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Perceptions and outcomes of conventional vs. organic apple orchard management

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ABSTRACT

Organic farming can improve soil quality and provide effective pest control with reduced inputs compared to conventional farming. Although organic and conventional farming are often viewed as dichotomous, they may overlap in pest management and soil quality goals and outcomes. Here, we assessed similarities and differences between conventional and organic apple orchards in Washington State by quantifying pesticide program risk to natural enemies, soil quality, leaf nitrogen, and abundance of woolly apple aphid (*Eriosoma lanigerum*) and its natural enemies. We also interviewed orchard owners, managers, and consultants to learn about their practices and opinions of conventional and organic management for aphids and soil quality. Organic orchards used more insecticide applications than conventional orchards, but the insecticides used were rated as less harmful to natural enemies. Conventional and organic orchards had similar soil quality, pest abundance, and natural enemy abundance. Woolly apple aphid abundance was not correlated to soil, plant, or natural enemy measurements. Interviews revealed that management goals were similar in both systems. Overall, our results suggest that both conventional and organic styles of farming are heterogenous. For example, conventional farmers may simply follow recommendations for inputs of synthetic fertilizers and pesticides or go further by using some organic or integrated practices; at the same time, organic farmers can vary in their use of organically certified pesticide sprays and ecologically based management tactics. Our study suggests that integrated management strategies that use a mix of appropriate tactics may be more important than being strictly conventional or organic to achieve superior soil and pest management outcomes.

1. Introduction

Conventional and organic agriculture are often considered dichotomous production systems. Conventional agriculture often emphasizes productivity, cost efficiency, and external inputs, whereas organic agriculture follows a certification program that restricts the use of most synthetic inputs (USDA, 2018) and tends to emphasize greater reliance on ecological processes to balance profit with environmental and social outcomes (Padel, 2001; Shennan et al., 2017). Many studies suggest organic agriculture promotes environmental, economic, and social sustainability (Bengtsson et al., 2005; Crowder and Reganold, 2015; Reganold and Wachter, 2016; Bai et al., 2018). However, both conventional and organic farms vary in their reliance on specific tactics such as pesticide use, calling into question the usefulness of framing organic and conventional farming as a dichotomy (Fairweather et al., 2009; Shennan et al., 2017). Indeed, although meta-analyses indicate differences between conventional and organic farms, the presence and magnitude of differences vary between crops, with the particular tactics used on them, and with other contexts (Bengtsson et al., 2005; Tuomisto et al., 2012; Tuck et al., 2014; Lee et al., 2015; Ponisio et al., 2015; Lori et al., 2017).

In Washington State, USA, where 12% of the apple acreage is organic (USDA, 2017), there is considerable overlap in conventional and organic soil and insect pest management practices. This region has an arid climate with low disease pressure and a restricted pest complex which reduces the need for pesticides on both conventional and organic orchards (Jones et al., 2009; Slattery et al., 2011). In addition, conventional apple orchards in Washington State extensively use organic-compatible tactics such as pheromone mating disruption, disease resistant cultivars, biological pesticides, and biological control, and to a

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lesser extent may use ground covers and compost (Jones et al., 2009; Slattery et al., 2011; Goldberger and Lehrer, 2016). These factors could lead to considerable overlap in organic and conventional pest and soil management outcomes.

To fully understand the similarities and differences between conventional and organic management strategies and their outcomes, the opinions of growers, managers, and consultants should be considered (Carolan, 2006; Goldberger, 2011). Compared with conventional tactics, such as quick-acting synthetic fertilizers and pesticides, common organic tactics, such as ground covers for weed suppression or conservation biological control for pests, are more complex and knowledge-intensive. These tactics may thus have a less apparent connection between cause-and-effect, hindering their appreciation and adoption (Padel, 2001; Carolan, 2006) and potentially influencing the choice of tactics used in conventional and organic apple orchards.

In our study, we assessed conventional and organic practices and outcomes in central Washington State apple orchards. Our study focused on a common pest, woolly apple aphid (*Eriosoma lanigerum* [Hausmann]), and soil quality. Aphid populations can be influenced by soil quality (Zehnder et al., 2007), plant nitrogen (Nevo and Coll, 2001), and biological control (Gontijo et al., 2015), so woolly apple aphid is a useful indicator species. We collected data on pesticide spray programs, tree nitrogen, soil quality, and woolly apple aphid abundance, and we interviewed apple orchard owners, field managers, and consultants to learn how their opinions and management decisions were related to these factors.

2. Methods

2.1. Study sites

Twenty orchard sites, comprising seven conventional, ten organic, and three organic-transitional management systems, were selected in 2014 after consultation with collaborators contacted by the authors (Supplementary Table S1). All orchard sites were in central Washington, USA, spanning the region between Chelan and Royal City (Table 1). The organic-transitional orchard sites were managed organically, but for less than the three years required for organic certification (USDA, 2018).

2.2. Spray record analysis

We obtained pest and fertility spray records for 2014 and 2015 from most orchard sites, although some records were missing because managers were unable to provide them. We analyzed two metrics of spray records: (1) the number of insecticide applications, and (2) a score characterizing spray program risk of harming natural enemy populations. Each unique application of an insecticide formulation was counted towards the number of applications. All pheromone, antibacterial, fungicide, herbicide, nutrient, and adjuvant chemicals were not scored and not included in the count of total insecticide sprays. We characterized spray program risk to natural enemies using risk values following Gallardo et al. (2016). Each pesticide spray was assigned a risk category with a numerical value associated with potential harm (1 = low, 2 = moderate, 3 = high risk); scores for each year and orchard site were calculated as the sum of risk values. When risk values were not available, we calculated the average of available values in the Orchard Pesticide Effects on Natural Enemies Database (OPENED) (Chambers et al., 2014; Gallardo et al., 2016), rounded to the nearest integer. All *Bacillus thuringiensis* and codling moth (*Cydia pomonella*) granulosis virus sprays were given scores of 0 because of their specificity to the target pest. One application of molasses was considered equivalent to petroleum oil due to its potential to smother insects and given a score of 1.

