Industry Perspectives on Heat Mitigation Technologies in Small Fruit Production Systems in the Pacific Northwest

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Abstract. Washington State's caneberry and blueberry industries, particularly processed red raspberries, face increasing exposure to extreme heat. Using data from a multimodal audience poll and an online survey of 40 small fruit stakeholders, this study documented current use, perceived barriers, and investment intentions related to heat mitigation technologies. Despite broad recognition of heat-related risks, adoption of structural and water-intensive technologies remains limited. Shade nets and overhead microsprinklers are infrequently used, with nonadoption primarily driven by operational and resource constraints rather than skepticism about climate risk or technology effectiveness. In contrast, biostimulants show higher reported use and stronger near-term investment interest, reflecting lower capital requirements and greater compatibility with existing production systems. Information regarding technology costs and returns reduces uncertainty and shapes profit expectations but does not uniformly increase expected profitability across heat-risk scenarios. Expected returns increase when heat events are assumed to be certain but decline under moderate-risk assumptions, indicating sensitivity to perceived event likelihood. Responses vary by role: producers revise expectations downward after receiving cost information, whereas advisory roles revise expectations upward, particularly under high-heat scenarios. While these findings provide baseline evidence for extension and future research, their interpretability was constrained by the small sample size, which limited external validity and generalizability to the broader industry.

Introduction

Washington State is a major producer of caneberries (raspberries: *Rubus idaeus*; blackberries: *Rubus* spp.) and blueberries (*Vaccinium corymbosum*) in the United States and plays a particularly dominant role in processed caneberry markets. The state leads national production of processed red raspberries and is a top producer of blackberries and blueberries, supplying a substantial share of frozen and processed berry products consumed domestically. For instance, Washington accounts for 90% of the nation's frozen red raspberry production (Washington Red Raspberry Commission 2025). Washington's average red raspberry production has declined in recent years. From 2017 to 2020, the average production was 31,139 t annually; however, it dropped to 23,724 t from 2021 to 2024 (Washington Red Raspberry Commission 2025). Nonetheless, caneberry and blueberries remain important to the state's economy. In 2024, the farmgate value of Washington-grown blueberries reached $204.7 million, while the farmgate value of red raspberries totaled $84.4 million (US Department of Agriculture, National Agricultural Statistics Service 2025).

One contributing factor of this decline has been extreme weather events. In particular, the 2021 Pacific Northwest heatwave shattered historical maximum temperature records across Washington and the Pacific Northwest (PNW) region, causing widespread yield losses (White et al. 2023). Similar heat stress events have been identified in the literature as disproportionally affecting shallow-rooted perennial fruit crops, including caneberries and blueberries, through reduced fruit set, sunburn, and plant mortality (Lobos and Hancock 2015; McGlothern and DeVetter 2023; Yang et al. 2019).

Climate change, particularly rising global temperatures and extreme weather events like heatwaves, are scientifically established phenomena (Hansen et al. 2006; Heeter et al. 2023; Loarie et al. 2009). Lindsey and Dahlman (2024) concluded that the 2014–23 period was the warmest since 1850, with 2023 being the warmest year of that entire period. A substantial body of literature concluded that climate change will have a detrimental impact on crop yields (Challinor et al. 2014; Schlenker and Roberts 2009; Schlenker et al. 2005, 2006; Zhang et al. 2017).

The Intergovernmental Panel on Climate Change (2014) posits that global climate change will lead to significant transformations in agriculture. For instance, a 2 °C increase in temperature is projected to reduce average crop yields by 25%. Furthermore, persistent climate variations will disrupt ecosystems (Deschênes and Greenstone 2007). The impact is particularly pronounced for crops grown in relatively localized regions, as exemplified by raspberries in Washington and the unprecedented heatwave of 2021 that affected both the US and Canadian PNW region. During this heatwave, temperatures increased by more than 5 °C above typical levels, reaching a peak of 49.6 °C. The consequences of this event were unprecedented, including mass mortality of marine life, river flooding caused by rapid snow and glacier melt, increases in wildfires, and reduced crop yields (Whittemore et al. 2025). Concerning raspberries, reports indicated yield losses ranging from 30% to 40%, with some growers experiencing complete crop losses (Central Oregon Daily 2021).

