1 Biological control adoption in western U.S. orchard systems: Results from grower surveys

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Abstract: As part of a USDA Specialty Crop Research Initiative project to enhance biological control (BC) in western U.S. orchard systems, we surveyed walnut growers in California and pear growers in Oregon and Washington about their pest management decision-making and use of BC practices. Seventy six percent of pear growers and 54% of walnut growers reported using one or more BC practices. BC users were more likely to minimize factors that harm natural enemies than enhance natural enemy habitats or release commercially produced natural enemies. Walnut growers with more education and orchard experience, as well as larger and more diversified operations, were more likely to use BC practices. Walnut and pear growers with some certified organic acreage, who considered environmental impacts when making pest management decisions, and who used selected pest management practices (pheromone mating disruption and degree-day calculations for codling moth control) were more likely to use BC practices. BC users relied more heavily on industry publications and university-based sources of pest management information, compared with non-users. The perceived benefits of BC adoption included reduced reliance on pesticides, reduced production costs, environmental protection, protection of beneficial insects, and improved worker safety and human health. The perceived barriers to BC adoption included lack of knowledge, questionable effectiveness, high cost, and lack of recommendation by pest management consultants. Our research not only contributes to the literature on the adoption of sustainable agricultural practices, but also can inform future BC research and outreach by offering insight into who uses BC practices and assessment of perceived adoption benefits and barriers.

Keywords: Biological control, pest management, diffusion of innovations, adoption, orchards

1. Introduction

The U.S. Food Quality Protection Act (FQPA) of 1996 called for the reassessment of tolerances (maximum limits for pesticide residues in food) and reregistration of all pesticides on a regular cycle to assess risks to human health and the environment (EPA, 2015a). The FQPA led to significant reductions in the use of organophosphate (OP) pesticides, for example the phase-out of Guthion (azinphos-methyl) in 2001–2013 (EPA, 2015b). Because of FQPA-mandated changes, U.S. growers have increasingly relied on reduced risk (OP-alternative) pesticides and integrated pest management (IPM) approaches (Jones et al., 2009, 2010; Van Steenwyk and Zalom, 2005). For example, the IPM programs used in western U.S. orchard systems now regularly combine the use of reduced risk pesticides with pheromone mating disruption and conservation biological control (BC) (Brunner et al., 2002; Goldberger et al., 2013; Jones et al., 2009). While many studies have investigated the adoption of IPM strategies (see, e.g., Feder and Savastano, 2006; Fernandez-Cornejo, 1994; Grieshop et al., 1988; Kaine and Bewsell, 2008; Peshin et al., 2009; Ridgley and Brush, 1992; Thomas et al., 1990), few have focused specifically on the adoption of BC practices. In this paper, we focus on conservation BC (protection or enhancement of natural enemy habitats) and augmentative BC (release of commercially produced natural enemies to supplement natural populations).

A review of the literature shows that we lack a comprehensive understanding of who uses BC practices as well as growers' perceptions of the benefits and barriers to adoption of BC. It is essential for researchers, extension personnel, and policy makers who believe BC practices offer substantial environmental, economic, and social benefits to understand the factors that influence growers' decisions to adopt such practices (Perkins and Garcia, 1999). This is especially true

given the recent regulatory and technological changes that have pushed growers to consider more IPM and BC options for orchard systems (Jones et al., 2009, 2010; Goldberger et al., 2013).

For this study, we analyze the results from surveys of walnut growers in California and pear growers in Oregon and Washington (hereafter, Pacific Northwest) to better understand the factors that influence growers' decisions to use BC practices in western U.S. orchard systems. We also examine growers' perceptions of the benefits and barriers to using BC. The surveys were conducted as part of an interdisciplinary, multi-institutional USDA Specialty Crop Research Initiative (SCRI) project designed to enhance BC in western U.S. orchard systems. In this paper, we begin by reviewing the social science literature on BC, with particular emphasis on studies of the factors that influence growers' decisions to adopt BC practices. We then discuss our research methods, data analysis procedures, and significant findings.

2. Literature review

The social science research on BC can be grouped into four categories: (1) studies of the influences on growers' decisions to adopt BC practices (Abdollahzadeh et al., 2015; Brodt et al., 2004, 2006; Grogan, 2014; Grogan and Goodhue, 2012; Moser et al., 2008; Niyaki et al., 2010; Ommani and Noorivandi, 2012; Warner 2007; Wawrzynski et al., 2001); (2) sociohistorical and political economic analyses of BC programs (Altieri, 1991; Altieri et al., 1997; Perkins and Garcia, 1999; van Lenteren, 2012; Warner et al., 2011; Warner and Getz, 2008); (3) public engagement and public opinion research on BC (McNeil et al., 2010; Warner, 2012; Warner et al., 2008); and (4) economic analyses of BC adoption (Cullen et al., 2008; Ervin et al., 1983; Griffiths et al., 2008; Jetter, 2005; Jetter et al., 1997; Jetter and Paine, 2004; Kipkoech et al., 2006; Myrick et al., 2014; Voegelé, 1989; Zeddies et al., 2001). Given that we surveyed walnut

and pear growers about their use of BC practices, our research contributes to the scholarly work on the influences of growers' decisions to adopt BC practices. We thus devote the majority of our literature review to category 1. However, we also provide brief summaries of categories 2–4 to cover the entirety of the social science literature on BC. To our knowledge, such a comprehensive review is lacking in the existing literature.