2.3. Woolly apple aphid and natural enemy analysis

There is no widely accepted single method for assessing woolly apple aphid abundance in apple orchards. Previous studies on this pest used metrics such as colonies observed per minute (Beers et al., 2010, 2016a), colonies per tree (Bergh and Stallings, 2016), colonies per shoot (Wearing et al., 2010), or a qualitative infestation rating (Quarrell et al., 2017). Timed counts or colonies per tree could be biased by variation in the size of trees (larger trees have more space for colonies),

Table 1
Information about study orchards sites.

Management	Site	Variety	Rootstock	Coordinates	Hectares	Soil Series and Type[b]	U.S. Soil Classification[b]
Transitional	I	Fuji	M26	47.2349, -119.9421	2.4	Shano silt loam	Coarse-silty, mixed, superactive, mesic Xeric Haplocambid
	J	Fuji	M9	47.2676, -119.8799	11.5	Taunton silt loam	Coarse-loamy, mixed, superactive, mesic Xeric Haplodurid
	K[a]	Gala	M9	47.2614, -119.6494	4.0	Sagehill very fine sandy loam	Coarse-loamy, mixed, superactive, mesic Xeric Haplocalcid
Conventional	A	Fuji	M9	46.9331, -119.5535	2.5	Kennewick silt loam	Coarse-silty, mixed, superactive, calcareous, mesic Xeric Torriorthent
	B	Fuji	M9	46.9347, -119.3688	9.6	Kennewick silt loam	Coarse-silty, mixed, superactive, calcareous, mesic Xeric Torriorthent
	C	Gala	M26	47.2027, -119.9486	8.1	Shano silt loam	Coarse-silty, mixed, superactive, mesic Xeric Haplocambid
	D	Fuji	M26	47.2204, -119.9692	5.2	Shano silt loam	Coarse-silty, mixed, superactive, mesic Xeric Haplocambid
	E	Gala	Mark	47.2202, -119.9600	2.0	Shano silt loam	Coarse-silty, mixed, superactive, mesic Xeric Haplocambid
	F	Fuji	M9	47.2643, -119.7996	6.9	Scoon silt loam	Loamy, mixed, superactive, mesic, shallow Xeric Haplodurid
	H	Gala	M26	47.8958, -120.0954	1.4	Chelan gravelly sandy loam, pumiceous	Ashy, glassy, mesic Vitritorrandic Haploxeroll
Organic	G	Gala	M26	47.7392, -120.1698	2.4	Supplee ashy very fine sandy loam	Ashy over sandy or sandy-skeletal, glassy over mixed, mesic Vitritorrandic Haploxeroll
	L	Fuji	M9	46.9129, -119.5646	2.4	Kennewick fine sandy loam	Coarse-silty, mixed, superactive, calcareous, mesic Xeric Torriorthent
	M	Fuji	M26	46.9329, -119.3972	3.9	Adkins very fine sandy loam	Coarse-loamy, mixed, superactive, mesic Xeric Haplocalcid
	N	Fuji	M26	47.2005, -119.9505	23.2	Shano silt loam	Coarse-silty, mixed, superactive, mesic Xeric Haplocambid
	O	Fuji	M26	47.2318, -119.9626	3.7	Shano silt loam	Coarse-silty, mixed, superactive, mesic Xeric Haplocambid
	P	Gala	M26	47.2208, -119.9589	1.7	Shano silt loam	Coarse-silty, mixed, superactive, mesic Xeric Haplocambid
	Q	Fuji	M7	47.2269, -119.9488	5.4	Shano silt loam	Coarse-silty, mixed, superactive, mesic Xeric Haplocambid
	R	Gala	M26	47.2748, -119.6444	7.3	Scoon stony silt loam	Loamy, mixed, superactive, mesic, shallow Xeric Haplodurid
	S	Fuji	M26	47.7447, -120.1639	3.7	Supplee ashy very fine sandy loam	Ashy over sandy or sandy-skeletal, glassy over mixed, mesic Vitritorrandic Haploxeroll
	T	Gala	M26	47.9036, -120.0936	4.2	Margerum gravelly silt loam	Fine-loamy, mixed, superactive, mesic Aridic Argixeroll

[a] Conventional in 2014, organic-transitional in 2015.
[b] Assessed using data from the United States Department of Agriculture Web Soil Survey tool version 3.3 (USDA, 2019).

so we assessed woolly apple aphid occurrence on a per shoot basis to allow for comparison of infestations between orchard sites, which varied in tree size due to rootstocks (Table 1) and age. In 2014, ten trees across four tree rows were selected in each site, flagged, and sampled for woolly apple aphids on each of 3–5 visits per block by inspecting 16 random shoots per tree. The number of shoots infested with any amount of woolly apple aphids was recorded. The sampled rows were spaced at even intervals and at least 30 m from block edges, and all 10 selected trees were at least 10 m away from each other and block edges. In 2015, woolly apple aphid monitoring was conducted as above, except only on four trees in each of four rows (16 total trees), and aphids were counted differently: the total number of woolly apple aphid colonies was counted on the trunk and 10 shoots of each tree.

In 2014 and 2015, four white sticky cards (18 × 18 cm) with squalene lures (Jones et al., 2011) were used to monitor green lacewings (*Chrysopa nigricornis*), and four yellow (13 × 19 cm) sticky cards with geraniol and 2-phenylethanol lures (Jones et al., 2016) were used to monitor *Aphelinus mali*, a specialist parasitoid of woolly apple aphid. The eight total cards were placed in a box formation around sampling areas, at least 10 m from each other and any sampling tree. The cards were hung from tree branches about 1.8 m from the ground. Fresh sticky cards were deployed on each visit, and old ones brought to the lab where insects were counted.