If mitigation measures to reduce emissions below intermediate levels (SSP2–4.5 from the Intergovernmental Panel on Climate Change Sixth Assessment Report, in which CO_2 emissions remain at approximately current levels until 2050 before falling without reaching net zero by 2100) are not successful, then climate model projections indicate that Washington State and other areas of the PNW will regularly experience 2021-like extreme heat events, with a 50% probability of annual occurrence by 2050 (Heeter et al. 2023). Increasing awareness that climate change is the primary driver of these events enables society to make informed climate decisions and prepare for future heatwaves, thereby mitigating their potential impacts (US Department of Agriculture 2025). In this context, technologies that facilitate agricultural adaptation to climate change are warranted. Some of these technologies necessitate investment, while others require enhancing awareness and building capacity to implement novel practices (Clements et al. 2011). Anecdotal evidence suggests that the PNW agricultural industry lacks the necessary preparedness to withstand extreme heat events. Technologies to mitigate heat-related damage include cooling systems, such as shade nets or water-based overhead cooling using microsprinklers (i.e., "evaporative cooling") (US Department of Agriculture 2025). Biostimulants or "priming agents" represent another, yet less established, heat-mitigation technology (Du Jardin 2015). These nonfertilizer agrochemical products composed of naturally occurring substances and/or microorganisms are applied to plants in small amounts, with growing evidence that their use can enhance tolerance to environmental stresses such as heat (Makonya et al. 2025; Niu et al. 2022). However, the decision to invest in these technologies is partially contingent on the belief that a heat event will repeat and associated investments will yield positive outcomes.

This study provides a descriptive characterization of the use and consideration of heat mitigation technologies in small fruit production systems. It documents stakeholders' reported beliefs about future heat events, expected profits under alternative mitigation scenarios, risk profiles, and key operational attributes as well as stated reasons for adoption, nonadoption, and investment intentions. By presenting these outcomes as summary statistics disaggregated by respondent type, this analysis offers an empirical snapshot of how industry participants currently perceive and evaluate heat mitigation options, thereby generating baseline evidence to inform extension programming and future research of climate adaptation in specialty crop industries. This approach is consistent with prior work that highlighted the importance of role-based differences in shaping technology perceptions and adoption behavior in agricultural systems (Gardezi et al. 2020).

These contributions should be interpreted in light the relatively small sample size, which was an important limitation of this study. While respondents represent diverse roles and production contexts, the limited number of observations constrained statistical precision and external validity; therefore, the heterogeneity of preferences and constraints across the industry may not have been fully captured. Accordingly, the findings are best viewed as indicative rather than representative, thereby providing exploratory insights that can guide the design of larger, more representative data collection efforts.

Materials and methods

Data collection. A multimodal survey instrument was used to collect data. Initially, an audience poll survey using Echo360 (Youngstown, OH, USA) was conducted at the 2024 Lynden Agriculture Show (Lynden, WA, USA) on 5 Dec 2024. This event is an agricultural trade show in western Washington that showcases the Washington Small Fruit Conference. The conference brings together industry and academia professionals from Washington, Oregon, and British Columbia. The presentation at which data collection occurred attracted 36 caneberry and blueberry industry participants (including 3 owners/lessees, 8 hired managers, 10 chemical consultants, 1 marketer, 10 respondents in other industry-related roles, and 4 participants who did not disclose their role). Because of the limited sample size, the analysis is restricted to descriptive statistics. For contextualization, the population of caneberry growers in Washington State is small despite its relative high acreage and production volume. For example, only 58 red raspberry growers were reported statewide in 2024 (Washington Red Raspberry Commission 2025).

Because of the limited number of observations initially collected, the authors aimed to supplement the dataset with responses from an online Qualtrics survey (Qualtrics, Provo, UT, USA). This online survey exactly replicated the audience poll survey, preserving identical wording, structure, and response scales across instruments. The online survey was distributed through the Washington and Oregon Raspberry Commissions and the British Columbia Raspberry Development Council in Apr 2025 using a three-wave method. The survey was launched on 2 Apr, followed by reminders on 14 Apr and 23 Apr, with distribution facilitated by a regional small fruit production extension specialist. This additional effort generated 14 responses, of which four were complete and usable (two owners/lessees, one chemical consultant, one other role). Combined with the original data collection, the final sample comprised 40 usable observations. All data collection protocols received Institutional Review Board approval (IRB #20816-001).

Questions in both the audience poll and online survey were developed in close consultation with Extension faculty who are knowledgeable of the small fruit industry and heat stress mitigation technologies. The instrument incorporated questions to assess respondents' risk preferences and quantify the maximum expected profit from using heat mitigation technologies under the assumption of a 100% probability of a heat event, and the same profit expectation but with a 50% probability of a heat event. Additional questions documented current utilization of heat mitigation technologies, including shade nets, overhead microsprinklers, and biostimulants, as well as the primary reasons for the nonutilization of each technology. Additionally, the surveys assessed the respondent's likelihood of investing in each of the three mitigation technologies within the next 5 years.