2.1. Influences on growers' decisions to adopt biological control practices

Despite decades of research on growers' adoption of IPM (see, e.g., Benbrook, 1996; Feder and Savastano, 2006; Fernandez-Cornejo, 1994; Grieshop et al., 1988; Kaine and Bewsell, 2008; Peshin et al., 2009; Ridgley and Brush, 1992; Thomas et al., 1990), only a limited number of studies have focused specifically on the factors that influence growers' decisions to adopt BC practices. Perkins and Garcia (1999) suggest that decisions to implement conservation BC, in particular, may be influenced by age, education, income, operation size, assessment of risk, faith in new technology, impacts on personal time, and implications for other parts of the operation; however, they do not present empirical data. The existing empirical research, typically involving surveys and in-depth interviews, tends to focus on grower demographics, operation characteristics, sources of agricultural information, participation in extension activities, knowledge of on-farm beneficial insects, and overall farm management style.

Wawrzynski et al. (2001) surveyed greenhouse operators in nine midwestern U.S. states to obtain information on the use of BC practices. Less than 10% of respondents used BC practices (predators or parasites) as part of their pest management programs. BC use was correlated with higher levels of education: 62% of BC users had a college degree or higher

113 compared to 38% of non-users. BC use was not related to the size of the greenhouse operation,
114 gross sales, or the number of employees.

115 Niyaki et al. (2010) studied the relationship between nine grower characteristics and the
116 use of *Trichogramma* spp. (Hymenoptera: Trichogrammatidae) to control rice stem borer, *Chilo*
117 *suppressalis* (Lepidoptera: Crambidae), among rice growers in northern Iran. Their data showed
118 statistically significant (positive) relationships between *Trichogramma* use and four variables:
119 education level, family size, years of experience in rice cultivation, and frequency of
120 participation in educational and extension activities. Ommani and Noorivandi (2012) found that
121 adopters and non-adopters of parasitic wasps (Hymenoptera: Braconidae) to control corn
122 *Caradrina* (Lepidoptera: Noctuidae) in western Iran differed significantly in terms of education,
123 income, farm size, level of mechanization, extension activities, social participation, and access to
124 information. Also working in Iran, Abdollahzadeh et al. (2015) found that rice growers who were
125 aware of the harmful effects of pesticides were more likely to be supportive of BC practices on
126 their farms.

127 In their study of the use of biologically integrated farming practices among California
128 almond and winegrape growers, Brodt et al. (2004, 2006) emphasize the importance of growers'
129 beliefs, attitudes, and goals in farm management decision-making. They found that
130 “environmental stewards” (growers who value the conservation of natural resources over high
131 yields or profits) and “networking entrepreneurs” (growers who enjoy exchanging information
132 about cutting-edge innovations with their peers and other experts) were more likely than
133 “production maximizers” (growers who strive to produce the highest possible yields and crop
134 quality) to use BC practices (Brodt et al., 2004).

In their discussions of conservation BC in California, Warner and his colleagues (Cullen et al. 2008; Warner 2007) emphasize the importance of “agroecological partnerships” among growers, extension agents, and scientists. Agroecological partnerships facilitate “social learning,” defined as “participation by diverse stakeholders as a group in experiential research and knowledge exchange to enhance common resource protection” (Warner, 2007). Warner argues that social learning is a key factor influencing the adoption of knowledge-intensive, ecologically based pest management strategies, such as conservation BC.

Also working in California, Grogan and Goodhue (2012) studied the factors associated with citrus growers’ use of beneficial insects to help control the major citrus pests. Survey results indicated that growers who relied on beneficial insects operated larger farms, had more farming experience, sold a larger share of their output to packinghouses (as opposed to processors), and reported pest control advisors (PCAs) as their primary information source. In another paper, Grogan (2014) explores how California citrus growers’ pest management decisions are influenced by knowledge (or lack of knowledge) of the presence of beneficial insects in their fields. She argues that growers who are aware of predatory and parasitic insects will mitigate the negative effects of pesticides and release additional predators. In contrast, growers who are unaware of the presence of beneficial insects will overuse chemical controls and drive predator populations to zero (Grogan, 2014).