Earwigs (*Forficula auricularia*) were monitored in 2014 and 2015 using cardboard shelters (Orpet et al., 2019a). In 2014, rolls of single-face corrugated cardboard (7.5 × 35.5 cm) were placed at the height of the first major limb on ten trees within the sampling area. In 2015, shelters were placed in each of the same trees where woolly apple aphid colonies were counted. Earwigs were shaken out of the shelters, counted, and released onto the ground on each visit.

2.4. Tree nitrogen analysis

In 2014, apple leaves were collected on one visit to each orchard site between 7 and 24 Jul. In each site, we collected 5 leaves from each of the 10 trees used for insect monitoring. In 2015, apple leaves were collected on each of 3 or 4 visits to orchard site between 19 May–29 Jul. We collected 3 leaves from each of 16 trees where insects were monitored. All leaves were fully expanded and located in the middle of shoots. The samples were sent to SoilTest Farm Consultants (Moses Lake, WA) for quantification of percentage nitrogen.

2.5. Soil quality analysis

2.5.1. Measurements

From 18 to 29 May 2015, five 1.7 cm diameter soil cores of 15 cm depth were collected from each site using a soil probe. All cores were taken from below the tree row next to one of the insect-monitored trees. Cores were divided into 0–7.5 cm and 7.5–15 cm depth sections. Fresh and dry weight (dried at 125 °C for 2 d) of cores were obtained and bulk density for each orchard site was calculated for 0–7.5 cm and 0–15 cm depths as the average mass of dry soil per cubic centimeter of fresh soil.

In 2016, six 1.7 cm diameter cores of 15 cm depth were collected, mixed, and stored in a cooler with ice until brought to a laboratory cold room. Then, 480 mL of soil from each orchard site were sent to SoilTest Farm Consultants Inc. (Moses Lake, WA) for determination of texture, organic matter, nitrate nitrogen, extractable phosphorous, cation exchange capacity, and electrical conductivity, according to soil-testing methods recommended by Gavlak et al. (2003). Another 240 mL of soil was shipped to Washington State University in Pullman, WA for quantification of microbial biomass carbon (Voroney et al., 2008) and dehydrogenase activity (Tabatabai, 1994).

In 2017, a visual assessment of the physical condition of the soil surface (0–10 cm) was made using a structure rating index (St), ranging from low (1) to high (10), developed by Peerlkamp (1967) and modified by McLaren and Cameron (1990). The averaged structure index value from six subsamples taken from across the study rows of each orchard site was used.

2.5.2. Soil quality index

We assessed soil quality using an index designed for apple orchards (Glover et al., 2000) as a framework. Following Glover et al. (2000), soil quality measurements were given normalized scores (from 0 to 1, 1 is highest quality) using a scoring curve equation for each parameter. Curve types depend on whether larger values of the raw parameter are better, worse, or if intermediate values are optimal. Curves for each parameter have a different set of critical values: a baseline (with score = 0.5), a lower threshold (with score = 0), an upper threshold (with score = 1.0), and a slope of the tangent line at the baseline (Glover et al., 2000).

Following Glover et al. (2000), we analyzed bulk density taken from 0 to 7.5 cm depth and the following parameters taken from 0 to 15 cm depth: soil organic carbon, nitrate nitrogen, extractable phosphorous, cation exchange capacity, electrical conductivity, pH, and microbial biomass carbon. We also substituted aggregate stability with a structure index (1–10 rating) using the aggregate stability scoring curve used by Glover et al. (2000), except with a baseline of 5 and upper threshold of 10. After each parameter received its score, we weighted them with the same multipliers used by Glover et al. (2000) and summed scores for each site. We then divided each summed score by 0.6925 (the maximum possible with our subset of parameters) or 0.4925 (for the two sites where we lacked the structure index) to obtain values from 0 to 1. Compared with Glover et al. (2000), we lacked data on earthworms, porosity, water-filled pore space, and microbial biomass nitrogen, and substituted the structure index for aggregate stability. In addition, Glover et al. (2000) used microbial biomass carbon at 0–7.5 cm depth in the "Resist surface structure degradation" function and 0–15 cm depth in the "Sustain fruit quality and productivity" function in their index, whereas we used the 0–15 cm depth data for the entire weight of microbial biomass carbon for both functions in our modified index. This was because we only collected 15 cm depth soil core samples for all parameters except bulk density.

Despite only analyzing up to 70% of the weighted soil quality index score used by Glover et al. (2000), the subset of soil parameters used in our study was suitable for assessing soil health in apple orchards. Our subset contained physical, chemical, and biological parameters relevant to a range of the four soil functions in Glover et al. (2000), including sustaining fruit quality and productivity, resisting surface structure degradation, accommodating water entry, and to a lesser degree facilitating water movement and availability. In addition, our subset included factors sensitive to apple orchard management practices; e.g., bulk density (Swezey et al., 1998; Glover et al., 2000) and microbial biomass carbon (Swezey et al., 1998; Glover et al., 2000).

2.6. Interviews

In 2014, interviews were requested with pest management decision-makers associated with the study sites, resulting in interviews with eight owners, field managers, or consultants. After a general solicitation for interviewees at Washington State extension meetings in 2016, 16 additional interviews were conducted in 2017 (Supplementary Table S1). Four individuals overlapped between the years for a total of 20 interviewees. Interviews were semi-structured, with a focus on experiences and opinions related to organic and conventional woolly apple aphid management. The only criterion for selection of the 2017 interviewees was that they must have a current role in making pest management decisions for commercially managed apple. Interviews were conducted in person, digitally recorded, and transcribed. A subset of the data from 2017 focused solely on biological control was discussed previously by Orpet et al., 2019b

2.7. Statistical analysis

We compared pesticide programs, woolly apple aphid, green lacewing, *A. mali*, European earwig, leaf nitrogen, and soil quality between conventional and organic sites. We excluded organic-transitional sites from comparisons because changes in soil quality (Drinkwater et al., 1995; Swezey et al., 1998; Peck et al., 2011) and insect communities (Wearing et al., 2010) in response to organic management practices likely occur over more than the three years of a typical transition period.

