Renewable Agriculture and Food Systems

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Research Paper

Cite this article: Haring S.C., Aoyama L., Lane-Massee M., Ponisio L.C., and Hallett L.M. 2025. Agricultural sustainability requires multidimensional solutions that address environmental and financial benefits in the Oregon hazelnut industry. *Renewable Agriculture and Food Systems*, **40**:e10, 1–12
https://doi.org/10.1017/S174217052500002X

Received: 10 June 2024
Revised: 21 August 2024
Accepted: 13 January 2025

Keywords:
Agroecology; diversified farming; environmental attitudes; farmer perspectives; sustainable agriculture

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Agricultural sustainability requires multidimensional solutions that address environmental and financial benefits in the Oregon hazelnut industry

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Abstract

Improvements to agricultural sustainability are required to maintain productivity in the face of ongoing global challenges, and growers need multiple kinds of support to adopt new sustainability practices and transform cropping systems. Farms are socio-ecological systems, and developing such systems requires tandem changes to human and nonhuman systems. This study evaluates agricultural sustainability practices and perception in the Oregon hazelnut industry, a small, intensified, and rapidly growing orchard production system in the United States. Using a mixed methods approach based on participant observation and an online survey of hazelnut growers in the spring of 2023, we found that growers were widely receptive to the sustainability messaging of industry groups and had widespread adoption of certain sustainability practices including disease-resistant tree varieties and changes in pesticide use, among other practices promoted by researchers. Larger hazelnut growers were more likely to adopt the sustainability practices in our survey, especially certain pest management practices. Growers with older hazelnut orchards turned to more sources of information but also perceived more barriers to implementing new sustainability practices than growers with younger orchards. Growers voiced different opinions about sustainability costs, with some growers expressing economic concerns about sustainability practices and others recognizing the financial benefits of sustainability practices. Differences in the perceived importance of short- and long-term benefits framed some of these concerns about the costs and benefits of sustainability practices. We argue that successful sustainability outreach will address both the short-term economic benefits of certain practices and the long-term sustainability benefits. Growers widely recognize the importance of sustainability, but more messaging about the multiple benefits of sustainability practices can better address both environmental and economic concerns.

Introduction

Agricultural development is central to ongoing sustainability challenges such as climate change, land use changes, and biodiversity loss (Haring et al., 2023). The rapid growth of certain cropping systems and agricultural sectors can shape how working lands are managed and have landscape-wide effects on ecological processes. For example, transitions from annual cropping systems to perennial cropping systems will have dramatic consequences for soil health (e.g., less tillage), hydrology (e.g., less need for irrigation), wildlife habitat (e.g., year-round ground cover), and many other ecological factors (Schulte et al., 2006).

Socio-ecological systems

Given that agroecosystems are socio-ecological systems (Blesh and Wolf, 2014; Lomba et al., 2020), farm management and farmers' attitudes toward sustainability dictate many of the ecological changes associated with a large-scale cropping system transition (Prokopy et al., 2008). Understanding these perspectives and attitudes can improve the success of sustainability efforts to help farmers adapt to changing climates and developing industries (Godfray and Garnett, 2014; Piñeiro et al., 2020). Researchers and extensionists have an imperative to attend to multiple aspects of ecological, biological, and sociopolitical sustainability in order to address farmers' complex needs within multifaceted agroecosystems (DeLonge et al., 2016; Gould et al., 2018).

Acting within the context of socioecological systems, farmers can be attentive to both the risks and benefits of a new practice, and effective sustainability outreach should address both in ways that incentivize more sustainable management decisions (Arbuckle and Roesch-McNally, 2015). However, significant headwinds for individual growers, such as economic challenges, agronomic challenges, and resistance to change, affect the adoption of many agricultural sustainability practices at multiple levels within agroecosystems (Rodriguez et al., 2009). For example, row crop farmers cite several ecological benefits of a sustainability practice like cover crops, but these benefits are frequently clouded by multiple concerns about time/labor, knowledge about species selection, and cost (Myers and Watts, 2015; O'Connell et al., 2015).

Helping farmers adopt new sustainability practices is a major focus of agricultural extension organizations, and extension organizations continue to focus on outreach based on technology transfer and diffusion of innovation. Recent sustainability trends necessitate updates to these extension modalities so that they rely less on top-down approaches to farmer outreach and place more emphasis on the several socioecological systems factors inherent in sustainable agricultural practices (Röling and van de Fliert, 1994; Neill and Lee, 2001). Continued efficacy of grower outreach programs depends on revising extension approaches to better address the values and concerns of growers adopting new sustainability practices, such as circular models of extension that allow for embeddedness and feedback between researchers and practitioners to more fully address the socioecological complexity of agroecosystems (Warner, 2008)

The development of sustainability practices across a region is not just the emergent practices of neighboring farmers but rather the outcome of complex social networks (Jarosz, 2000; Parks, 2022). Farmer perceptions of sustainability are built on multifaceted value systems affected by information sources, previous experiences with certain management practices, adherence to broader farm management frameworks, and many other socioecological factors (Wayman et al., 2017; Dentzman and Jussaume, 2017). Cooperation among growers to form new information networks is a hallmark of effective agricultural sustainability (Lubell et al., 2011).

One outcome of such complex socioecological systems is unintended consequences that "lock-in" certain patterns of practice, potentially failing to include certain valuable sustainability strategies or creating other resilient, undesirable outcomes (Dornelles et al., 2020). For example, modern agricultural systems have often locked in intensified, high-input, highly specialized practices for sustainability, to the exclusion of many practices that use agricultural land to promote noncrop biodiversity. While most growers generally value sustainability, it can be difficult to materially change production practices because of the specific, idiosyncratic factors affecting how farmers view a new management practice as sustainable.

Research context and questions

The Oregon hazelnut industry provides a valuable study system for analyzing how swift changes in farming practices create implications for sustainability. Importantly, this study system represents a relatively small, tight-knit group of growers who are collectively experiencing demographic shifts within their industry connected to rapid growth, inflow of new farmers, and increasing connection to global markets.

Ultimately, new sustainability practices must address both farmers' operational concerns and real ecological challenges, and our objective is to identify what factors can motivate such "win-win" scenarios that lead to industry-wide agricultural sustainability improvements. In the Western United States, highly visible, regionally specific technical information has been shown to support the adoption of novel sustainability practices (Durant et al., 2021; Lavoie et al., 2021; Petrzelka et al., 2024), and Oregon hazelnuts provide another unique opportunity to demonstrate how growers connect with new sustainability messaging.

As farmers and land managers face more acute challenges caused by climate change and other factors, there is a growing need to understand the decision-making behind sustainability practices in large-scale, rapidly changing cropping systems. What sustainability practices are typically practiced on farms with different farm characteristics? What information sources are associated with these different farms? What do farmers in a rapidly changing industry care about regarding agricultural sustainability?

In this study, we attempt to answer these questions using a mixed methods survey that relies on quantitative modeling and close analysis of free-response questions. This study contributes to a body of literature analyzing growers' perspectives and behaviors on environmental stewardship by highlighting critical opportunities for multidimensional agricultural outreach that can address multiple agronomic, economic, and ecological issues within transforming industries.

Methods

Study system

In the Willamette Valley, Oregon, USA, the rapid development of the hazelnut industry has created an important case study for agroecosystem transitions. This area is home to over two-thirds of Oregon's population as well as a diverse and productive agricultural region home to various crops including grass seed, small grains, winegrapes, berries, hops, stone fruit, and hazelnuts.

Hazelnuts have become an increasingly important commodity within this system. Over 99% of the United States' hazelnut production is concentrated in the Willamette Valley, and hazelnuts represent the fourth most widely grown crop in Oregon behind hay and wheat (much of which are grown in areas of Oregon outside of the Willamette Valley), as well as grass seed (National Agricultural Statistics Service, 2019). While hazelnuts have been grown commercially for over a century, the hazelnut production area was more than doubled in the 2010s to nearly 30,000 ha. This growth has been spurred by several technological advancements in hazelnut production (Silvestri et al., 2021) alongside broader growth in multiple tree nut industries across the Western US to meet growing consumer demand and leverage economic and agronomic advantages of orchard crops (Asci and Devadoss, 2021). Doubling of hazelnut acreage in the previous decade has created an opportunity for long-term changes in sustainability practices, as many farmers care for an influx of young trees and consider the multidecade effects of their management practices.