Following the presentation of estimated costs and returns for each of the three heat mitigation technologies derived from preliminary field trial results from ongoing projects, the surveys re-elicited respondents' expected profits under the same heat event assumptions. The economic information presented was based on a raspberry production case study. Because most

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participants reported growing a mix of small fruit crops, this case was used as a reference framework to illustrate how heat mitigation technologies may alter production cost structures and expected profitability under alternative heat event scenarios. The cost and return information presented to respondents is provided in Table 1. Next, the survey inquired about the anticipated probabilities of a heat event occurring at least once within the next 5 years. Finally, questions pertaining to agricultural operations were included, such as the crop mix and the size and location of growers' raspberry operation. Additionally, sociodemographic information about the principal operation was collected, including age, years of decision-making experience, highest level of education attained, role in the small fruit industry, and the percentage of household income in 2024 derived from the raspberry operation.

Data description. Table 2 summarizes the production profile, farm size distribution, and geographic location of survey respondents reported for the pooled sample and disaggregated by professional role. There were five role categories: (1) owners (note co-owners and lessees were classified as owner/lessee); (2) managers, including those identified as hired managers; (3) chemical consultants; (4) marketers; and (5) other. Owners and managers were denoted as individuals with decision-making authority in the operation. Four individuals left this question blank and were not categorized. Most participants were engaged in diversified berry production rather than single-crop systems, with mixed berry operations representing the dominant category across roles. A sizable share of respondents, particularly chemical consultants and those classified as "other", reported not directly producing crops, consistent with advisory and support functions within the caneberry and blueberry value chains.

Reported farm size varied widely, reflecting heterogeneity in operational scale across respondent roles. Owners and lessees were more concentrated in smaller acreage categories, whereas managers and consultants were more frequently associated with larger operations, as reflected in higher weighted average farm sizes. Missing farm size information was common, especially among nonproducer roles, which limits inference on scale for the full sample. Geographically, respondents were primarily located in northwestern Washington, with additional representation from British Columbia and northwestern Oregon. As with farm size, location information was more frequently omitted by nonproducer respondents.

Table 3 characterizes the socioeconomic composition of survey participants. Overall, respondents represented a broad cross-section of age cohorts and professional experience levels, reflecting both early-career and highly experienced individuals within the caneberry and blueberry industries. Differences across respondent roles suggest generational and career stage variations, with managers tending to be younger and less experienced on average, and owners, lessees, and chemical consultants exhibiting longer industry tenure.

Educational attainment was relatively high across the sample. Most respondents reported bachelor's degree attainment, although the distribution of education levels varied by role, reflecting differences in training pathways across production, advisory, and marketing functions.

Income dependence on farming differed substantially across respondents, underscoring heterogeneity in economic exposure to production risk. While a subset of participants derived most or all household income from farming, a large share, particularly among nonproducer roles, reported limited or no reliance on farm income.

Risk preferences were elicited using a multiple price list framework in which respondents chose between a risky lottery and sequence of guaranteed payments. The risky option offered a 70% probability of receiving the highest payoff ($1500/acre) and a 30% probability of receiving zero returns, while the guaranteed alternatives were certain payments that increased monotonically from $600/acre to $6000/acre. Respondents were classified as risk-neutral if they switched from the risky option to the guaranteed option at question 7 ($4200/acre). Switching at later questions indicated risk-loving behavior, whereas switching earlier indicated risk aversion. This elicitation approach followed the work of Singerman and Useche (2019). In the sample, risk preferences differed across respondent roles, with risk-averse behavior prevailing in the pooled results. Advisory and support roles exhibited particularly conservative risk profiles, whereas owners and managers showed greater dispersion across risk categories.

Heat mitigation technologies, perceived barriers, and expected profits. Table 4 summarizes the current use of heat mitigation technologies, perceived barriers to adoption,

Table 1. Cost and return information for heat mitigation strategies presented to a group of small fruit industry stakeholders during a survey on Dec 2024 in Lynden, WA, USA.