For analysis of pesticide programs, we analyzed the number of sprays and cumulative natural enemy risk scores each with a linear mixed effects model. For analysis of woolly apple aphid abundance, we first summarized infested shoots for 2014 and colony counts for 2015 within sites into a season-long average for each year. Because of the different sampling methods used, we analyzed each year separately with Wilcoxon rank-sum tests. For green lacewings, *A. mali*, and earwigs, we calculated the average number of insects per sticky card or shelter per day of sampling device deployment across inspection days. We used linear mixed models to compare conventional versus organic green lacewing and earwig values. To compare *A. mali* values, we used a separate Wilcoxon rank-sum test for each year because of two outliers in 2014. We analyzed leaf nitrogen measurements with a linear mixed effects model incorporating all measurements across years. For analysis of soil quality, we performed two multivariate analysis of variances (MANOVA), one with response variables of all soil properties (bulk density, nitrate N, extractable P, cation exchange capacity, electrical conductivity, pH, microbial biomass carbon, organic carbon, organic matter, and dehydrogenase activity) and one with response variables of soil quality index scores. Because we could not access orchard sites H and T in 2017 for structure index measurements, we analyzed the available structure index values and scores with *t*-tests and did not include structure index in MANOVAs.

For mixed effects models, we used the 'glmmTMB' function of the 'glmmTMB' package in R (R Core Team, 2018), with fixed factors of management (conventional or organic), year (2014 or 2015), their interaction, and a random factor of block. This function returns *Z* statistics and *P* values for Wald's tests on fixed effects, allowing us to infer whether conventional versus organic metrics differed. When response variables were count data, we used linear mixed effects models if model residuals were normally distributed; if not, we compared Poisson and negative binomial models using the 'AICctab' function of the R package 'bbmle' and used the most well supported model. For MANOVAs, we used the 'manova' function in R.

To assess correlations between woolly apple aphids and other measured factors, we used Spearman's rank correlations for each year. Variables considered were cumulative natural enemy risk scores from pesticide programs, leaf nitrogen (averaged between observations for 2015), overall soil quality index score (the same values were used for 2014 and 2015), average green lacewings per card per day, average *A. mali* per card per day, and earwigs per shelter per day.

3. Results

3.1. Spray record analysis

Organic and conventional blocks used a similar number of pesticide sprays ($Z = 0.64$, $P = 0.52$) (Fig. 1a and b). Although year did not affect pesticide sprays (Z = 0.64, $P = 0.52$), there was a significant management by year interaction ($Z = 3.06$, $P = 0.0022$), reflecting that organic orchards used 1.4 times more sprays in 2015 than in 2014, while conventional orchards used 1.05 times more in 2015 than 2014. Conventional blocks had higher natural enemy risk scores ($Z = -4.7$, $P < 0.0001$) (Fig. 1c and d), and there was no significant effect on natural enemy risk scores from year ($Z = 1.57$, $P = 0.12$) or year by management interaction ($Z = 1.5$, $P = 0.13$). Numbers of sprays and cumulative natural enemy risk scores for each site are available in Supplementary Table S2.

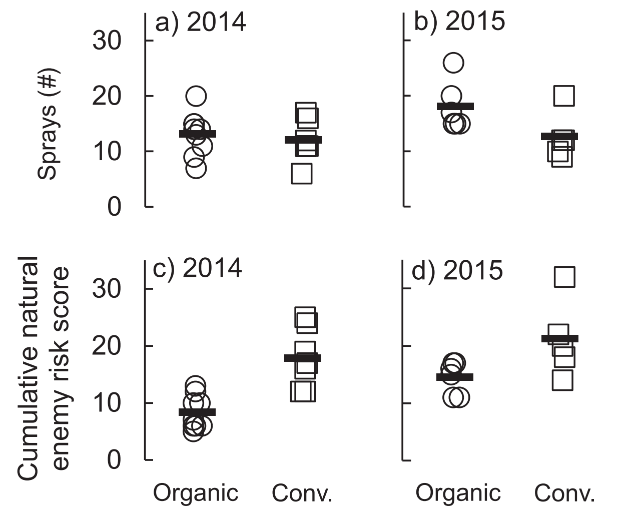

Fig. 1. Number of pesticide sprays (not including herbicides and fungicides) used at conventional and organic orchard sites in 2014 (a) and 2015 (b), and cumulative natural enemy risk scores in 2014 (c) and 2015 (d) (higher numbers indicate greater risk to natural enemies) for sites where spray records were obtained. Open circles and squares represent orchard sites. Bars represent means.

3.2. Woolly apple aphid and natural enemy analysis

Woolly apple aphid counts were similar between organic and conventional sites in 2014 ($S = 94$, $Z = 0.71$, $P = 0.48$) and 2015 ($S = 56.5$, $Z = -0.59$, $P = 0.55$) (Fig. 2a and e). Green lacewing abundance was also not affected by management ($Z = -0.91$, $P = 0.36$), but was notably affected by year ($Z = -1.83$, $P = 0.068$), and the management by year interaction ($Z = -1.83$, $P = 0.079$), reflecting that lacewings were more abundant in conventional orchards in 2014 and organic orchards in 2015 (Fig. 2b and f). Although two organic sites had high *A. mali* counts, *A. mali* levels were similar between conventional and organic in 2014 ($S = 70$, $Z = -0.49$) and 2015 ($S = 52.5$, $Z = -0.98$, $P = 0.33$) (Fig. 2c and g). Earwigs were also not affected by management regime ($Z = -0.01$, $P = 0.99$) but were affected by year ($Z = 2.72$, $P = 0.007$), reflecting greater abundance of earwigs in both types of orchards in 2015 compared to 2014 (Fig. 2d and h). Summary data on each insect per site, including the transitional orchards, is in Supplementary Table S3.