The Oregon State University Extension Service and professional organizations like the Nut Growers Society of OR, WA, & BC have worked for decades to support the growth of the hazelnut industry (Mehlenbacher and Olsen, 1997). These groups have focused on the sustainable growth of the industry, such as through sustainability improvements like the development and promotion of integrated pest management practices (including Eastern Filbert Blight-resistant hazelnut varieties, which reduce the need for fungicide applications, and improved sanitation and management of filbertworms), denser tree spacing systems for increased yield, drip irrigation, and a broad focus on soil health. Targeted development of such sustainability practices, coupled with coordinated growth in the hazelnut industry, has created a production system that is relatively centralized compared to similar specialty crop production systems.

Survey design

To evaluate hazelnut growers' perceptions of sustainability practices, we conducted an online survey of Nut Growers Society of OR, WA, & BC (Oregon, Washington, and British Columbia) members. The Nut Growers Society is a professional society representing the interests of hazelnut growers in Oregon and the Pacific Northwest; it is the largest voluntary organization of Oregon hazelnut growers. The Nut Growers Society is part of an industry-funded research and promotion organization that supports the hazelnut industry and gives feedback to affiliated organizations, including the Hazelnut Marketing Board and the Oregon Hazelnut Commission (Industry, n.d.). In particular, the Oregon Hazelnut Commission is funded by an assessment of hazelnuts sold within Oregon and uses this funding to support hazelnut research. In turn, the Nut Growers Society arranges several educational events each year to support its grower members, including significant programming related to sustainability research funded by the Oregon Hazelnut Commission and performed at Oregon State University.

We developed this survey based on over 2 years engaged in participant observation of the hazelnut industry, beginning with cooperative field research with hazelnut growers (Penkauskas et al., 2022). Subsequently, the authors spent hundreds of hours working directly with commercial hazelnut growers and attending hazelnut industry events. Additionally, we developed an additional research relationship with a multigenerational hazelnut farm that generated informal interviews and detailed field experience. Experiences at multiple grower events, especially in the summer of 2022 and winter of 2023, allowed us to observe sustainability messaging and development within the industry. We analyzed materials at these events to identify critical themes and sustainability practices that were repeatedly brought up at these events. We used participant observation as the basis for survey design, and we limited questions in our survey only to sustainability practices and sustainability narratives that we observed being formally discussed at several industry events.

Survey administration

We recruited survey participants by sending 431 postcards to Nut Growers Society Members in March 2023. We used addresses as maintained by the Nut Growers Society, and we excluded any addresses that were outside of Oregon or had institutional affiliations that identified the recipient as someone not affiliated with a farm (e.g., government officials, agricultural researchers, rural financial institutions). Additionally, we recruited participants from four in-person informational events in March and April 2023, two of which were sponsored by the Nut Growers Society and two of which were sponsored by a hazelnut processor. We sent postcards and distributed business cards, respectively, that had QR codes and a shortened web address to link to our survey site. We discontinued survey recruitment in April 2023 to accommodate concerns about duplication of efforts between this survey and the hazelnut industry's Oregon Hazelnut Stewardship Program.

The survey was conducted in April and May 2023. We used the online survey software Qualtrics to ask matrix multiple-choice questions and open-ended questions. We asked matrix questions to identify the sustainability practices used on participants' hazelnut farms, the barriers they associated with each practice, and the perceived expertise and information that is influential for adopting new sustainability practices. We also asked open-ended questions about the factors motivating the adoption of sustainability practices and perceived changes to hazelnut sustainability in the past and future. Finally, we asked questions about the operational characteristics of participants' farms. Questions and their possible responses are listed in Table 1. Survey participants were offered a $20 gift card as an incentive to promote completion of the survey (Ryu et al., 2006). Participants were required to provide an email address in order to receive the incentive, but no other personally identifiable information was collected.

Table 1. List of questions asked of hazelnut growers in an online survey administered through Qualtrics in the Spring of 2023

Question number	Question text	Response type
Page 1: Sustainability practices		
1	Which of these orchard sustainability practices do you currently use?	Matrix table (values displayed in Fig. 2)
2	What barriers do you associate with each of these sustainability practices? (mark all that apply)	Matrix table (values displayed in Fig. 4)
3	What factors motivate how you implement sustainability practices on your farm?	Open-ended text box
Page 2: Sustainability challenges		
4	How much do you value the following information or incentives when learning about new management practices?	Matrix table (values displayed in Fig. 3A)
5	How frequently do you rely on expertise from the following groups when considering new management practices?	Matrix table (values displayed in Fig. 3B)
6	How do you think changes to hazelnut production in the last several decades have impacted sustainability of the industry?	Open-ended text box
7	How do you think hazelnut production will have to change in the next 50 years in order to maintain sustainability?	Open-ended text box
Page 3: Demographics		
8	About how many acres of hazelnuts do you farm?	Multiple choice (values displayed in Fig. 1B)
9	About what percentage (%) of your orchards fall into each of the following age classes?	Form field (values displayed in Fig. 1A)
10	What other crops do you farm? (mark all that apply)	Multiple choice
11	In what counties do you farm hazelnuts? (mark all that apply)	Multiple choice (values displayed in Fig. 1D)
12	Briefly describe your role in the farm operation and any other information about your farm that you think is important	Open-ended text box
13	If you want to receive a $20 Amazon gift card for your participation, please enter your email address here. We will not use, distribute, or save your email address for any other purpose	Short text box

https://doi.org/10.1017/S174217052500002X Published online by Cambridge University Press

We received 64 responses, with a response rate of 14.8%. Our respondents represented over 10% of our targeted Nut Growers Society membership and about 3.7% of the 1331 hazelnut-producing operations recognized by the Census of Agriculture (National Agricultural Statistics Service, 2019). We removed responses that were mostly incomplete, though we did include two responses that were partially incomplete but seemed otherwise accurate. We also removed a demographic question response that reported apparently inaccurate information, namely having orchard age categories that added up to significantly more than 100%, but we maintained the rest of this participant's responses. We also checked responses for completion time and automated data quality checking for fraud and computer-generated responses in Qualtrics, and we did not remove any responses based on these tests. Based on these quality criteria, there were slight variations in response counts to the summary data presented below (Figs. 1–4), but our statistical analyses used 49 complete, high-quality responses.

Data analysis

Analyses were conducted in R 3.4.3 (R Core Team, 2023). We used the *qualtRics* package to download data from Qualtrics (Ginn et al., 2022), and we manipulated and visualized data with the *tidyverse* packages (Wickham et al., 2019). To assess how farm characteristics affect sustainability practice use, we modeled the number of sustainable practices a grower employed as predicted by farm characteristic variables. In order to be included as a sustainability practice, growers could have responded that they used each practice "in some orchards" or "everywhere". The farm characteristics we analyzed were approximate farm size, average age class of orchards on each farm, number of other crops grown on the farm, and growing regions (north, mid, or south Willamette Valley). Farm size and orchard age were modeled as continuous variables because survey questions were designed to assess these variables based on equal intervals of practical importance (e.g., the difference between a 50- and 51-year-old orchard is less important than between 3- and 4-year-old orchards, and the question design accounts for such differences). We fit a generalized linear model (GLM) with a quasi-Poisson distribution using the *glm* function from the *stats* package (R Core Team, 2023). We visually checked model assumptions using the *plot* function from base R as well as the *check_model* function from the *performance* package (Lüdecke et al., 2021).

Next, we focused on farm size, which we determined to be a key farm characteristic in the above analyses, to evaluate if any specific sustainability practices were implemented differently across different kinds of farms. We created separate logistic regressions for each sustainability practice to determine if the use of each practice differed across farm sizes. These tests were implemented by using each sustainability practice as a binary response variable and farm