Moser et al. (2008) studied perceptions of and experiences with BC agents among strawberry growers in Germany, Israel, and Italy. Eighty-five percent of surveyed growers had experimented with the use of BC agents (e.g., *Phytoseiulus persimilis* Athias-Henriot [Acari: Phytoseiidae] to control spider mites, *Tetranychus* spp. [Acari: Tetranychidae]; *Aphidius colemani* Viereck [Hymenoptera: Braconidae] to control aphids [Hemiptera: Aphididae]). Media

coverage about BC agents, the perceived positive attributes of BC agents (e.g., less environmental impact, increased worker safety, and no chemical residues), and years of strawberry farming experience significantly affected growers' confidence in BC agents. More experienced strawberry growers tended to be less confident in BC agents compared with less experienced growers, suggesting possibly that more established growers are skeptical about "somewhat experimental" pest management strategies (Moser et al., 2008).

Based on the above review, it appears that more educated growers who interact readily with others (e.g., other growers, extension agents, scientists, pest management consultants) are more likely to adopt BC practices. BC adopters also tend to value natural resource conservation and information exchange. They are aware of the harmful effects of pesticides and the presence of beneficial insects on their farms. The results are mixed for years of farming experience, while age and gender do not appear to influence growers' decisions to use BC practices. We explore the importance of many of these variables in our study of BC adoption among California walnut growers and Pacific Northwest pear growers.

2.2. Sociohistorical and political economic analyses

Sociohistorical and political economic analyses examine issues of political and economic power within particular social and historical contexts. Perkins and Garcia (1999) employ a political economic framework to examine the allocation of resources to BC research during the 1980s. After examining multiple indicators (e.g., literature output, trained personnel, and new areas or research), they conclude that the BC research effort is "vigorous" and "vibrant" (Perkins and Garcia, 1999). In contrast, Warner et al. (2011) examine the *decline* in BC programs, specifically within the University of California Land Grant System and the California

Department of Food and Agriculture over a 45-year period. In a similar fashion, van Lenteren (2012) discusses the political, economic, and regulatory factors that have limited the use of augmentative BC. He not only decries the attitudes of the pesticide industry, governmental institutions, and regulatory agencies, but also criticizes the BC research community for not effectively promoting and defending their work (van Lenteren, 2012). “Biological control workers,” he writes, “are their own worst natural enemy!” (van Lenteren, 2012). In their systematic socioeconomic analysis of the commercial natural enemy industry in North America, Warner and Getz find that the “general economic status of the industry (rearing, not distributing) is static or in some production lines, declining” (2008).

Miguel Altieri (1991; also see Altieri et al., 1997) describes the social inequities and dependency relationships associated with classical BC programs, which attempt to permanently suppress pests by importing and releasing specialist natural enemies. “Industrialized countries have accrued a ‘biological control debt’ with developing countries,” Altieri et al. (1997) argue, because of the one-way transfer of natural enemies from the Global South to Global North. While “agronomically successful,” classical BC programs “may not be [successful] in social terms” (Altieri, 1991). For example, the majority of classical BC programs have emphasized the pests of commercial crops mostly grown by large-scale farmers, rather than meeting the needs of the rural poor and small farm sector (Altieri, 1991). To counter these trends, Altieri et al. (1997) call for more farmer-centered BC approaches, such as farmer-to-farmer IPM networks and grassroots biopesticide production, as a means of social empowerment.

2.3. Public engagement and public opinion research

Public engagement and opinion research includes work by Keith Warner and colleagues (Warner, 2012; Warner et al., 2008) in the United States and Jeremy McNeil and colleagues (McNeil et al., 2010) in Canada. Warner et al. (2008) argue that BC researchers and practitioners must build strategic alliances with five “publics” (clients, funders, regulators, scientific allies, and contrarian scientists) to cultivate public support for BC initiatives. Warner (2012) outlines specific strategies, such as using “restorative” or “therapeutic” (rather than “militaristic”) analogies and employing “trustworthy messengers,” for engaging the public about the introduction of classical BC agents for nature conservation. McNeil et al. (2010), drawing on results from the first national survey on the public perception of BC, report that 55% of Canadians considered themselves informed about the use of BC agents to control agricultural pests and 70% expressed a preference for food produced using BC agents rather than insecticides. Thus, while there is some public support and knowledge about BC (at least in Canada), there nevertheless seems to be room to work with the public at large, as well as with Warner et al.’s (2008) five specific publics, to more effectively implement BC programs.

2.4. Economic analyses of biological control adoption

Economic analyses have included studies of the role of uncertainty in decisions to adopt a BC program (Jetter, 2005), the economic costs and benefits associated with the adoption of conservation BC (Cullen et al., 2008; Griffiths et al., 2008), and urban residents’ willingness to pay for the introduction of the egg parasitoid *Anaphes nitens* Siscaro (Hymenoptera: Mymaridae) to control the eucalyptus snout beetle, *Gonipterus scutellatus* Gyllenhal (Coleoptera: Curculionidae), in southern California (Jetter and Paine, 2004). Additional studies have assessed the economic costs and benefits of classical BC programs in California (Ervin et al., 1983; Jetter

et al., 1997), India (Myrick et al., 2014), Western Samoa (Voegelé, 1989), and sub-Saharan Africa (Kipkoech et al., 2006; Zeddies et al., 2001). The results of these cost/benefit analyses suggest that significant financial benefits have been gained from investments in classical BC programs. Lastly, members of our USDA-SCRI project team have examined the economic value of BC by estimating the cost savings resulting from using pest management approaches that cause minimal disruption to natural enemies (Gallardo and Brunner, 2013; Gallardo et al., 2016).