3.3. Leaf nitrogen analysis

Leaf nitrogen was not significantly affected by management regime ($Z = 0.030$, $P = 0.98$), year ($Z = 0.72$, $P = 0.47$), or their interaction ($Z = -0.031$, $P = 0.98$). Mean leaf nitrogen in 2014 was 2.31% (SD = 0.20) in organic and 2.48% (SD = 0.34) in conventional sites. After taking the average of multiple measurements within blocks in 2015, mean leaf nitrogen was 2.36% (SD = 0.22) in organic and 2.53% (SD = 0.26) in conventional sites.

3.4. Soil quality analysis

There was no effect of management on individual soil properties (MANOVA: Pillai-Bartlett statistic = 0.95, approximated $F_{3,11} = 5.2$, $P = 0.10$) (Table 2). Similarly, there was no effect of management on soil quality index scores (Supplementary Table S4; MANOVA: Pillai-Bartlett statistic = 0.52, approximated $F_{8,8} = 0.49$, $P = 0.81$) or overall weighted index (Fig. 3). The mean structure index raw values

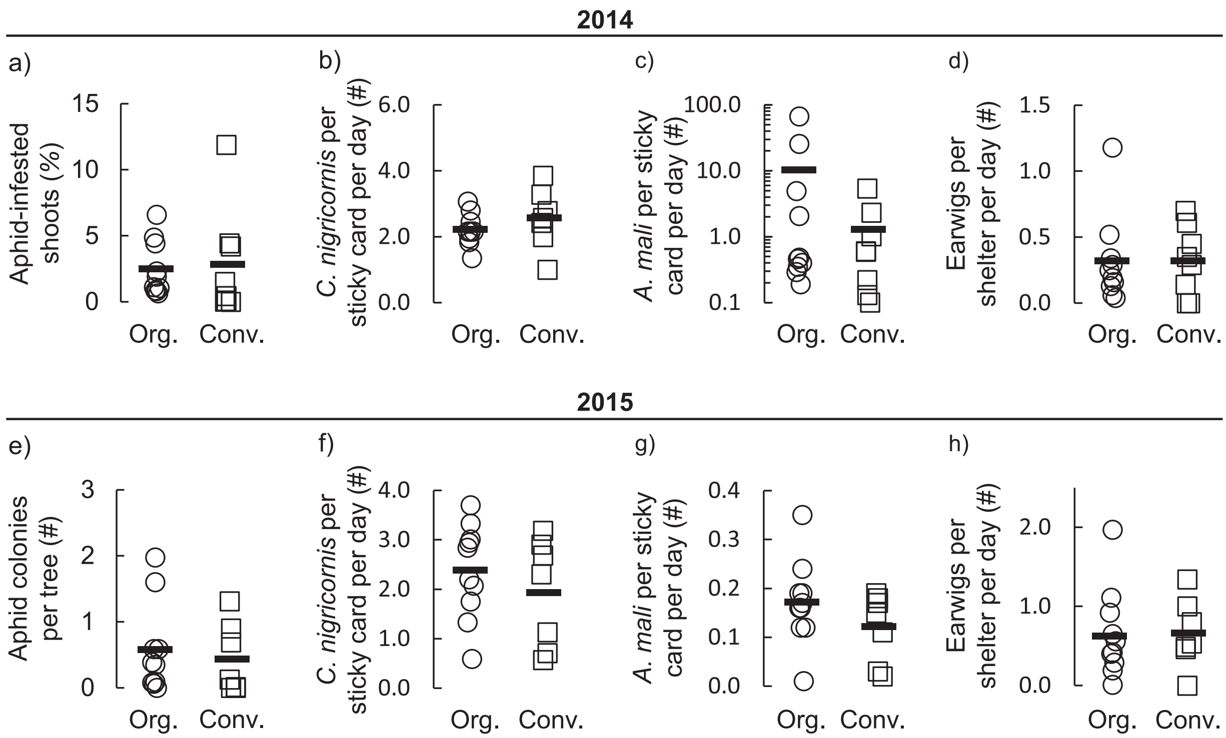

Fig. 2. Summary of insect monitoring data from conventional and organic orchard sites in 2014 (a, b, c, and d) and 2015 (e, f, g, and h). Open circles and squares show the average insect count for an orchard site across the season. Bars show means. Woolly apple aphid data are shown as the average percentage of infested shoots out of 16 per tree (a) or the average number of colonies found on each trunk and 10 shoots per tree (e).

(Table 2) and scores (Table S4), which were excluded from MANOVAs because of missing data, were similar between conventional and organic (raw values: $t = 0.68$, $df = 14$, $P = 0.51$; scores: $t = 0.51$. $df = 14$, $P = 0.62$). Data on soil texture are in Supplementary Table S5, along with organic matter and dehydrogenase activity, which were included as individual soil properties in MANOVA above but were not scored in the soil quality index.

3.5. Correlations between measurements

Woolly apple aphid counts were not significantly correlated to pesticide program natural enemy risk scores, soil quality index, leaf

Table 2
Soil quality raw parameters at orchard sites measured in 2015.

