenchus* abundance in soil and roots in the field experiments, effects of these treatments were observed in the greenhouse bioassay with treated soils from the three field sites. In soil from Sites 1 and 2, *Pratylenchus* abundance in roots was lower and root surface area was greater when plants were grown in compost-amended soils than in the non-amended control. In addition, there was evidence that healthier roots could potentially be more resistant to attack by *Pratylenchus*, since the abundance of *Pratylenchus* in roots of plants grown in soils from Sites 1 and 2 was positively associated with percent necrotic root surface area, and negatively associated with total root surface area. Forge et al. (2008) found that paper mulching doubled root biomass, and reduced the number of *Pratylenchus penetrans* per gram root. This study suggested that reduced nematode damage may be one of the possible reasons for enhanced root growth under mulch. When soil from Site 3 was used as a growing medium, *Pratylenchus* abundance in soil and roots was also significantly lower in compost-amended soil than in non-amended soil; however, *Pratylenchus* abundance in roots did not correlate with percent root necrosis. This suggests that root necrosis of plants grown in Site 3 soil may have been associated with other plant parasitic nematodes, and/ or a fungal complex.

While organic amendments had no effect on trunk cross sectional area in the initial three years of this study, compost increased leaf area, an indicator of tree productivity, in the youngest orchard, site 1 relative to that in trees grown in non-amended soil. By year 3 compost and mulch were enhancing the mineral nutrient content of leaves and this was particularly evident at site 3, the old established orchard. Leaf nitrogen, phosphorus and potassium were higher in compost-amended trees than in trees grown in bare soil at site 3 and foliar P was higher in mulch-amended trees at sites 1 and 3 than in trees grown in non-amended soil. Compost addition enhanced the soil nutrient status (Table 4 and 5) and may have improved soil moisture,

allowing great uptake by plant roots. P and K are immobile nutrients that move to the roots primarily through diffusion and Neilsen et al. (2010) showed that they were most affected by irrigation frequency. By year 3 fruit quality was also enhanced by organic amendment treatment, as indicated by higher fruit firmness and stem pull in compost treatment at sites 3 and 1, respectively and greater colour and soluble solids in mulch treatments, compared to non-amended treatments. These are significant factors in determining fruit quality and enhancing pricing according to the model used in the cost/benefit analysis.

Cost/Benefit Analysis for Organic Amendments

The economic analysis of the short-term data reveals more potential for the compost amendment than for mulch. This is an expected result as mulch generally takes more time to decompose and for its benefits to be realized. However, results are not convincing that the benefits surpass the cost on the soils under study. Sandier soils with lower plant mineral nutrient content and lower water holding capacity, as found in the south Okanagan may benefit more from such amendments. A major component of the costs is the physical application of the amendment. As such compost, requires more frequent application than mulch, which explains why there are doubts about the profitability of using compost amendments. Longer- term analysis may show more net benefits for the application of both mulch and compost, since additional benefits would occur, in particular, if they reduce replant disease when the grower decides to replant to a new variety or fruit species and due to the potential increase in fruit quality. For the latter, short-term studies indicate the potential of organic amendments to increase fruit firmness, colour and soluble solids. There is also the potential to reduce the costs of adding synthetic fertilizers and reduced water usage.

Postharvest Deficit Irrigation

A reduction in irrigation by 25% postharvest had no detrimental effects on tree growth, leaf mineral content, fruit yield or quality in the two years following its initial application and the trees showed no sign of water stress as measured by stem water potential. Marsal et al. (2010) showed that, with a 50% reduction in postharvest irrigation, fruit yield and quality were maintained at similar levels to those in fully irrigated sweet cherry trees in Spain, although, after cold storage, some quality attributes including firmness and SSC were slightly reduced. In the Okanagan Valley, sweet cherry yield was not affected by imposing either high or low irrigation frequency (Neilsen et al., 2010). However, higher SSC and color, as well as lower TA, firmness, and stem pull force were reported from orchards with low frequency irrigations (Neilsen et al., 2010, 2014). Our data suggest that a 25% saving in water use postharvest may be achieved without adversely affecting tree growth, fruit yield and quality. It would be useful to conduct further trials with increasing reduction in postharvest irrigation to determine the upper limit for maintaining tree health, productivity and fruit quality.