3. Research methods

3.1. Grower surveys

We conducted two surveys of western U.S. orchardists for this study. First, we surveyed walnut growers in California in March–June 2010. The survey population (N=2,688) included all growers in California’s top-ten walnut-producing counties (in terms of walnut acres): Butte, Glenn, Kings, San Joaquin, Stanislaus, Sutter, Tehama, Tulare, Yolo, and Yuba. We obtained growers’ contact information from the County Agricultural Commissioner in each county. Fifty percent of the growers were randomly selected to receive an initial letter with paper questionnaire and three follow-up mailings. The remaining growers received an initial letter (without paper questionnaire) and two reminder postcards. Second, we surveyed pear growers in Oregon and Washington in March–May 2011. The survey population included pear orchard owners, managers, and lessees. We compiled a list of growers (N=1,001) using mailing list information provided by the Pear Bureau Northwest. Growers were contacted four times by mail: an initial letter with questionnaire, a reminder postcard, a second letter with questionnaire, and a second reminder postcard. We provided a link to an online version of the survey in all mailings.

The two surveys used nearly identical 16-page survey instruments with questions about grower demographics, operation characteristics, insect monitoring, use of BC practices, reasons for using or not using BC practices, management of key pests, use of insecticides, secondary pest problems, sources of information for making pest management decisions, and frequency of contact with university extension. Survey procedures (e.g., attractive questionnaire layout, carefully timed mailings, and use of multiple survey modes) followed the Tailored Design Method (Dillman et al., 2009).

3.2. Data analysis procedures

For this study, the *use of biological control* was measured by the following survey question: “In [2009/2010] did you rely on one or more biological control practices described in the box above to control for insect pests in your [walnut/pear] orchard(s)?” A box appeared directly above the question with the following information: “Biological control refers to the reliance on living organisms (natural enemies such as predators or parasitoids) to suppress pests. Biological control includes the following practices: minimizing factors (e.g., broad-spectrum pesticides) that harm natural enemies, enhancing natural enemy habitats (e.g., creating refuges, planting flowering plants or ground covers), and releasing commercially produced natural enemies.” The first two practices represent conservation BC, while the third practice represents augmentative BC. Our study did not focus on classical BC, which is rarely used by individual pest control decision makers. Nor did our study focus on the use of biopesticides (see Bailey et al., 2010; Chandler et al., 2011; and Marrone, 2009 for discussions of biopesticide adoption).

The primary objective of the analysis presented below is to explore the relationship between the use of BC and four sets of variables: grower demographics, operation

characteristics, selected pest management practices, and sources of pest management information. All of the variables presented in the tables were measured by direct survey questions. The answer categories for the information source variables ranged from 1=“not important” to 5=“very important”; we treat these responses as interval-level data in our analysis. We recoded the continuous variables (e.g., age, total acres operated) into categorical variables for the purpose of analysis.

We conducted Pearson chi-square tests to determine whether BC users and non-users differ significantly in various characteristics. The Pearson chi-square test is designed to test for independence between two nominal variables (Agresti and Finlay, 2009). The null hypothesis is that the two variables are statistically independent. The test is based on a comparison between the observed and expected frequencies in the cells of a cross-classification table. In cases with significant Pearson chi-square test results ($P \leq 0.05$), we examined pairwise comparisons of row proportions using the Bonferroni correction. For the information source variables, which did not satisfy the assumptions of normality (Shapiro-Wilk test), we used the nonparametric, independent samples Mann-Whitney U test. The null hypothesis is that the distributions of the two populations (in our case, BC users and non-users) are equal. We used SPSS 22.0 software (IBM Corporation, Armonk, NY) for all statistical analyses.

4. Results

4.1. Grower demographics and orchard characteristics

The response rates for the California walnut and Pacific Northwest pear grower surveys were 21% and 36%, respectively. For both surveys, 93% of respondents were male. Mean age was 58 for walnut growers and 57 for pear growers. Slightly over 50% of both survey groups had

a four-year college and 20% had attended graduate school. Walnut growers had spent 22 years, on average, involved in walnut production as orchard owners, managers, or primary decision makers. Pear growers had 25 years of experience on average. Nearly 90% of both survey groups were orchard owners, partners, or lessees, while 9% were hired managers. Walnut growers operated, on average, 385 acres of total farmland with 110 acres of bearing walnuts and 21 acres of non-bearing walnuts. Chandler, Hartley, and Howard were the most popular walnut varieties grown. Pear growers operated, on average, 140 acres of total farmland with 46 acres of pears. Green Anjou and Bartlett were the most popular pear varieties grown.