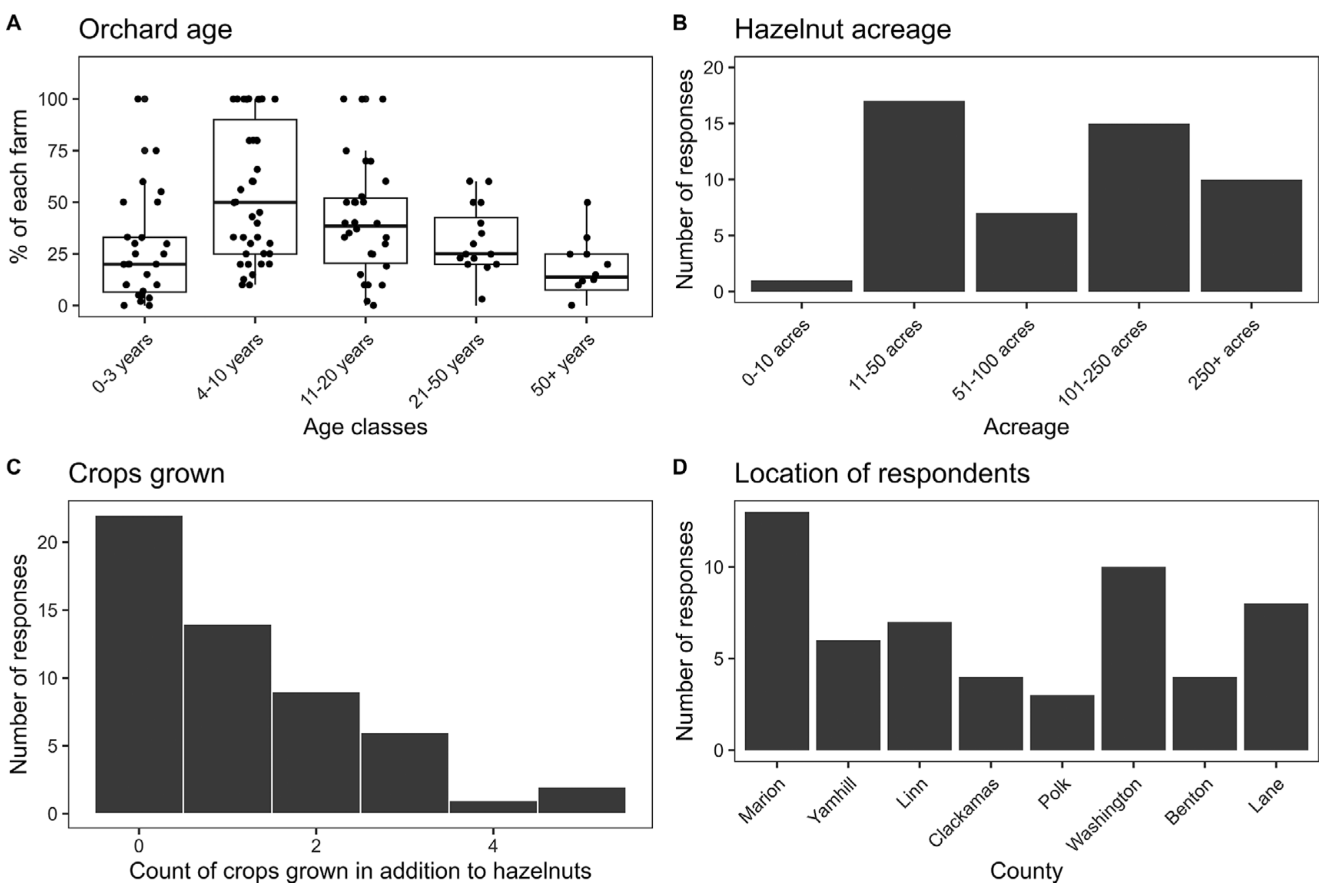

Figure 1. Charts showing the farm characteristics of respondents to a survey of hazelnut growers. (A) Age of hazelnut orchards. Each point represents the percentage of orchards on each farm that fall into that particular age class. Each grower's responses should add up to 100% across the categories, though some variation due to self-reporting and rounding may exist. (B) Approximate number of hazelnut acres under management. Bar height represents the number of responses in each category. (C) Number of crops other than hazelnuts grown on each farm. Bar height represents the number of responses in each category. (D) The county location of each respondent. Bar height represents the number of responses in each category. Counties are listed in descending order of hazelnut production (Marion County produces more hazelnuts than any other counties in Oregon, etc.).

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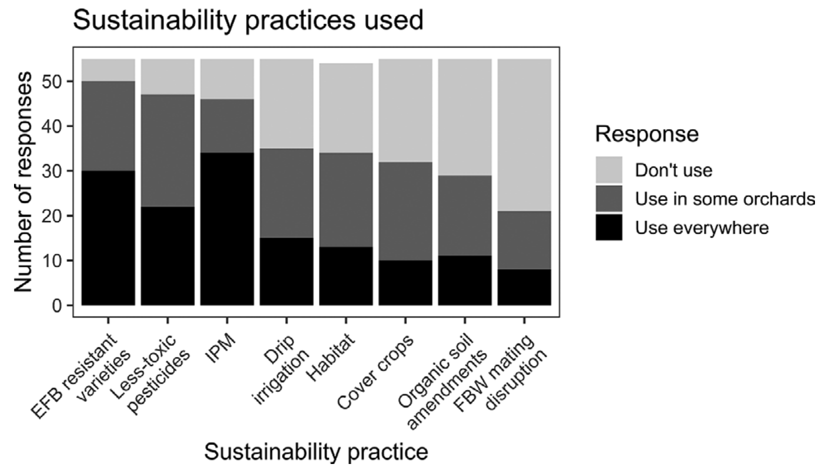

Figure 2. Bar chart showing use of certain sustainability practices by hazelnut growers. Bar height represents the number of respondents who use each practice, and darker colors indicate higher levels of implementation of each practice.

size as a continuous predictor within the *glm* function from *stats*, with significance set at $P = 0.05$ and a Bonferroni correction for multiple comparisons.

To assess how farm characteristics affect factors related to sustainability outreach, we used hierarchical clustering as a data reduction technique to group similar responses together. We created one cluster analysis for perceived barriers to sustainability practices (Question 2) and one cluster analysis including both valued information (Question 4) and valued expertise (Question 5). For each cluster analysis, we calculated pairwise distances comparing the similarities of each response to all other responses using Gower's formula with the *daisy* function in the *cluster* package (Maechler et al., 2022), which standardized Likert-type responses to these questions onto a common scale. Then, we clustered those pairwise distances using *hclust* from *stats* based on the *ward.D2* method. Lastly, we visually inspected results with *pheatmap* (Kolde, 2019) to choose the appropriate number of clusters. We created a GLM with a binomial distribution that used either information/expertise or barriers clusters as the binary response variable (both cluster analyses produced two clusters of responses) and farm characteristics, as described in the previous paragraph, as predictors.

Qualitative data from open-ended questions were analyzed by coding in two stages by one member of the research team. First, we closely read responses to identify emerging themes based on the descriptive and affective narratives contained within each response. Then, we read responses to assign them to coded themes and select representative quotes. All authors reviewed selected quotes to demonstrate the breadth of viewpoints we received in our survey.

Results

Summary results

The raw results from the survey indicate that our respondents had young orchards planted within the last decade and a decreasing number of older orchards (Fig. 1A). This result is in line with industry estimates that over 36% of hazelnut acres have young trees that are nonbearing (National Agricultural Statistics Service, 2019); hazelnut orchards reach bearing maturity between about 4 and 10 years of age. Survey participants were largely comprised of growers from small farms (11–50 acres of hazelnuts) and moderately large farms (101–250 acres) (Fig. 1B). Many growers grew only hazelnuts, while many had operations comprising of hazelnuts and one, two, or three other crops (Fig. 1C). Respondents came from every county in the Willamette Valley (Fig. 1D).

Our results indicate that several sustainability practices we asked about were used on some level by over half of the respondents (Fig. 2). Particularly, Eastern Filbert Blight-resistant tree cultivars and integrated pest management were widely used (Fig. 2). Relatedly, less-toxic pesticides were also attempted by most growers, though not used across entire farms as frequently (Fig. 2). Cover crops, drip irrigation, and wildlife habitat were other practices widely attempted but not necessarily adopted across entire farms (Fig. 2). Filbertworm mating disruption and organic soil amendments were less likely to have been adopted by growers (Fig. 2).

Most growers' perceptions of sustainability practices were informed by multiple sources of information (Fig. 3A). Importantly, field demonstrations, personal experiences, and research presentations were universally seen as important, while third-party certifications were seen as less important than other factors (Fig. 3A). Likewise, growers valued expertise of many different information sources (Fig. 3B), with nearly everyone agreeing on the importance of the Nut Growers Society, Oregon State University Extension, and other growers.

Growers perceived a wide variety of challenges associated with these sustainability practices (Fig. 4). Notably, expense was the number one concern for all included practices except for integrated pest management (Fig. 4). Interference with orchard management was generally the second greatest concern, except for filbertworm mating disruption and integrated pest management where lack of technical support was more important (Fig. 4). Growers generally agreed that they have heard of these practices and that they do improve orchard sustainability (Fig. 4).