Management	Site	BD (g/cm^3)	St (1–10)	OM (%)	OC (Mg/ha)	NO_3 N (kg/ha)	P (kg/ha)	CEC (meq/100 g)	EC (dS/m)	pH	MBC (ug/g)
Transitional	I	1.32	7.7	1.5	22.4	4.5	46.6	10.7	0.33	6.7	222.1
	J	1.26	7.8	1.5	21.5	96.3	117.0	11.0	0.66	6.7	45.7
	K	1.41	6.0	1.0	23.8	4.5	96.9	12.9	0.16	7.0	179.2
	Mean	**1.33**	**7.2**	**1.2**	**22.6**	**35**	**87**	**11.5**	**0.38**	**6.8**	**144**
	SD	**0.06**	**0.8**	**0.3**	**0.95**	**53**	**36**	**1.2**	**0.3**	**0.2**	**88**
Organic	G	0.99	7.7	1.9	19.80	16.8	59.1	8.4	0.18	7.6	61.6
	L	1.22	7.8	2.1	21.12	24.6	76.8	10.8	0.19	7.6	209.3
	M	1.13	6.6	2.1	19.64	10.1	66.0	9.6	0.20	7.7	203.0
	N	1.22	7.6	2.5	21.45	30.2	218.4	10.3	0.61	7.4	57.5
	O	1.06	7.8	1.6	19.14	6.7	99.2	10.2	0.17	7.1	137.7
	P	1.25	8.1	1.5	22.11	81.8	114.6	8.7	0.37	5.7	26.8
	Q	1.3	7.1	1.7	22.44	7.8	85.7	10.9	0.20	7.1	210.8
	R	1.4	7.7	1.9	24.75	11.2	49.5	15.7	0.21	7.1	305.2
	S	1.03	5.7	1.8	18.48	20.2	65.5	6.0	0.18	7.6	63.3
	T	0.85	n/a	1.9	15.02	9.0	12.3	5.9	0.10	6.9	71.1
	Mean	**1.15**	**7.3**	**1.9**	**20.4**	**22.0**	**85.0**	**9.7**	**0.2**	**7.2**	**142**
	SD	**0.16**	**0.7**	**0.3**	**2.5**	**22.0**	**55.0**	**2.8**	**0.10**	**0.6**	**85**
Conventional	A	1.34	7.5	1.2	22.44	22.4	59.2	10.3	0.29	7.6	135.6
	B	1.13	6.1	1.4	19.97	9.0	61.7	10.0	0.13	6.9	267.6
	C	1.38	7.0	1.2	23.10	2.2	56.7	9.3	0.07	6.8	258.5
	D	1.22	7.4	1.5	22.11	9.0	52.3	9.3	0.13	7.0	173.8
	E	1.19	7.3	1.2	21.78	117.6	103.0	9.1	0.33	6.7	75.3
	F	1.26	7.3	1.9	21.29	20.2	31.0	12.4	0.30	7.8	371.5
	H	0.85	n/a	2.5	15.18	9.0	6.9	6.3	0.10	6.2	56.0
	Mean	**1.20**	**7.1**	**1.6**	**20.8**	**27**	**53**	**9.5**	**0.19**	**7.0**	**198**
	SD	**0.16**	**0.5**	**0.5**	**2.5**	**41**	**30**	**1.8**	**0.1**	**0.5**	**115**

BD, bulk density 7.5 cm depth; St, structure index; OM, organic matter; OC, organic carbon; NO_3 N, Nitrate nitrogen; P, extractable phosphorous; CEC, cation exchange capacity; EC, electrical conductivity; MBC, microbial biomass carbon.

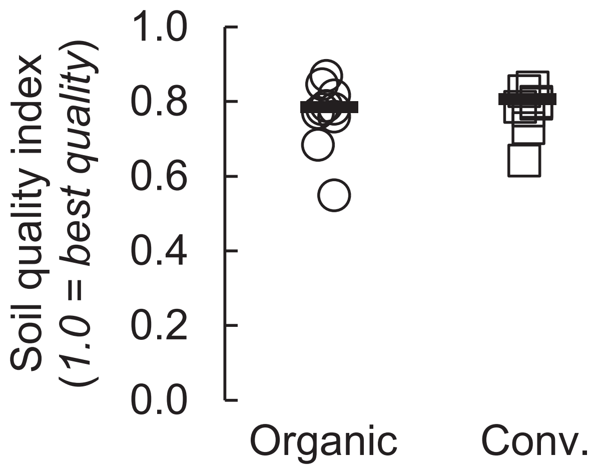

Fig. 3. Overall weighted soil quality index scores for conventional and organic orchard sites in 2015. Circles represent orchard sites and lines represent means. There was no significant difference in the mean soil quality index between conventional and organic (t = -0.44, df = 15, P = 0.66).

nitrogen, or natural enemies in 2014 (all $P >$ 0.18). In 2015, there was a significant correlation between woolly apple aphids and green lacewings (ρ = 0.77, P = 0.0001) but no other variables (all $P >$ 0.16). There was no significant correlation between any natural enemy species with natural enemy risk scores in 2014 or 2015 (all $P >$ 0.24).

3.6. Interviews

3.6.1. General opinions on organic versus conventional management and sustainability

The main motivation for growing organic apples was profit: "[we grow organic] because it's making the owner money" (manager #3). Non-economic benefits were mentioned occasionally, but always secondary: "you're not using as strong as sprays, but the number one reason [I grow organic] is economic" (owner #4). Farm sustainability was a shared goal between management styles: "my goal is to farm as sustainably as possible…we're not organic, but we are awfully darn close" (manager #1). Improvements to conventional management were sometimes spurred from organic management experience: "organic [experience] is what has allowed us to soften our conventional programs" (owner #5).