4.2. Use of biological control practices

Our study focused on the use of temporary pest suppression, specifically changes in pesticide use to minimize harm to natural enemies, the enhancement of natural enemy habitats, and the release of commercially produced natural enemies. Our survey results indicated that 54% of walnut grower respondents and 76% of pear grower respondents used one or more BC practices (Table 1). In both crops, minimizing harm to natural enemies by modifying pesticide use was far more common than enhancing natural enemy habitats and releasing commercially produced natural enemies.

The findings presented in Table 1 may underrepresent walnut and pear growers' use of pesticide modification as a form of conservation BC. In another part of the survey, respondents were asked specific questions about their use of insecticides for codling moth (*Cydia pomonella*) control. Ninety percent of walnut growers and 98% of pear growers reported "sometimes" or "always" selecting insecticides that are least disruptive to the natural enemies of secondary pests. Seventy-seven percent of walnut growers and 90% of pear growers reported "sometimes" or

“always” timing insecticide applications so they are least disruptive to natural enemies. These results suggest that some survey respondents did not recognize or consider these practices to be a form of BC based on their answers to the direct questions about BC.

4.3. Grower demographics and use of biological control practices

Demographic, socioeconomic, and other individual-level characteristics tend to be associated with innovativeness, defined as “the degree to which an individual ... is relatively earlier in adopting new ideas than other members of a system” (Rogers, 2003). However, we found few statistically significant relationships between grower demographics (gender, age, education, and farming experience) and the use of BC practices (Table 2). None of the demographic variables were related to the use of BC practices among Pacific Northwest pear growers. All of the pear grower demographic categories had consistently high (>70%) BC use rates. In the case of California walnut growers, there were statistically significant differences between BC users and non-users in terms of education and years of orchard experience. Walnut growers with a college degree (or higher) were more likely than growers without a college degree to use BC practices. Walnut growers with 20–29 years of orchard experience were more likely to use BC practices compared with growers with less than 10 years of experience.

4.4. Operation characteristics and use of biological control practices

Most technology adoption studies consider not only the role of the demographic and socioeconomic characteristics of potential adopters, but also the importance of operation characteristics, particularly operation size (Rogers, 2003). Thus, we explored the relationship between the use of BC and three measures of operation size: total acres operated, total

walnut/pear acres, and annual gross walnut/pear income. We also analyzed the importance of three additional operation characteristics: operation of some certified organic acreage, the production of agricultural products other than walnuts/pears, and the percentage of household income from farming (Table 3).

In the case of California walnuts, our test results indicate several statistically significant relationships (Table 3). Respondents with the largest operations (≥ 250 total acres, ≥ 250 walnut acres, and $\geq \$500,000$ annual walnut income) were more likely to use BC practices compared with respondents with the smallest operations (< 25 total acres, < 25 walnut acres, and $< \$10,000$ annual walnut income). Mid-sized walnut growers did not differ significantly from the largest nor smallest growers in terms of use of BC practices (Table 3). Moreover, walnut growers who produced agricultural products (such as almonds, prunes, or peaches) in addition to walnuts were more likely to use BC practices compared with growers who produced only walnuts. In contrast, for Pacific Northwest pear growers, we found no statistically significant relationships between BC use and operation size or production of other agricultural products. The different findings for pear and walnut orchards may be related to the much higher percentage of BC use among pear growers, which could signify that the adoption process is much further along resulting in fewer significant differences between BC users and non-users.

California walnut growers and Pacific Northwest pear growers with some certified organic acreage were more likely to use BC practices compared with respondents with no certified organic acreage (Table 3). Eighty-three percent of walnut growers with some certified organic acreage used one or more BC practices, compared with 53% of growers without organic acreage. Ninety-one percent of pear growers with some certified organic acreage used one or more BC practices, compared with 75% of growers without organic acreage. The higher

percentages for pear growers provide further evidence that the BC adoption process is further along in pears compared with walnuts.

4.5. Selected pest management practices and use of biological control practices

Growers have different management styles (e.g., environmental steward, networking entrepreneur, and production maximizer) based on their beliefs, attitudes, and goals; these differences affect the adoption of BC practices (Brodt et al., 2004, 2006). We, therefore, explored the relationship between the use of BC and the perceived importance of the “environmental impacts of pest management” when making pest management decisions. The importance placed on environmental impacts is an indication of environmental orientation, which can be considered part of a grower’s overall farm management style. Our analysis showed a statistically significant relationship between the use of BC practices and the importance placed on environmental impacts by both groups surveyed when making pest management decisions (Table 4). Growers who believed environmental impacts were “very important” were more likely to use BC practices compared with growers who believed environmental impacts were “not important.” These results are not surprising because BC practices aim to manage pests with minimal disruption to natural ecological processes. However, the differences between walnut and pear growers are striking. For example, while a majority (54%) of pear growers who believed environmental impacts were “not important” still used BC practices, only 14% of walnut growers with a similar environmental orientation were BC users (Table 4).