Cost/benefit analysis of postharvest deficit irrigation treatment

Based on the observed results, the PDI does not negatively affect cherry yield and quality. We conclude that this irrigation treatment has the potential to be beneficial for growers under study. The main benefits would be a reduction in water usage cost, if water pricing in the area evolves. At present there is very little incentive to reduce water usage since growers are typically allocated more water than they need. However, we expect pricing based more on actual water usage to be implemented in the Okanagan, given the expected long-term changes in water availability with climate change. One interesting advantage of PDI is the negligible cost of implementation. Growers can implement the technique without capital expenditures. Due to the growth of

cherry production in the area, there will more competition for water. PDI may help growers with water accessability after harvest. Most of the benefits that may be realized are private benefits to the growers. Since there is no clear evidence that the water may have alternative usage at the time it is saved for the community, social benefits are limited. For social benefits to be greater and systematic, water would need to be saved earlier in the season.

4.2 Objective 2

For this objective, a greenhouse bioassay was used to test soils from 6 newly-cultivated and 12 old orchards distributed throughout the Okanagan Valley. Growth of young fruit trees replanted into old orchard soil is often poor relative to soil that has not previously cropped tree fruits (Mazzola 1999; Mazzola and Manici 2012). The results from this experiment were in agreement with previous research and demonstrated that plants grown in untreated (non-sterilized soil) new orchard soil had greater growth relative to that in new orchard soil with reduced microbial activity (sterilized soil). Conversely, sterilizing soil from older orchards resulted in greater plant growth relative to untreated (non-sterile) soil. There were likely more beneficial microbial communities, and fewer biological impediments to growth of cherry trees planted in soils that had never cropped sweet cherry or related tree fruits. To determine which soil health indicators significantly predicted plant growth in non-sterilized new and old orchard soils, all available biotic and abiotic variables were subjected to multiple regression analyses and a data reduction technique to identify the least number of properties that best described variation in the data. The positive predictors of shoot growth were total organic carbon, FDA hydrolysis, and sodium. The variables calcium and magnesium were negative predictors of shoot height increment.

It is not surprising that organic carbon was a positive predictor of shoot height increment in both new and old orchard soils. Organic carbon plays a central role in determining soil physical, chemical, and biological fertility (Ferreras et al. 2006; Tejada et al. 2009; Torres et al. 2015). Practices that increase carbon inputs, such as surface mulching, should be employed on old orchard soils, since small changes in total carbon content can have disproportionally large effects on a range of soil properties (Powlson et al. 2011). The rate of hydrolysis of FDA provides a measure of microbial activity in soil, an estimate of the quantity and quality of biologically available organic substances in soil, as well as indicating the level of biological suppression (Hoitink and Boehm 1999). Fluorescein diacetate (FDA) hydrolysis was a positive predictor of shoot height increment in both new and old orchard soils, and was positively correlated with POXC, and negatively correlated with the abundance of *Pratylenchus* g^{-1} dry root in the PCA. Permanganate oxidizable carbon (POXC) reflects a readily decomposable pool of soil organic carbon (Culman et al. 2012). Therefore, soils with increased POXC may provide a readily available nutrient source for soil microorganisms, thus increasing their activity, which may create a food web suppressive to *Pratylenchus*. The finding that sodium was a positive predictor of plant growth was surprising as high sodium content is usually associated with salinity and may be detrimental to plant growth (Bonanomi et al. 2011) and microbial activity (Rietz and Haynes 2003). However, no soils in this study had sodium levels considered to be toxic to plant growth, i.e. over 100 mg/kg (Letey 2000).

Findings from this study demonstrate that (1) new orchard soils were more 'biologically suitable' for planting sweet cherry than old orchard soils, and (2) the lower plant growth observed in old orchard soils may

have resulted from changes in the microbial community, rather than from abiotic elements in the soil environment. Furthermore, results from multiple regression suggest that orchard management practices that maintain soil organic carbon levels, and stimulate an active microbial community will benefit growth of cherry trees in both new and old orchard soils.

5.0 Knowledge Transfer

A field tour of the orchard sites near Vernon, Kelowna and Summerland was conducted for about 25 soil scientists attending the annual meeting of the Canadian Society of Soil Science on May 14, 2016. Paige Munro presented a poster based on the data obtained under objective 2 at the UBC Okanagan Biology Graduate Student Symposium on Sept 7, 2016, attended by approximately 100 faculty and students. She presented a poster at the Annual BC Regional Meeting of the Canadian Phytopathological Society in Summerland BC on Oct 27, 2016, attended by about 60 scientists and students from all over BC. Her presentation won the best poster award. An article about the project was published in Orchard & Vine, vol. 57, no. 4, p. 30-31 in 2016. An oral presentation of the project was made to the private Foundation that supports this project in partnership with FAIP on Oct 12, 2016. Following this meeting, the Foundation agreed to provide an additional $50,000 for the third year of the project, after the FAIP project ends. Louise Nelson presented a brief overview of the project at the Annual meeting of the BC Cherry Association, attended by about 100 growers, marketers, government and industry personnel.