Farm characteristic impact on sustainability practices

When analyzing the effect of farm characteristics on number of sustainability practices used, only farm size was associated with the number of sustainability practices used (Fig. 5). We did not detect influence from orchard age, number of other crops grown, and region (Fig. 5). In general, respondents with larger orchard acreages were more likely to report implementing more sustainability practices. Given our finding that farm size was a key farm characteristic, we evaluated whether farm size had a relationship with growers

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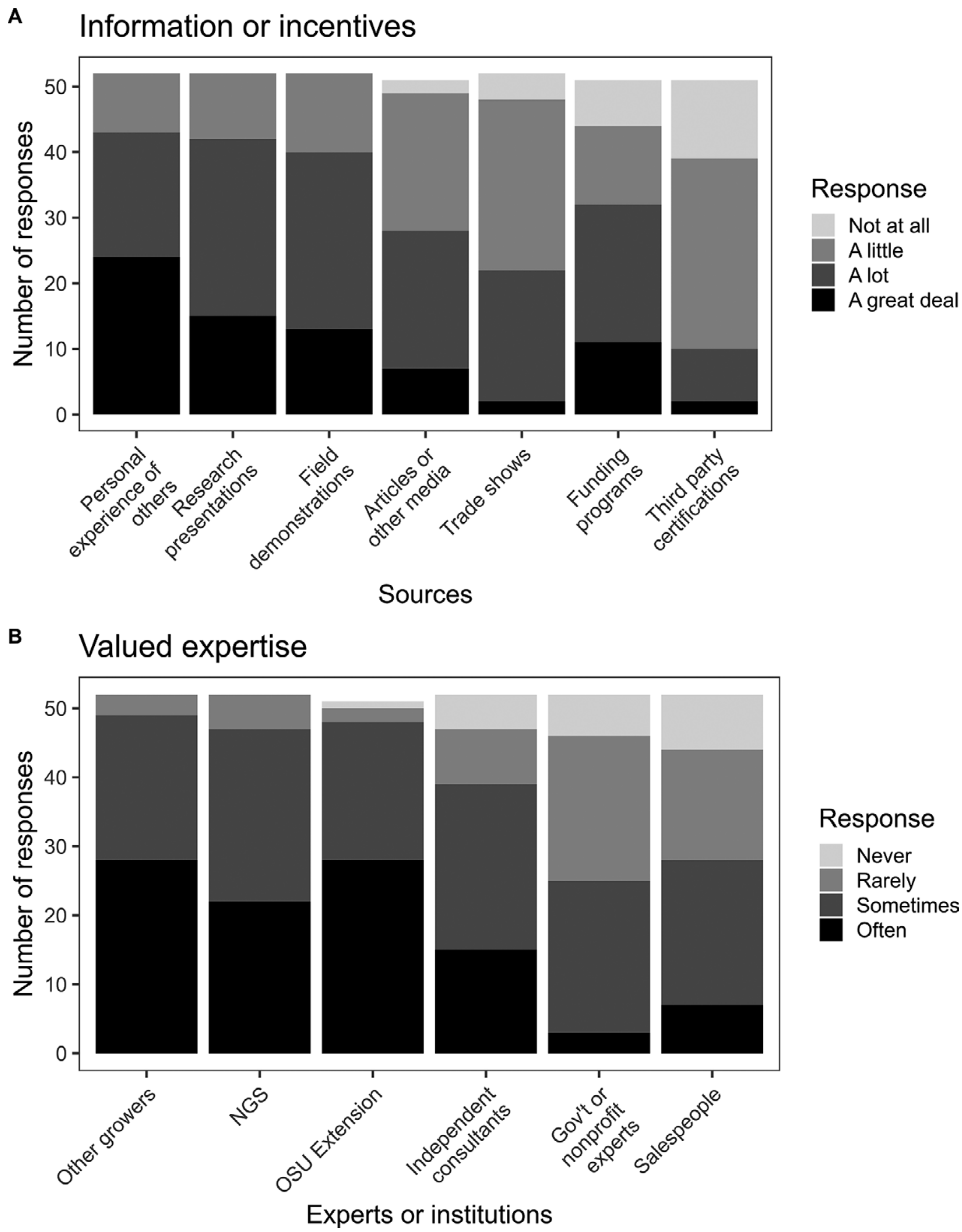

Figure 3. Bar chart showing how much hazelnut growers value certain information or incentives (A) or certain expertise from external stakeholders (B) when considering agricultural sustainability practices. Bar height represents the number of respondents for each category, and darker colors indicate higher levels of value for each category.

who practice specific sustainability practices in our survey. We detected differences in the average farm size of users and nonusers of two practices: integrated pest management and less-toxic pesticides ($P = 0.004$ for both, Fig. 6). Larger farms were more likely to have reported implementing these practices. These practices are conceptually similar, and there was significant overlap between users and nonusers of both practices, though there were several individual respondents that differed between the two practices.

Farm characteristic impact on sustainability messaging

When analyzing clusters of responses about valuable sustainability information and expertise, we found that our respondents were best described by two clusters (Fig. 7A). One cluster represented most respondents, who commonly reported the value of research presentations, field demonstrations, and personal experience of other growers. The other, smaller cluster of growers reported several additional important sources of sustainability information, including trade shows and other media. Growers with older orchards were more likely to fall into the latter group (Fig. 7B).

When analyzing clusters of responses about barriers to sustainability, we found that our respondents were best described by two clusters (Fig. 8A). Respondents in both groups reported barriers associated with the cost of implementing less-toxic pesticides, filbertworm mating disruption, and cover crops and with challenges integrating cover crops and drip irrigation into existing production systems. Additionally, respondents in the smaller group commonly reported several challenges in finding technical support and skilled labor or appropriate machinery to implement practices like organic soil amendments, habitat for native species, and

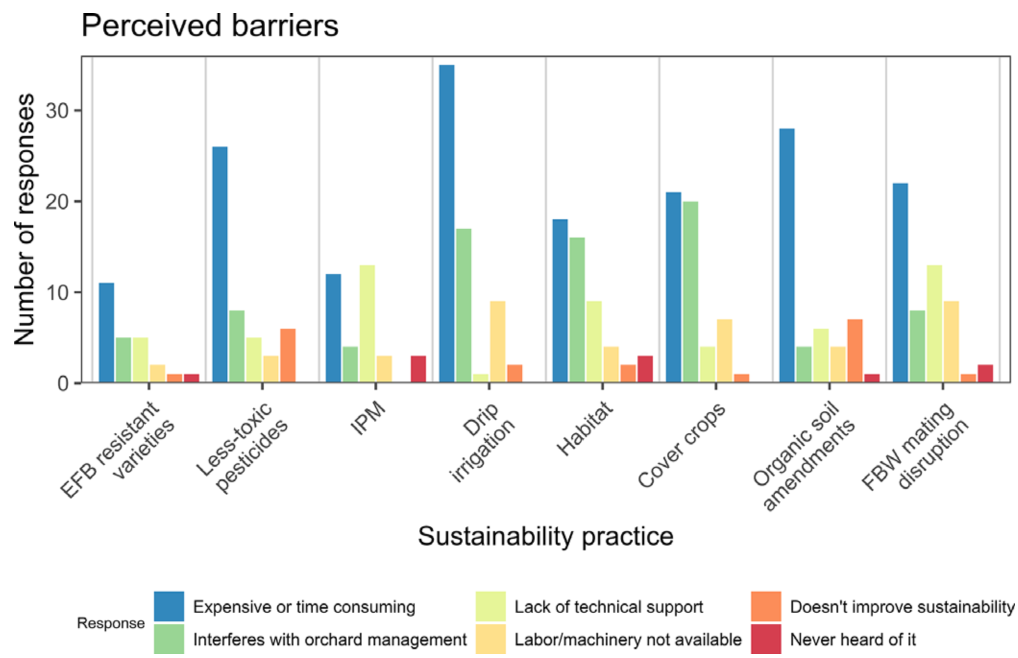

Figure 4. Bar chart showing growers' perceived barriers to implementing eight different hazelnut sustainability practices. Bar height represents the number of respondents who selected each barrier.

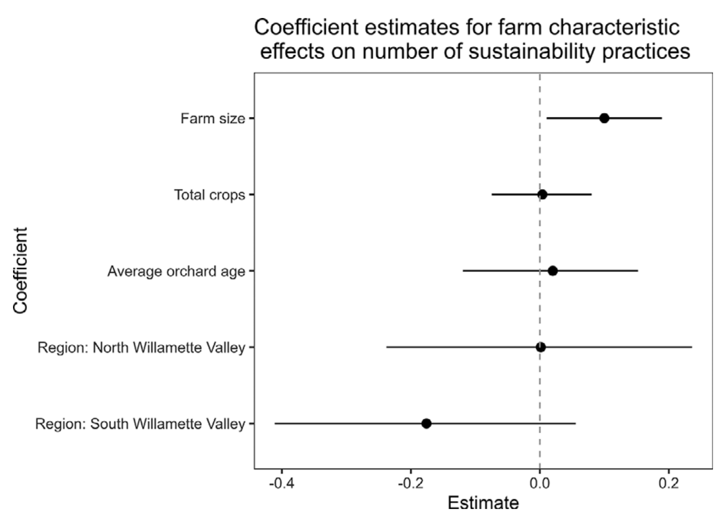

Figure 5. Coefficient estimates (points) and 95% confidence intervals (lines) for different farm characteristic effects on the number of sustainability practices used on each farm, as estimated by a generalized linear model with a quasi-Poisson distribution. Positive relationships (coefficient estimates further to the right) indicate a general increase in the number of sustainability practices implemented relative to other farms with lower values for each farm characteristic.

filbertworm mating disruption. Growers with older orchards and from the southern Willamette Valley were more likely to belong to this group which reported several additional sustainability barriers (Fig. 8B).