A grower’s use of particular pest management practices can also provide insight into his/her overall farm (or pest) management style. We examined the relationship between the use of BC and the use of three other pest management practices: OP insecticides (Lorsban

[chlorpyrifos] and Guthion [azinphos-methyl] for codling moth control in walnuts and pears, respectively); pheromone mating disruption for codling moth control; and degree-day calculations to predict codling moth generations, monitor infestation levels, and/or properly time sprays for different generations. We found statistically significant relationships for all three practices for both California walnut growers and Pacific Northwest pear growers (Table 4). Growers who did not use OP insecticides for codling moth control were more likely to use BC practices compared with OP-insecticide users. Growers who used pheromone mating disruption and degree-day calculations were also more likely to use BC practices compared with growers who did not use these IPM practices.

4.6. Sources of pest management information and use of biological control practices

While classic agricultural technology adoption studies tended to focus on individual-level and operation characteristics, more recent adoption studies have emphasized the importance of social networks in explaining individuals' innovativeness (Rogers, 2003). This social network emphasis is readily apparent in studies of the adoption of 'alternative' and 'sustainable' agricultural innovations (Coughenour, 2003; Hassanein, 1999; Jussaume and Glenna, 2009; Moore, 2008). Writing specifically about BC adoption, several scholars have remarked that the information needed to implement certain BC practices is extensive and thus requires a shift from 'traditional' forms of agricultural information transfer (where information flows from researcher to extension personnel to stakeholders) to new forms involving social learning within supportive grower networks (Cullen et al., 2008; Warner, 2007; also see Jones et al., 2009 about the shift from traditional extension outreach to decision support systems within tree fruit IPM programs). We, therefore, explored the relative importance of selected industry-based, university-based, and

informal sources of pest management information reported by users and non-users of BC practices.

PCAs and fieldmen affiliated with chemical supply companies were by far the most important source of pest management information for both users and non-users of BC practices (Table 5). Pear growers ($\bar{x} = 4.26$, $sd = 1.19$) reported a significantly higher level of importance for chemical supply company affiliates compared with walnut growers ($\bar{x} = 3.65$, $sd = 1.49$); Mann-Whitney $U = 56929.5$, $P \leq 0.001$. For both crops, however, the reported importance of chemical supply company affiliates did not differ significantly between BC users and non-users. Walnut growers who used BC practices reported significantly higher levels of importance for industry-sponsored events, trade publications, and marketing organizations compared with walnut growers who did not use BC practices. Pear growers who used BC practices reported a significantly higher level of importance for trade publications, but not industry-sponsored events nor marketing organizations, compared with pear growers who did not use BC practices (Table 5).

Walnut and pear growers who used BC practices relied more heavily on university-based sources of pest management information compared with non-users of BC practices. We found statistically significant differences between BC users and non-users for nearly all of the university-based sources of information (Table 5). These results are not surprising given the important roles the western land-grant institutions (University of California, Oregon State University, and Washington State University) have played in BC research and outreach. It is worth noting, however, that walnut growers ($\bar{x} = 3.09$, $sd = 1.39$) reported a significantly higher level of importance for university extension advisors compared with pear growers ($\bar{x} = 2.83$, $sd = 1.45$); Mann-Whitney $U = 59724$, $P \leq .05$. We had similar Mann-Whitney U test results for

university extension publications and university-sponsored conferences, workshops, and seminars.

Lastly, we explored the importance of three informal sources of pest management information: other growers, immediate neighbors, and family members. Based on previous research (e.g., Hassanein, 1999; Warner, 2007) that showed extensive networking and knowledge sharing among growers involved in ‘alternative’ and ‘sustainable’ agricultural systems, we expected BC users to rely more on informal sources of information compared with non-users. However, for both walnuts and pears, we found no significant differences between BC users and non-users in reported levels of importance (Table 5).

4.7. Growers’ perceptions of the benefits and barriers to biological control adoption

Our research focused on not only who was using (and not using) BC practices, but also growers’ perceptions of the benefits and barriers to the adoption of BC. In an open-ended survey question, California walnut growers and Pacific Northwest pear growers who used one or more BC practices to control for insect pests in their orchards were asked to describe the primary benefits of using such practices. The benefits mentioned most often by survey respondents were reduced reliance on pesticides, reduced production costs, environmental protection, increase in and protection of beneficial insects, and improved worker safety and human health. Less frequently mentioned benefits included reduced pest pressure, effectiveness (better control), reduced pesticide resistance, and improved plant health and product quality. The frequency distributions of responses were nearly identical for the two grower groups, suggesting that the perceived benefits of BC are not crop-specific.