3.6.2. Spray programs

Judicious selection of pesticides and timing of their application were always goals for both conventional and organic orchards. However, interviewees often considered organic programs to be softer, in some cases resulting in lower woolly apple aphid abundance and greater biological control: "[woolly apple aphid is a worse problem in] conventional…because we're spraying insecticides…that disrupt the predator complex" (consultant #3), and "when I find [woolly apple aphids] in conventional, it's really bad, and I feel like you don't have the predators there and so it becomes an even worse problem than it does in organic" (consultant #6). Some interviewees noted organic pesticide programs only have the potential to be softer: "I know that if we're not careful there's greater propensity to disrupt their natural controls with conventional tools [but] I'm not doing that" (consultant #1). Only one person was highly doubtful that organic programs are softer: "I'm not going to say conventional orchards have less [natural enemies] because of a spray program and organic have more because it's a softer program… I just have seen enough evidence where I don't [observe this]" (consultant #4).

3.6.3. Woolly apple aphid management in organic and conventional

Eleven of the interviewees considered woolly apple aphid a key pest, and three of these reported it either their "number one" concern or of equal concern to other pests. Major outbreaks in the 2010s increased concern, particularly in organic orchards because no organic certification-compatible intervention tactics were seen as effective. In conventional orchards, two insecticides, chlorpyrifos and diazinon, were considered effective, but their high toxicity to natural enemies and worker safety issues were drawbacks. As two interviewees commented: "I completely transitioned away from using organophosphates years ago. Woollies [*i.e.*, woolly apple aphids] are the reason every now and then I have had to move backwards…and I don't like doing that" (consultant #1) and "diazinon is a great product, the most-used product for woollies…[but] it's an organophosphate and a lot of guys just don't want to do that anymore" (consultant #9).

One other insecticide, spirotetramat, a systemic insecticide that can kill both above and belowground woolly apple aphids was considered effective. Although 12 interviewees reported using spirotetramat to manage woolly apple aphids, only two specifically considered it as a tactic to manage root colonies. This was because most people were unaware that woolly apple aphids fed belowground, or because belowground aphids were 'out of sight and out of mind': "My concern is aboveground, I'm certainly aware of the belowground damage, but you can't easily see that, so it doesn't bother me as much" (manager #4).

There were two views on how woolly apple aphid abundance was related to soil quality or fertilization practices: (1) three interviewees said that "healthy" trees are more resistant to aphids, and (2) ten interviewees said that vigorous trees encourage aphid population growth. However, only one person was confident that higher soil quality increases pest resistance, while all interviewees either thought soil quality was of unknown or inconsequential importance.

Beside biological control (Orpet et al., 2019b), three non-chemical tactics for woolly apple aphid management were prominent. First, 14 interviewees were aware of Geneva rootstocks with woolly apple aphid resistance. Although woolly apple aphid resistance was considered a benefit of these rootstocks, interviewees were more interested in fire blight resistance and horticultural characteristics, and these rootstocks are currently in short supply. Second, four interviewees planted sweet alyssum (*Lobularia maritima*) to attract woolly apple aphid predators. One of them thought this improved control in both conventional and organic blocks, but the other three reported that the plants were difficult to maintain and would not recommend them. Third, two people mentioned washing off aphids with water or soapy water, and three people mentioned pruning out infested plant material. None of these physical tactics was considered effective.

3.6.4. Soil quality and tree nutrition

Fertilization goals were generally viewed as the same between management styles. For example: "the same amount of N is the ultimate goal… [It is] verified through leaf analysis, and you have to meet those goals whether it's conventional or organic fertilizers" (consultant #1). Nonetheless, five interviewees thought either that organic orchards tended to be less vigorous than conventional ones, or that it was easier to over-fertilize conventional orchards. Only one person reported a problem with over-fertilization in an organic orchard, where too much compost was applied when field staff were new to organic management. Two interviewees said that compost is used typically only in organic orchards, but they also used it in some conventional orchards when they wanted to increase soil organic matter. In addition, not all organic systems reportedly used compost: one consultant estimated about half of the organic orchards they worked with used composted manures and the other half used other "animal byproducts" (feather and bone meals). Responses were mixed on whether organic management leads to increased soil quality. Of the conversations where this was discussed, two people thought organic management increased soil quality but could not say to what extent, another didn't know, and one (owner #3) said "Supposed to. I don't think so to be honest."

4. Discussion

Commercially managed conventional and organic apple orchards in our study had similar ratings of pesticide risk to natural enemies, abundance of woolly apple aphid, abundance of natural enemies (European earwigs, lacewings, and *A. mali*), leaf nitrogen, and soil quality. Interview and spray records suggest the two management styles did not represent a clear 'either/or' dichotomy in management practices and goals, which may explain the similarities in management outcomes. These similarities could be interpreted as an example of organic "conventionalization," where organic farms substitute synthetic inputs with certified organic alternatives rather than fully exploit ecological or technological techniques (Goldberger, 2011; Guthman, 2014; Marliac et al., 2015). At the same time, conventional orchards in Washington State, USA, have been moving toward integrated management which blends organic and conventional practices. For example, some conventional pesticide programs in our study were rated with less risk to natural enemies than some organic ones, and conventional orchards occasionally used animal products for fertilization. Overall, our study and others suggest that managers' perceptions and regional contexts could affect management practices and outcomes more than organic certification standards.

In contrast to our results, other studies indicate organic apple orchard management can promote soil quality (Swezey et al., 1998; Reganold et al., 2001). However, each of these studies was tightly controlled with four replicated plots on a large experimental site of a commercial farm so all organic and conventional replicates had the same soil, apple variety, and rootstock. We could not locate similar paired side-by-side organic/conventional apple orchards with the same soil, apple variety, and rootstock, and we also could not control for initial soil types before the start of organic farming. These factors likely limited our ability to detect effects of organic versus conventional management on soil quality (Reganold, 2013; Kirchmann et al., 2016). The previous studies (Swezey et al., 1998; Reganold et al., 2001) were also designed to use a distinctly different set of practices. For example, organic treatments in both studies (Swezey et al., 1998; Reganold et al., 2001) used composted poultry manure. Use of manure instead of synthetic nitrogen fertilizers can lead to improvements to soil quality, particularly in soil organic matter content (Reganold et al., 2001; Bai et al., 2018). However, inconsistent use of this tactic and others across commercial orchards (Slattery et al., 2011) could contribute to why we did not observe greater average soil quality in organic orchards.