Sustainability practice implementation

When asked to describe qualitatively how producers decide how to implement sustainability practices, cost was a prevailing issue. Money and economics were portrayed in multiple different ways, including explicitly through references to money or cost–benefit analysis as well as less directly by referring to tradeoffs against crop yield or productivity as well as specific costs like labor. Several growers included economic factors as exacerbating other concerns, such as those related to broader regulatory factors affecting farmers:

> "[C]osts and whether they actually work not just a practice brought to us from the federal government that works in the [M]idwest but is marginally effective here in the [W]illamette [V]alley"

While the majority of growers seemed to be referring to short-term sustainability costs, several growers identified long-term or systems approaches to considering sustainability costs:

> "If there are long term benefits that outweigh the short term costs. If there are funding programs available to help implement certain practices or develop the infrastructure needed"

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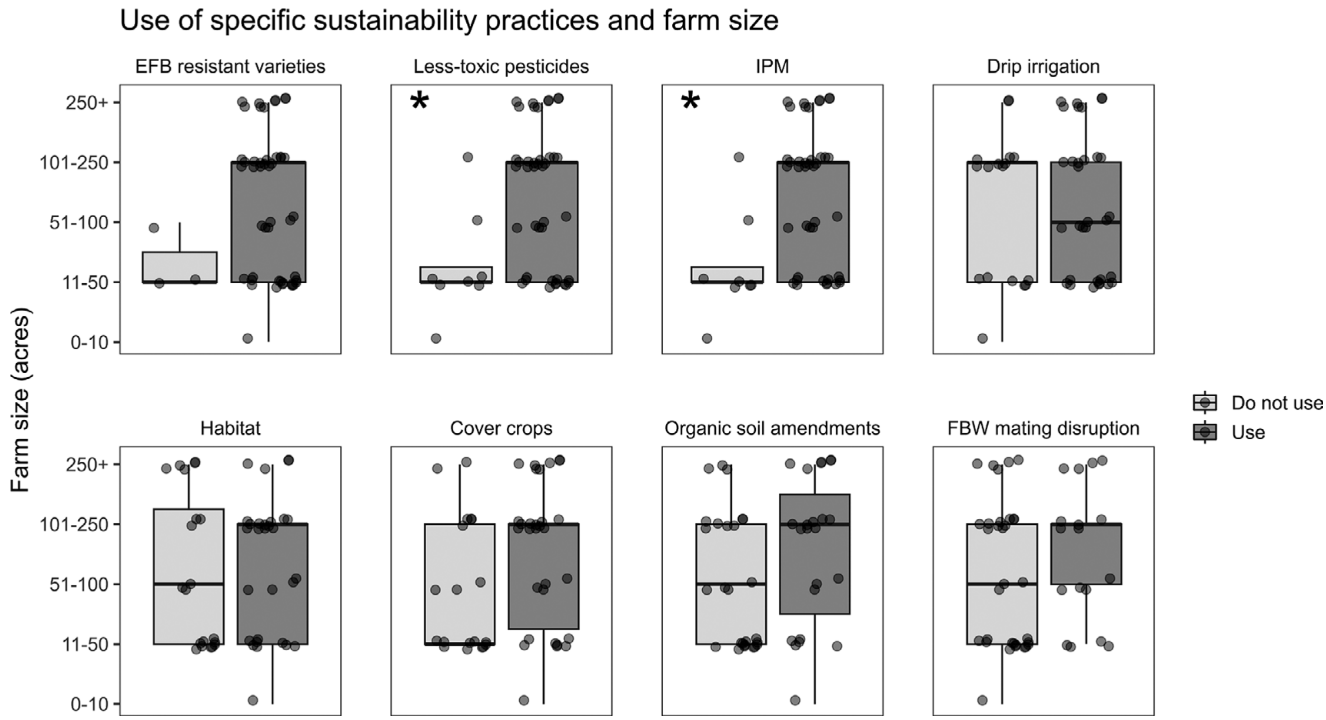

Figure 6. Box plots showing the farm size of users and nonusers of each sustainability practice included in our survey of hazelnut growers. Center lines represent the median farm size, hinges represent the upper and lower quartiles, and whiskers represent the range of data within 1.5 times the interquartile range. Panels with asterisks represent sustainability practices with a significantly different farm size between users and nonusers of that practice.

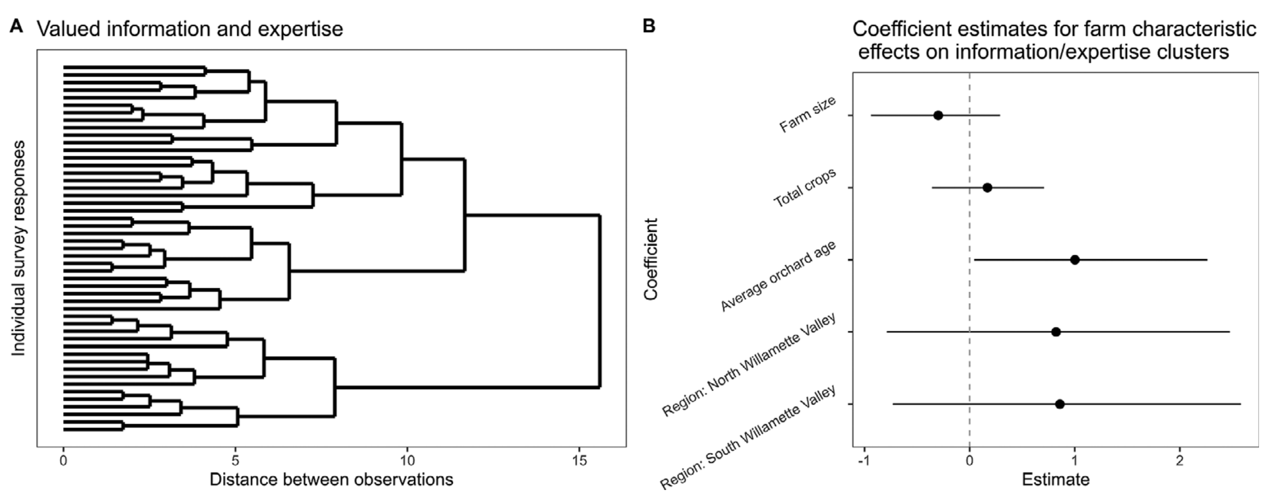

Figure 7. Charts summarizing patterns of valuable sustainability information and expertise reported by Oregon hazelnut growers. (A) A dendrogram depicting similarity of responses among growers. Each branch on the left represents one growers' response, and distances between pairs of responses are based on Ward's Distance. Greater distances between individual responses indicate greater dissimilarity in the pattern of valued sustainability information and expertise from those growers. (B) Coefficient estimates (points) and 95% confidence intervals (lines) for different farm characteristic effects on the groupings of similar responses to valued sustainability information and expertise. Positive relationships (coefficient estimates further to the right) indicate a general increase in the number of sustainability information sources viewed as important relative to other farms with lower values for each farm characteristic.

Lastly, a few growers also brought about adherence to broader sustainability frameworks as they relate to the cost of sustainability:

> "We are progressing down the path of regenerative ag. We believe in it fully, but it's a learning process, so we don't want to get too far over our skis and have insurmountable failures/learnings. And the price of hazelnuts is currently a huge barrier."

Previous sustainability changes

When asked about perceived changes to hazelnut system sustainability, growers provided a range of positive and negative answers. Growers asserting that hazelnut production has become more sustainable typically focused on the widespread adoption of a particular sustainable technology, especially including blight-resistant trees.