To better understand the barriers to the adoption of BC practices, we asked survey respondents who did *not* rely on one or more BC practices to explain their primary reasons for not using such practices. The primary reasons for non-adoption among walnut growers were lack of knowledge, minimal pest pressure (no perceived need), high cost, not recommended by PCAs, perceived ineffectiveness (unreliable, unproven), and small operation size. In addition, several walnut growers recounted negative previous experiences with BC practices: “we brought in biological predators but they failed,” “biological control practices were tried with little or no results,” “we tried in the past and [BC] caused a major flare-up in pests,” and “I tried about 15 years ago and it didn’t work!” Among pear growers, the primary reasons for non-adoption were perceived ineffectiveness, lack of knowledge, not recommended by chemical supply company and packinghouse fieldmen, preference for other pest management approaches (e.g., chemical control), and high cost.

5. Discussion and future directions

Our study contributes to the social science literature on BC, especially scholarly work focused on the influences on growers’ decisions to adopt BC practices. Drawing on data from surveys of California walnut growers and Pacific Northwest pear growers, we measured the use of BC practices, explored the factors that influence growers’ decisions to use BC practices, and examined growers’ perceptions of the benefits and barriers to using BC. In this section we discuss our most significant findings and suggest ideas for future research and outreach.

5.1. Selective adoption of biological control practices

We found that a majority of California walnut growers (54%) and Pacific Northwest pear growers (76%) used one or more BC practices. The higher use rate of BC among the latter group suggests that the BC adoption process is further along in pear orchards compared with walnut orchards. The reasons for this may be due to the use of mating disruption among pear and walnut growers, the geographic distribution of pear and walnut production, and the timing of our surveys. First, mating disruption has been used to a greater extent in pear orchards compared with walnut orchards (Brunner et al., 2002; Grant et al., 2003; Welter et al., 2005). Mating disruption users may be much more familiar with the potential benefits of BC adoption. Second, the geographic distribution of California walnuts is more extensive than that of Pacific Northwest pears, resulting in a greater range of localized pest management decisions. Lastly, we surveyed California walnut growers one year before Pacific Northwest pear growers; thus, pear growers had an additional year of potential exposure to educational outreach related to BC. Time is a key element in explaining the diffusion of innovations (Rogers, 2003).

For both walnut and pear growers, minimizing harm to natural enemies by modifying pesticide use was far more common than enhancing natural enemy habitats or releasing commercially produced natural enemies. These findings confirm past research on growers' selective adoption of different pest management practices (see, e.g., Benbrook, 1996; Lewis et al., 1997; Orr, 2009; Ridgley and Brush, 1992). The modification of pesticide use is typically the most frequently used practice in the BC 'tool box' because it does not fundamentally challenge the prevailing "therapeutic approach of killing pest organisms with toxic chemicals" (Lewis et al., 1997). In contrast, enhancing the density of resident natural enemy populations by modifying cropping patterns or manipulating non-crop vegetation requires an in-depth understanding of how natural enemies function as part of total agricultural ecosystems (Lewis et al., 1997). The

implied need for a ‘paradigm shift’ from therapeutic to more ecologically informed approaches explains, in part, why habitat manipulation techniques are not widely implemented by growers (Lewis et al., 1997; Orr, 2009). As Cullen et al. (2008) explain, “farmers cannot simply replace pesticides with cover crops, companion plantings, and natural enemy nutrient supplements without some understanding of ecological relationships and principles.”

Given growers’ preference for pesticide modification and the increasing availability of reduced risk pesticides with different impacts on natural enemies, we believe growers might be especially interested in the entomological findings from our USDA-SCRI project designed to enhance BC in western U.S. orchard systems. Especially notable are the results from laboratory and field research focused on the effects of reduced risk pesticides on natural enemies and strategies for selecting and timing pesticide sprays to protect natural enemies (Amarasekare et al., 2016; Beers et al., 2016; Jones et al., 2016; Mills et al., 2016; Shearer et al., 2016).

5.2. Significant influences on growers’ use of biological control practices

We explored the relationship between the use of BC practices and grower demographics, operation characteristics, the use of selected pest management practices, and sources of pest management information. In the case of California walnuts, we found significant associations between BC use and both education and years of orchard experience. We also found that the largest, most profitable, and diversified walnut growers used BC practices to a much greater extent than the smallest, least profitable, and non-diversified growers. These results, but not our Pacific Northwest pear grower survey results, confirm past research on BC adoption (Moser et al., 2008; Niyaki et al., 2010; Ommani and Noorivandi, 2012; Wawrynski et al., 2001). Our walnut grower survey findings related to operation size lend credibility to the argument that

larger farms can play an important role in increasing the sustainability of orchard pest management, despite a common association of sustainable agriculture with small farms (Goldberger et al., 2011).