"Healthy" soil in organic systems is commonly thought to reduce incidence of pest outbreaks (Zehnder et al., 2007). Use of manure usually has a negative effect on pest abundance compared with conventional fertilizers (Garratt et al., 2011), and greater plant nitrogen content can increase aphid fecundity (Nevo and Coll, 2001). Some interviewees in our study mentioned these relationships, but we did not find correlations between soil quality or tree nitrogen with aphids. These results, along with those from other studies showing conflicting effects of organic and conventional approaches on abundance of aphid pests in apples (Knight, 1994; Dib et al., 2016), suggest fertilization strategies may not have a considerable effect on woolly apple aphid populations in apples.

We found similar woolly apple aphid and natural enemy abundance between organic and conventional orchards. This may have been due to similarities in pest management strategies. Both organic and conventional orchards may use a combination of pesticides and biological control (although organic farmers are limited to organically certified pesticides). There was a high number of sprays under organic management in our study because common organic insecticides, such as granulosis virus for codling moth or oil for a range of pests, have less persistence compared with many synthetic insecticides. This may cause managers to choose to spray them more frequently (Simon et al., 2007). Conventional pesticide programs were rated with higher risk to natural enemies, but we found no evidence that natural enemies were less abundant in conventional orchards. Our findings corroborate other studies that show high variation in pesticide use for organic apple orchards (Marliac et al., 2015, 2016) and overlapping biodiversity outcomes in organic compared with conventional apple orchards (Samnegård et al., 2018). However, natural enemies tend to be more abundant in organic over conventional European apple orchards (Porcel et al., 2018; Samnegård et al., 2018). Regional differences in pest complexes and landscape could explain discrepancies between studies (Samnegård et al., 2018). For example, our study region of arid central Washington State has a restricted pest complex, and managers extensively use mating disruption for codling moth management and a web-based decision support tool to effectively time sprays based on pest phenology (Jones et al., 2009, 2010; Granatstein and Peck, 2017). This permits both organic and conventional orchards in Washington to use relatively few pesticide sprays compared with humid regions such as New Zealand and the Eastern United States (Delate et al., 2008).

There was a positive association between green lacewing counts and woolly apple aphids in one year, suggesting green lacewings may have responded numerically to prey density. It was surprising that this was the only association we found between woolly apple aphids and natural enemies because other studies strongly implicate several natural enemy species as key for aphid biological control (Gontjo et al., 2015; Bergh and Stallings, 2016; Quarrell et al., 2017; Orpet et al., 2019b, Orpet et al., 2019c). Recent studies based on natural enemy and pest monitoring in apple orchards in Washington State, USA, and Europe could identify neither strong biological control relationships nor effects of variability in pesticide programs on biocontrol (Marliac et al., 2015; Beers et al., 2016a, 2016b; Samnegård et al., 2018). An exception within the above studies was a negative correlation between European earwigs and woolly apple aphids (Beers et al., 2016a, 2016b), but no such correlation was observed in our present study. The aforementioned studies and our results in this paper point out the difficulty of inferring whether a pesticide spray poses a threat to biological control without more frequent sampling to provide a clear and detailed picture of non-target organism population dynamics.

The subjective perceptions of orchardists played a role in which tactics they adopted for their organic and conventional orchards. For example, sweet alyssum plantings can promote suppression of woolly apple aphid by attracting and supporting natural enemy populations (Gontijo et al., 2013), but these plants were considered both impractical and ineffective to orchardists interviewed in our study. This underscores that orchardists consider multiple criteria when deciding which practices to use, and it can be difficult for farm managers to perceive benefits of difficult-to-observe factors such as benefits of functional biodiversity (Penvern et al., 2019; Swiergiel et al., 2019). However, soft pesticide programs and compost were considered effective tactics, and were adopted in conventional orchards after managers gained experience with them under organic management. Long-term experience and the necessity of experimenting with new techniques when shifting to organic management can promote farm innovations and their spread (Penvern et al., 2019). Overall, our findings support conclusions that extension and research efforts should address not just the effectiveness of new techniques but also how their audience experiences the techniques, such as their practicality, ability to address multiple management needs, and perceptibility of results (Carolan, 2006; Gadino et al., 2016; Penvern et al., 2019; Swiergiel et al., 2019).

Our results suggest that both conventional and organic styles of farming can be heterogenous. More specifically, conventional farmers may simply follow recommendations for inputs of synthetic fertilizers and pesticides, or go further by using some organic or integrated practices (Fairweather et al., 2009; Merfield et al., 2015). At the same time, organic farmers can vary in their use of organically certified pesticide sprays and ecologically based management tactics (Marliac et al., 2015). Experiences and perceptions of farm managers affect the extent to which different organic or conventional tactics are used (Penvern et al., 2019; Swiergiel et al., 2019), and organic-compatible tactics that are perceived as highly effective can be adopted on conventional farms. Overall, sustainability might be improved more by considering a mix of tactics suited to local conditions rather than either using strictly conventional practices or achieving organic certification (Puech et al., 2014; Merfield et al., 2015; Kirchmann et al,. 2016; Reganold and Wachter, 2016; Shennan et al., 2017).

5. Data availability statement

The dataset collected and analyzed for this study is available from the authors by request and is also freely downloadable on Figshare, http://doi.org/10.6084/m9.figshare.9894020.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at doi:https://doi.org/10.1016/j.agee.2019.106723.

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