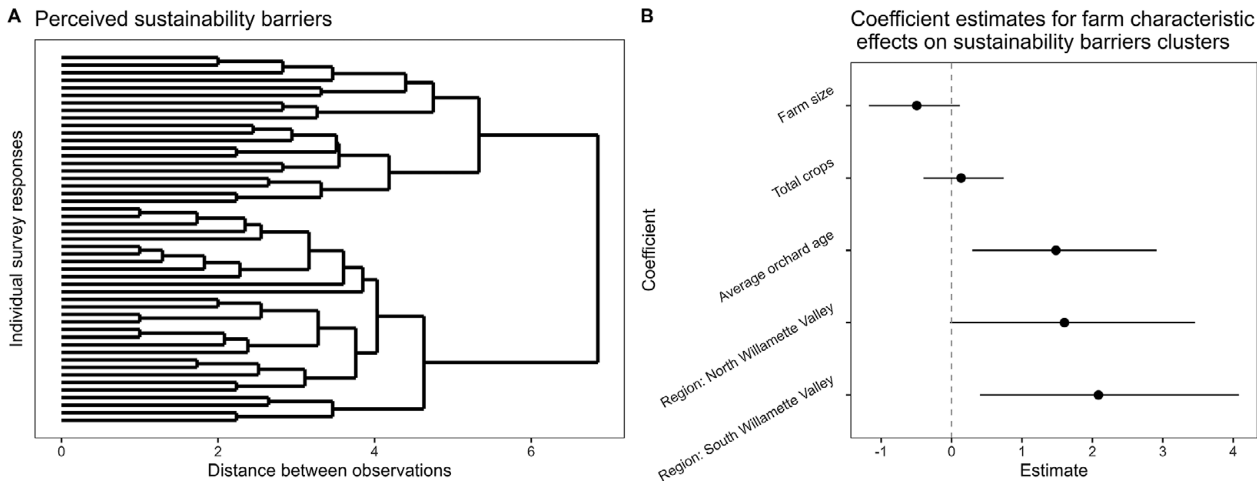

Figure 8. Charts summarizing patterns of perceived barriers to sustainability reported by Oregon hazelnut growers. (A) A dendrogram depicting similarity of responses among growers. Each branch on the left represents one growers' response, and distances between pairs of responses are based on Ward's Distance. Greater distances between individual responses indicate greater dissimilarity in the pattern of perceived sustainability barriers from those growers. (B) Coefficient estimates (points) and 95% confidence intervals (lines) for different farm characteristic effects on the groupings of similar responses to perceived sustainability barriers. Positive relationships (coefficient estimates further to the right) indicate a general increase in the number of perceived sustainability barriers relative to other farms with lower values for each farm characteristic.

One grower identified several specific sustainability technologies that were also highlighted by other growers:

> "The development of new varieties has helped the industry survive. Less-toxic chemicals have maintained more [beneficial insects] within the orchard. Better fertilizers allow us to do more with less."

Similarly, growers concerned about hazelnut sustainability tended to focus on the impacts of a few specific technologies, several of which overlapped with the technologies highlighted by those growers with positive outlooks:

> "Largely detrimental, too much soluble fertilizer, largely applied at the wrong times. Massive amounts of soil compaction and erosion. Bare soil being the predominant practice is horrible for soil health. Little to no regard for soil biology."

> "I am horrified at the erosion [I] see in the bare ground between trees. Especially since the excuses of difficult to harvest are pretty shallow as we've been harvesting on cover crop our entire orchard life."

Lastly, a few growers acknowledged contrasting opinions about the overall trajectory of hazelnut sustainability and once again framed these costs and benefits alongside explicit economic concerns:

> "I think it's going in the right direction unfortunately our markets haven't grown as fast as our production. It would be great to keep working on solutions at breeding that will help down the road to sustainability such as less suckering trees, less need for hand pruning, drought tolerant, wet soil tolerant, etc."

> "The industry has shifted to a much greater emphasis on shorter term orchards and higher [yields] supported by increased inputs and higher technology. This will require more emphasis on sustainable practices to offset the greater environmental impacts. Older low impact growers and practices have been displaced. Recent declines in prices may reverse this trend in part."

Future sustainability changes

When asked about speculated upcoming changes to hazelnut sustainability, many growers focused on the future development of specific technologies, especially those related to pest, water, and nutrient management. These responses displayed techno-optimism that new technologies would obviate the need for broader changes in hazelnut production:

> "The main thing is being smart with water and advancing in our knowledge of chemical use. Being more strategic with our chemicals and finding better delivery method of said chemicals."

In contrast, several growers did highlight the need for larger shifts to the production system:

> "To sustain by definition means to maintain the status quo, to regenerate means to improve. Just maintaining won't cut it, orchards are so degraded that they won't be viable for another 50 years without massive wholesale change and rethinking and relearning everything we thought we knew about hazelnut farming. We, on our farm, are currently in the middle of this and it's an extremely exciting journey, but not for everyone, farmers have to be willing and desirous of learning how to farm completely different than they do today."

Additionally, several growers highlighted the connection between hazelnut production practices and broader societal issues. These growers called for the development of new marketing opportunities for hazelnuts and underscored the importance of local decision-making within the hazelnut industry:

> "I think the way the farmer is paid will need to renegotiated or there will be a huge reduction in those farming. Packers and processors should not be protected from lowered prices. If the growers receive 40% of the prior years payment, perhaps the processors should take a hit as well."

> "[K]eep big government out of it. [L]et ag be profitable and we will adapt to any changes with help from our consultants private and local government [such as OSU extension.]"

https://doi.org/10.1017/S174217052500002X Published online by Cambridge University Press

Discussion

Our study indicates that cost is a critical factor driving the implementation of agricultural sustainability practices on hazelnut farms. For sustainable practices to satisfy producers' operational expectations, researchers and extensionists must address economic concerns. The sustainability practices in our study were generally recognized as sustainable and widely implemented by our respondents, which was expected given that we selected practices already promoted by the hazelnut industry.

Impact of large farms

Larger farmers reported implementation of more sustainability practices, which challenges narratives that small farms are better equipped to implement sustainability practices (Guthman, 2000; Prokopy et al., 2019; Ranjan et al., 2019). Larger operations might have the financial capital to invest in implementing sustainable practices. Farms with older hazelnut orchards not only reported using more information sources for sustainability decision-making but also reported more challenges associated with the adoption of sustainability practices. This trend could be influenced by a combination of historical management practices or unique economic factors for older operations. Likewise, growers in the southern Willamette Valley reported more sustainability barriers, which could be influenced by specific regional challenges.

Hazelnut growers have experienced multiple rapid changes in their industry, leading to different ways of approaching sustainability and agroecosystem management. In particular, the increased implementation of integrated pest management and less-toxic pesticides on larger farms corroborates the importance of economic issues. Integrated pest management and less-toxic pesticides are both practices that can be expensive and complicated to implement, necessitating integrative outreach programs and whole-farm planning to facilitate adoption (Schroeder et al., 2018). In addition to bearing extra production costs, these practices require growers to modify long-standing aspects of their production systems despite the risk of immediate negative outcomes (e.g., increases in pest damage, pesticide failures). While larger farms might better afford the expense of adopting new pest management practices, they also could be adopting new practices to avoid the higher costs associated with older practices that have more negative impacts across bigger farms.

Impacts and barriers of specific practices

In other cropping systems, changes to pest management programs can be challenging to implement, because growers commonly adhere to techno-optimism that new, singular pest management solutions can obviate the need for broader sustainability improvements to pest management programs (Dentzman et al., 2016). Cost was an especially acute concern in the hazelnut industry during the time of the survey, after a decade of growth and high prices gave way to increased production costs and low prices (Allen, 2023), and findings in this study related to economics could be driven, in part, by pessimism about the contemporaneous price of hazelnuts.

Practices like Eastern Filbert Blight-resistant varieties are widely adopted in the hazelnut industry, in part, because they can be implemented for little cost at the time of orchard establishment. Disease-resistant tree varieties exemplify a sustainability practice that satisfies several requirements for widespread adoption because they achieve positive sustainability outcomes during regular orchard establishment practices while also producing short-term economic benefits for the grower through reductions in the amount of fungicide purchased for the farm. In contrast, sustainability practices like cover cropping have somewhat more uncertainty in terms of economic payoffs, and additional research and outreach efforts that specifically demonstrate economic value could bolster cover crop adoption.

Differences in sustainability perceptions and information between growers with young and old orchards further highlight the importance of identifying opportunities for additional sustainability implementation during the rapid expansion of the hazelnut industry; growers with younger orchards generally identified fewer sustainability barriers and using generally fewer information sources, and thus would be potentially well served by additional sustainability outreach efforts.

Win-win sustainability solutions

Growers' collective response to ongoing economic challenges underscores the importance of not just finding sustainable solutions that are cost-effective in the short and long terms but also convincing growers that adoption of these solutions is good for the bottom line. Our survey results highlight the connectedness of the Oregon hazelnut industry, and many studies confirm the importance of social networks for information sharing among farmers (Tsouvalis et al., 2000; Falconer, 2000; Parks, 2022). These information networks extend off the farm (Coughenour, 2003), and we found that many growers within a well-connected industry turn to the same sources for management information.