It was not surprising to find a statistically significant relationship between the use of BC practices in both groups surveyed and the operation of some certified organic acreage. In their review of arthropod pest management in organic crops, Zehnder et al. (2007) state, “the underlying principles of arthropod pest management in organic systems involve the adoption of ecologically sound practices specified by international and national organic production standards.” Moreover, according to the U.S. Department of Agriculture’s National Organic Program standards, certified organic growers should prioritize cultural, physical, mechanical, and biological control practices over biopesticides and synthetic substances allowed for use in organic crop production (USDA-AMS, 2013). A 2008 survey conducted by the U.S. Department of Agriculture’s National Agricultural Statistics Service revealed that 32% of U.S. organic farmers and ranchers “maintained beneficial insect/vertebrate habitat,” 31% used “biological pest management,” and 16% “released beneficial organisms” (USDA-NASS, 2010). Farmers and ranchers with both conventional and certified organic acres may ‘borrow’ some of the more successful and cost-effective practices from their organic operations for use in their conventionally managed operations.

Our survey results also indicated that growers who considered environmental impacts when making pest management decisions and who relied on pheromone mating disruption and degree-day calculations for codling moth control were more likely to use BC practices. Thus, it appears that growers who use BC practices do so as a part of a comprehensive, ecologically oriented IPM program. This is likely a result of university-based IPM guidelines. For example,

guidelines for California walnut production (UC Statewide IPM Program, 2013) and northwestern U.S. pear production (Beers et al., 1993; Dunley et al., 2001) recommend the use of alternative (i.e., non-OP) insecticides, pheromone mating disruption, degree-day models, and BC practices, among other cultural, behavioral, and physical controls. In other words, while BC practices can be considered standalone ‘technologies’ or ‘innovations’, they are often part of a larger, ecologically oriented, integrated approach to pest management.

Driven by recent scholarship on how social networks help explain the innovativeness and adoption behavior of farmers (e.g., Jussaume and Glenna, 2009; Moore, 2008; Warner, 2007), we also evaluated the relative importance of different sources of pest management information reported by users and non-users of BC practices. Walnut and pear growers who used BC practices relied more heavily on university-based sources of pest management information compared with non-users of BC practices, suggesting the significant role played by the western land-grant institutions in BC research and outreach. We found no statistically significant differences in the reported importance of informal sources of pest management information, contradicting past research (e.g., Hassanein, 1999; Warner, 2007) that has demonstrated extensive networking and knowledge sharing among “alternative” and “sustainable” agriculturalists.

5.3. Ideas for future research and outreach

Our findings related to perceived adoption barriers, in particular, suggest opportunities for future research and educational outreach. Given that lack of knowledge and perceived ineffectiveness were often cited by walnut and pear growers as reasons for not using BC practices, extension personnel and other agricultural service providers could develop new

educational outreach programs that highlight practices proven to offer significant advantages relative to other pest management approaches (e.g., chemical control). Because some walnut and pear growers perceive “cost” as a significant adoption barrier, future educational outreach programs could also include the results of research on the economic costs of BC versus chemical control for controlling insect pests in orchard systems. For example, economic analyses of apple, pear, and walnut pest management costs have shown significant benefits associated with the integration of BC practices into orchard pest management programs (Gallardo and Brunner, 2013; Gallardo et al., 2016). Moreover, our survey results indicated that “reduced cost” was the second most often cited perceived benefit of using BC practices. “Reduced pesticide use” was the most often cited perceived benefit, which arguably is associated with cost savings as well.

Given that “not recommended by PCA” and “not recommended by fieldman” were also mentioned as primary reasons for not using BC practices, future social science research could explore further the relationship between orchardists and their primary source of pest management information: chemical supply company affiliates. In our surveys, we found that 90% of walnut and pear growers regularly use the services of one or more pest management consultants (including chemical supply company affiliates) and over 90% of these growers adhere closely to the consultants’ recommendations. Yet, BC advice must vary among consultants because we do not find across-the-board adoption (or non-adoption) among growers. Why do some consultants recommend BC practices, while others do not? What are consultants’ primary sources of pest management information? Do PCAs and fieldmen affiliated with chemical supply companies face a conflict of interest because they are in the business of recommending and selling pest control products? These are important questions for future research.

Survey research by Brodt et al. (2005) on California almond growers' reliance on PCAs for pest management decision-making offers some insight into the complexities of grower-PCA relationships. For example, they found that PCAs affiliated with agricultural product suppliers were not more likely than independent PCAs to recommend the use of common chemical controls for insect and mite pests. However, growers who used independent PCAs reported feeling more knowledgeable about IPM compared with growers who used supplier-affiliated PCAs. Brodt et al. (2005) caution that their study "does not show whether this association occurs due to PCA influence on growers or because growers who hire independent PCAs are already predisposed toward IPM." Future research would be well served by utilizing Brodt et al.'s (2005) survey instrument to explore the relationship between growers and pest management consultants (including PCAs) in other orchard systems (e.g., walnuts, pears). Moreover, future research could explore consultants' perspectives (see, e.g., Goldberger et al., 2013; Maizlish et al., 1995) to better understand grower-consultant relationships with respect to BC promotion and adoption.

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