In April 2017 we met with a representative from Coral Beach Farms, one of our partners in the field research to present a summary of our research to date. We organized a field tour of the two orchard sites near Vernon on Sept 22, 2017. It was advertised by the BC Cherry Association and attended by 24 people from the fruit growing and processing industry, banking industry, agricultural chemical suppliers, growers, academia, and municipal and provincial governments. Paige Munro and Tirhas Gebretsadikan presented posters at the UBC Okanagan Biology Graduate Student Symposium on Sept 12, 2017, attended by approximately 100 faculty and students. Paige Munro presented a poster at the Future IPM 3.0 international conference in Riva del Garda, Italy, Oct 17-20, 2017, attended by about 250 academics and horticultural industry participants. She won a prize in the student competition. Louise Nelson presented an annual progress report to the private Foundation that supports this project in partnership with FAIP on Oct 25, 2017 attended by our project members, two representatives from the Foundation and two representatives from UBC Development. Louise Nelson presented an overview of the project and Tirhas Gebretsadikan presented a poster of her research at the BC Agricultural Climate Adaptation Research Workshop in Abbotsford, BC Dec 7, 2017, attended by 59 representatives from academia, government and industry. The project members and Gayle Krahn, Horticulture Manager, Coral Beach Farms participated in the making of a video of the project that will be made available to the public via the FAIP website.

Paige Munro successfully defended her M.Sc. thesis on January, 19, 2018 and her thesis is now accessible on the web via cIRcle, the University of British Columbia's digital repository for research and teaching materials. Louise Nelson was invited to present the results of the FAIP project at the Annual Conference of the Certified Organic Association of British Columbia, Feb 23-25th, 2018 in Abbotsford BC. A

winter storm prevented her from attending, but her presentation will be placed on the COABC website and will be accessible to its members. She has also been invited to speak at the Pacific Regional Society of Soil Science Spring Workshop on March 24, 2018 in Vancouver BC. We plan to produce two fact sheets based on the project in 2018 and will provide a summary of the research to the BC Cherry Association for inclusion on their website.

6.0 Conclusions and Recommendations

Objective I

Field trials at two newly established sweet cherry orchards in the north Okanagan and one established orchard in the central Okanagan were established to test the effects of two organic amendments and of postharvest deficit irrigation on crop and soil health, water use efficiency, and fruit yield and quality. After three growing seasons our data suggest that surface application of compost may be a viable option to increase soil and leaf nutrient status in both newly-cultivated and older orchard soils and improve fruit quality. Compost application may also maintain soil health, and mitigate future soil-borne disease in newly established orchard soils that have never cropped sweet cherry or other tree fruits. Woodchip mulch had no detectable effect on soil nutrient status and soil biology after three growing seasons, but increased foliar P at two sites. It may have benefits longer term in enhancing soil organic matter and improving soil water holding capacity. Cost/benefit analysis suggests that compost amendment has greater potential for benefits to be realized in the short term than mulch, but the costs may outweigh the benefits to be gained. Overall, we conclude that the use of organic amendments may be an effective tool to maintain and/or restore soil organic carbon in perennial horticulture and to enhance sweet cherry production. However, it is important to recognize that the benefits of adding organic amendments' to soil are incremental, and that the use of organic amendments is a long-term investment in soil health.

Postharvest deficit irrigation with a 25% reduction in water application had no detrimental effects on soil physiochemical or biotic properties, on tree growth, tree water stress, foliar nutrient status, fruit yield or quality in the two years following its implementation. Water use efficiency increased with its implementation. Cost/benefit analysis suggests that adoption of postharvest irrigation would be beneficial as costs of implementation are minimal, but there is little incentive presently for growers to adopt this management practice as water allocations in the Okanagan Valley are sufficient to meet current grower needs. Longer term, with water availability expected to decrease under climate change and the projected imposition of water pricing based on water usage, the use of postharvest deficit irrigation should provide significant economic benefits to growers.

Objective II

Soils from six new orchard sites and 12 old orchard sites throughout the Okanagan were selected for a greenhouse bioassay to assess the contribution of indigenous microbial communities to plant growth and for analysis of soil abiotic and biotic properties. The bioassay indicated that (1) new orchard soils were more ‘biologically suitable’ for planting sweet cherry than old orchard soils, and (2) the lower plant growth observed in old orchard soils may have been the result of changes in the microbial community, rather than from abiotic

elements in the soil environment. Results from the multiple regression analysis suggest that orchard management practices that maintain soil organic carbon levels, and stimulate an active microbial community will benefit growth of cherry trees in both new and old orchard soils.

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