While previous studies indicate the importance of sustainability messaging that targets growers' individual and specific needs (Fish et al., 2003; Brodt et al., 2006; Wauters et al., 2010), we argue that the hazelnut industry provides an example of a community of growers that would benefit from messaging that broadly highlights the multiple benefits of sustainability practices to all growers. Such sustainability outreach could both reinforce growers' existing connections to sustainability and allow growers to expand their connections to sustainability practices and practitioners (Singh et al., 2018). Repeated messaging across information sources can continue to spread information about the general economic and ecological benefits of sustainable practices, in addition to individualized technical support.

Socio-ecological sustainability

Growers in our study expressed commitment to adopting sustainability practices, but they also recognized the importance of economics in the farm ecosystem. These competing concerns led to perceptions that sustainability practices were handed down to growers from outside sources, leaving growers to figure out how to balance new practices against other production constraints, especially constraints related to cost. Farmers frequently experience conflict about the best way to integrate sustainability practices into existing systems (Carr and Tait, 1991). While many farmers desire to form positive ecological connections between their farms and the surrounding environment, the formation of such symbiotic relationships can be limited by farmer knowledge that is situated within a preexisting, well-established production system (Ellis, 2013; Shattuck, 2019). Identifying locally adapted sustainability practices that create a variety of agronomic and ecological benefits can improve grower support (Harrison et al., 1998; Durant and Ponisio, 2021); coupling such practices with explicit economic improvements will further improve implementation.

https://doi.org/10.1017/S174217052500002X Published online by Cambridge University Press

Agroecosystems, and especially orchard systems, necessitate long-term sustainability thinking, but current food systems require farm owners to balance the competing demands of short- and long-term concerns. Information about agricultural sustainability practices needs to address the complex ecological benefits of a practice as well as its economic benefits. Agricultural sustainability is essential for maintaining agroecosystem productivity in the face of multiple modern challenges. Increasing adoption of sustainable agricultural practices requires cooperation between the grower and multiple sources of technical support to determine which practices provide sustainability benefits as well as financial benefits.

Future research should address how these sustainability perceptions change with more participants, or over time as growth in the Oregon hazelnut industry normalizes, such as through longitudinal surveys. Additional research integrates sustainability attitudes research into extension needs assessments, allowing extensionists to work toward more reciprocal relationships with stakeholders. Finding commonalities across diverse stakeholders is frequently a productive way to approach sustainability challenges in complex agroecosystems (Selfa et al., 2008). Future adoption of new sustainability practices requires the development and dissemination of practices that create multiple ecological and economic benefits that are rooted in the local conditions and specific requirements of a particular cropping system.

Acknowledgments. We gratefully acknowledge helpful feedback from Hallett Lab members, especially Maddy Case, Cal Penkauskas, Carmen Watkins, Ethan Torres, Jasmin Albert, Lisa Buche, Eliza Hernandez, and Gabi Altmire, and Colleen Nihen, Nut Growers Society, during this project. This manuscript was prepared on and concerns the stewardship of Kalapuya Ilihi, the traditional indigenous homeland of the Kalapuya people. Today, descendants are citizens of the Confederated Tribes of Grand Ronde Community of Oregon and the Confederated Tribes of Siletz Indians of Oregon, and continue to make important contributions in their communities and across the land we now refer to as Oregon.

Author contribution. All authors participated in the survey design and critical review of the manuscript. LA, LCP, and LMH conceived of, planned, and initiated the research. SCH led survey administration, data analysis, and manuscript drafting.

Competing interest. This research was supported by the intramural research program of the U.S. Department of Agriculture, National Institute of Food and Agriculture, accession number 1015214. The authors have no competing interests to declare related to this work.

Ethical standard. This study was reviewed by University of Oregon Research Compliance Services and determined to be exempt from further oversight based on the minimal risk associated with participation. Informed consent was obtained from all study participants.

References

Allen, L. (2023) *March 2. Hazelnuts: Declining prices, declining acreage*. Farm Progress [Internet]. Available at Website https://www.farmprogress.com/tree-nuts/hazelnuts-declining-prices-declining-acreage.

Arbuckle, J.G. and Roesch-McNally, G. (2015) 'Cover crop adoption in Iowa: The role of perceived practice characteristics', *Journal of Soil and Water Conservation*, **70**(6), pp.418–429.

Asci, S. and Devadoss, S. (2021) 'Trends and issues relevant for the US tree nut sector', *Choices*, **36**(2), pp.1–7.

Blesh, J. and Wolf, S.A. (2014) 'Transitions to agroecological farming systems in the Mississippi River Basin: Toward an integrated socioecological analysis', *Agriculture and Human Values*, **31**(4), pp.621–635.

Brodt, S., Klonsky, K., and Tourte, L. (2006) 'Farmer goals and management styles: Implications for advancing biologically based agriculture', *Agricultural Systems*, **89**(1), pp.90–105.

Carr, S. and Tait, J. (1991) 'Differences in the attitudes of farmers and conservationists and their implications', *Journal of Environmental Management*, **32**(3), pp.281–294.

Coughenour, C.M. (2003) 'Innovating conservation agriculture: the case of no-till cropping', *Rural Sociology*, **68**(2), pp.278–304.

DeLonge, M.S., Miles, A. and Carlisle, L. (2016) 'Investing in the transition to sustainable agriculture', *Environmental Science & Policy*, **55**, pp.266–273.

Dentzman, K., Gunderson, R. and Jussaume, R. (2016) 'Techno-optimism as a barrier to overcoming herbicide resistance: Comparing farmer perceptions of the future potential of herbicides', *Journal of Rural Studies*, **48**, pp.22–32.

Dentzman, K. and Jussaume, R. (2017) 'The ideology of U.S. agriculture: How are integrated management approaches envisioned?', *Society & Natural Resources*, **30**(11), pp.1311–1327.

Dornelles, A.Z., Boyd, E., Nunes, R.J., Asquith, M., Boonstra, W.J., Delabre, I., Denney, J.M., Grimm, V., Jentsch, A., Nicholas, K.A., Schröter, M., Seppelt, R., Settele, J., Shackelford, N., Standish, R.J., Yengoh, G.T. and Oliver, T.H. (2020) 'Towards a bridging concept for undesirable resilience in social-ecological systems', *Global Sustainability*, **3**, p.e20.

Durant, J.L., Goodrich, B.K., Chang, K.T. and Yoshimoto, E. (2021) 'Growers follow the label: An analysis of bee-toxic pesticide use in almond orchards during bloom', *California Agriculture*, pp.1–10.

Durant, J.L. and Ponisio, L.C. (2021) 'A regional, honey bee-centered approach is needed to incentivize grower adoption of bee-friendly practices in the almond industry', *Frontiers in Sustainable Food Systems*, **5**.

Ellis, C. (2013) 'The symbiotic ideology: Stewardship, husbandry, and dominion in beef production', *Rural Sociology*, **78**(4), pp.429–449.

Falconer, K. (2000) 'Farm-level constraints on agri-environmental scheme participation: A transactional perspective', *Journal of Rural Studies*, **16**(3), pp.379–394.

Fish, R., Seymour, S. and Watkins, C. (2003) 'Conserving English landscapes: Land managers and agri-environmental policy', *Environment and Planning A: Economy and Space*, **35**(1), pp.19–41.

Ginn, J., O'Brien, J. and Silge, J. (2022) *qualtRics: download "Qualtrics" survey data.*

Godfray, H.C.J. and Garnett, T. (2014) 'Food security and sustainable intensification', *Philosophical Transactions of the Royal Society B: Biological Sciences*, **369**(1639), p.20120273.

Gould, F., Brown, Z.S. and Kuzma, J. (2018) 'Wicked evolution: Can we address the sociobiological dilemma of pesticide resistance?', *Science*, **360**(6390), pp.728–732.

Guthman, J. (2000) 'Raising organic: An agro-ecological assessment of grower practices in California', *Agriculture and Human Values*, **17**(3), pp.257–266.

Haring, S., Pesci Schmulevich, S., Manser, G.M. and Cooper, M.H. (2023) 'Rethinking scientists' ongoing participation in "feeding the world"', *Frontiers in Sustainable Food Systems*, **7**.

Harrison, C.M., Burgess, J. and Clark, J. (1998) 'Discounted knowledges: Farmers» and residents» understandings of nature conservation goals and policies', *Journal of Environmental Management*, **54**(4), pp.305–320.

Industry. (n.d.) Nut Growers Society of OR, WA & BC *[Internet]*. Available at Website https://members.oregonhazelnuts.org/page/Industry.

Jarosz, L. (2000) 'Understanding agri-food networks as social relations', *Agriculture and Human Values*, **17**(3), pp.279–283.

Kolde, R. (2019) *pheatmap: pretty heatmaps*.

Lavoie, A.L., Dentzman, K. and Wardropper, C.B. (2021) 'Using diffusion of innovations theory to understand agricultural producer perspectives on cover cropping in the inland Pacific Northwest, USA', *Renewable Agriculture and Food Systems*, **36**(4), pp.384–395.

Lomba, A., Moreira, F., Klimek, S., Jongman, R.H., Sullivan, C., Moran, J., Poux, X., Honrado, J.P., Pinto-Correia, T., Plieninger, T. and McCracken, D.I. (2020) 'Back to the future: Rethinking socioecological systems underlying high nature value farmlands', *Frontiers in Ecology and the Environment*, **18**(1), pp.36–42.

Lubell, M., Hillis, V. and Hoffman, M. (2011) 'Innovation, cooperation, and the perceived benefits and costs of sustainable agriculture practices', *Ecology and Society*, **16**(4).

Lüdecke, D., Ben-Shachar, M.S., Patil, I., Waggoner, P. and Makowski, D. (2021) 'performance: An R Package for Assessment, Comparison and Testing of Statistical Models', *Journal of Open Source Software*, **6**(60), pp.3139.

Maechler, M., Rousseeuw, P., Struyf, A., Hubert, M. and Hornik, K. (2022) *Cluster: cluster analysis basics and extensions.*

Mehlenbacher, S.A. and Olsen, J. (1997) The hazelnut industry in Oregon, USA. *Proceedings of the Fourth International Symposium on Hazelnut*, pp.337–345.

Myers, R. and Watts, C. (2015) 'Progress and perspectives with cover crops: Interpreting three years of farmer surveys on cover crops', *Journal of Soil and Water Conservation*, **70**(6), pp.125A–129A.

National Agricultural Statistics Service. (2019) *2017 Census of agriculture*. Washington, DC: USDA National Agricultural Statistics Service.

Neill, S.P. and Lee, D.R. (2001) 'Explaining the adoption and disadoption of sustainable agriculture: The case of cover crops in northern Honduras', *Economic Development and Cultural Change*, **49**(4), pp.793–820.

O'Connell, S., Grossman, J.M., Hoyt, G.D., Shi, W., Bowen, S., Marticorena, D.C., Fager, K.L. and Creamer, N.G. (2015) 'A survey of cover crop practices and perceptions of sustainable farmers in North Carolina and the surrounding region', *Renewable Agriculture and Food Systems*, **30**(6), pp.550–562.

Parks, M. (2022) 'Exploring the influence of social and informational networks on small farmers' responses to climate change in Oregon', *Agriculture and Human Values*, **39**(4), pp.1407–1419.

Penkauskas, C., Brambila, A., Donahue, D., Larson, T., Miller, B. and Hallett, L.M. (2022) 'Hogs and hazelnuts: Adaptively managing pest spillover in the agricultural-wildland matrix', *Agroforestry Systems*, **96**(3), pp.637–649.

Petrzelka, P., Ulrich-Schad, J. and Yost, M. (2024) '"We're very late to the party": Motivations and challenges with improving soil health in Utah', *Agriculture and Human Values*, **41**(1), pp.381–386.

Piñeiro, V., Arias, J., Dürr, J., Elverdin, P., Ibáñez, A.M., Kinengyere, A., Opazo, C.M., Owoo, N., Page, J.R., Prager, S.D. and Torero, M. (2020) 'A scoping review on incentives for adoption of sustainable agricultural practices and their outcomes', *Nature Sustainability*, **3**(10), pp.809–820.

Prokopy, L.S., Floress, K., Arbuckle, J.G., Church, S.P., Eanes, F.R., Gao, Y., Gramig, B.M., Ranjan, P. and Singh, A.S. (2019) 'Adoption of agricultural conservation practices in the United States: Evidence from 35 years of quantitative literature', *Journal of Soil and Water Conservation*, **74**(5), pp.520–534.

Prokopy, L.S., Floress, K., Klotthor-Weinkauf, D. and Baumgart-Getz, A. (2008) 'Determinants of agricultural best management practice adoption: Evidence from the literature', *Journal of Soil and Water Conservation*, **63**(5), pp.300–311.

R Core Team. (2023) *R: A language and environment for statistical computing.* Vienna, Austria: R Foundation for Statistical Computing.

Ranjan, P., Church, S.P., Floress, K. and Prokopy, L.S. (2019) 'Synthesizing conservation motivations and barriers: What have we learned from qualitative studies of farmers' behaviors in the United States?', *Society & Natural Resources*, **32**(11), pp.1171–1199.

Rodriguez, J.M., Molnar, J.J., Fazio, R.A., Sydnor, E. and Lowe, M.J. (2009) 'Barriers to adoption of sustainable agriculture practices: Change agent perspectives', *Renewable Agriculture and Food Systems*, **24**(1), pp.60–71.

Röling, N. and van de Fliert, E. (1994) 'Transforming extension for sustainable agriculture: The case of integrated pest management in rice in Indonesia', *Agriculture and Human Values*, **11**(2), pp.96–108.

Ryu, E., Couper, M.P. and Marans, R.W. (2006) 'Survey incentives: Cash vs. in-kind; face-to-face vs. mail; response rate vs. nonresponse error', *International Journal of Public Opinion Research*, **18**(1), pp.89–106.

Schroeder, J., Barrett, M., Shaw, D.R., Asmus, A.B., Coble, H., Ervin, D., Jussaume, R.A., Owen, M.D.K., Burke, I., Creech, C.F., Culpepper, A.S., Curran, W.S., Dodds, D.M., Gaines, T.A., Gunsolus, J.L., Hanson, B.D., Jha, P., Klodd, A.E., Kniss, A.R., Leon, R.G., McDonald, S., Morishita, D. W., Schutte, B.J., Sprague, C.L., Stahlman, P.W., Steckel, L.E. and Van-Gessel, M.J. (2018) 'Managing wicked herbicide-resistance: Lessons from the field', *Weed Technology*, **32**(4), pp.475–488.

Schulte, L.A., Asbjornsen,H., Liebman,M. and Crow,T.R. (2006) 'Agroecosystem restoration through strategic integration of perennials', *Journal of Soil and Water Conservation*, **61**(6), pp.164A–169A.

Selfa, T., Jussaume, R.A. and Winter, M. (2008) 'Envisioning agricultural sustainability from field to plate: Comparing producer and consumer attitudes and practices toward 'environmentally friendly' food and farming in Washington State, USA', *Journal of Rural Studies*, **24**(3), pp.262–276.

Shattuck, A. (2019) Risky subjects: Embodiment and partial knowledges in the safe use of pesticide. Geoforum:S0016718519301459.

Silvestri, C., Bacchetta, L., Bellincontro, A. and Cristofori, V. (2021) 'Advances in cultivar choice, hazelnut orchard management, and nut storage to enhance product quality and safety: An overview', *Journal of the Science of Food and Agriculture*, **101**(1), pp.27–43.

Singh, A., MacGowan, B., O'Donnell, M., Overstreet, B., Ulrich-Schad, J., Dunn, M., Klotz, H. and Prokopy, L. (2018) 'The influence of demonstration sites and field days on adoption of conservation practices', *Journal of Soil and Water Conservation*, **73**(3), pp.276–283.

Tsouvalis, J., Seymour, S. and Watkins, C. (2000) 'Exploring knowledge-cultures: Precision farming, yield mapping, and the expert–farmer interface', *Environment and Planning A: Economy and Space*, **32**(5), pp.909–924.

Warner, K.D. (2008) 'Agroecology as participatory science: Emerging alternatives to technology transfer extension practice', *Science, Technology, & Human Values*, **33**(6), pp.754–777.

Wauters, E., Bielders, C., Poesen, J., Govers, G. and Mathijs, E. (2010) 'Adoption of soil conservation practices in Belgium: An examination of the theory of planned behaviour in the agri-environmental domain', *Land Use Policy*, **27**(1), pp.86–94.

Wayman, S., Kissing Kucek, L., Mirsky, S.B., Ackroyd, V., Cordeau, S. and Ryan, M.R. (2017) 'Organic and conventional farmers differ in their perspectives on cover crop use and breeding', *Renewable Agriculture and Food Systems*, **32**(4), pp.376–385.

Wickham, H., Averick, M., Bryan, J., Chang, W., McGowan, L.D., François, R., Grolemund, G., Hayes, A., Henry, L., Hester, J., Kuhn, M., Pedersen, T.L., Miller, E., Bache, S.M., Müller, K., Ooms, J., Robinson, D., Seidel, D.P., Spinu, V., Takahashi, K., Vaughan, D., Wilke, C., Woo, K. and Yutani, H. (2019) 'Welcome to the tidyverse', *Journal of Open Source Software*, **4**(43), p.1686.