	No heat event					Heat event					
Heat mitigation treatment	Yield (lb/acre)	Total returns ($/acre) at $2.4/lb	Variable costs ($/acre)	Fixed costs ($/acre)	Net returns ($/acre)	Yield (lb/acre)	Total returns ($/acre) at $2.4/lb	Variable costs ($/acre)	Fixed costs ($/acre)	Net returns ($/acre)	Difference with respect to do nothing ($/acre)[i]
Do nothing	9,605	23,052	11,531	5,869	5,652	6,724[ii]	16,136[i]	11,531	5,869	−1,264[ii]	NA
Shade netting	9,605	23,052	11,531	8,893[ii]	2,628[ii]	9,605	23,052	11,698[ii]	8,893[ii]	2,461	3,725
Microsprinklers	9,605	23,052	11,531	6,392[ii]	5,129[ii]	9,605	23,052	11,936[ii]	6,392[ii]	4,724	5,988
Biostimulant	9,605	23,052	11,531	5,869	5,652	8,164[ii]	19,594[ii]	11,699[ii]	5,869	2,026	3,290

[i] The estimates reflect the incremental net returns of shade netting, microsprinklers, or biostimulant relative to the do nothing scenario under a heat event.
[ii] Numbers are estimated based on data from field studies.
NA = not applicable.

Table 2. Distribution of farm characteristics, crops grown, farm size, and location pooled and by respondent role.

Variable/category	Pool (N = 40)	Owner and lessee (N = 5)	Manager (N = 8)	Chemical consultant (N = 11)	Marketer (N = 1)	Other (N = 11)	Blank (N = 4)
Crops grown							
Blueberry only	1 (2.5)[i]	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	1 (9.1)	0 (0.0)
Red raspberry only	1 (2.5)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	1 (9.1)	0 (0.0)
Mix of berries	20 (50.0)	2 (40.0)	7 (87.5)	6 (54.5)	1 (100.0)	3 (27.3)	1 (25.0)
Mix of berries and other	2 (5.0)	1 (20.0)	1 (12.5)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)
Other	1 (2.5)	1 (20.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)
Do not grow	14 (35.0)	1 (20.0)	0 (0.0)	5 (45.5)	0 (0.0)	6 (54.5)	2 (50.0)
Blank/NA	1 (2.5)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	1 (25.0)
Farm size (acres)[ii]							
Less than 25	6 (15.0)	3 (60.0)	0 (0.0)	1 (9.1)	0 (0.0)	2 (18.2)	0 (0.0)
25–50	2 (5.0)	0 (0.0)	1 (12.5)	1 (9.1)	0 (0.0)	0 (0.0)	0 (0.0)
51–100	1 (2.5)	0 (0.0)	1 (12.5)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)
101–250	1 (2.5)	1 (20.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)
251–500	4 (10.0)	0 (0.0)	2 (25.0)	1 (9.1)	0 (0.0)	1 (9.1)	0 (0.0)
501–1,000	3 (7.5)	0 (0.0)	2 (25.0)	1 (9.1)	0 (0.0)	0 (0.0)	0 (0.0)
More than 1,000	2 (5.0)	0 (0.0)	1 (12.5)	0 (0.0)	0 (0.0)	1 (9.1)	0 (0.0)
Blank/NA	21 (52.5)	1 (20.0)	1 (12.5)	7 (63.6)	1 (100.0)	7 (63.6)	4 (100.0)
Weighted average farm size (acres)	*327.9*	*62.6*	*480.7*	*297.1*	–	*356.4*	
Location							
British Columbia (Canada)	3 (7.5)	2 (40.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	1 (25.0)
Northwest Washington	12 (30.0)	1 (20.0)	7 (87.5)	1 (9.1)	0 (0.0)	3 (27.3)	0 (0.0)
Northwest Oregon	2 (5.0)	0 (0.0)	1 (12.5)	1 (9.1)	0 (0.0)	0 (0.0)	0 (0.0)
Blank/NA	23 (57.5)	2 (40.0)	0 (0.0)	9 (81.8)	1 (100.0)	8 (72.7)	3 (75.0)

[i] Values are number of respondents and percentages are shown in parentheses.
[ii] 1 acre = 0.404686 ha.
NA = not applicable.

and stated investment intentions across respondent roles. Overall adoption of structural and water-intensive technologies, such as shade nets and overhead microsprinklers, was limited in the pooled sample. When these technologies were not in use, nonadoption was driven primarily by operational constraints rather than skepticism about climate risk or technology effectiveness. For shade nets, respondents across roles consistently emphasized implementation difficulty, reflecting challenges related to infrastructure. Similarly, nonuse of microsprinklers was most frequently associated with negative or unintended consequences and water access limitations, underscoring the importance of water availability, regulatory constraints, and concerns about disease pressure or system compatibility. In contrast, biostimulants exhibited substantially higher reported use across roles, particularly among producers and chemical consultants. Compared with shade nets and microsprinklers, barriers to biostimulant adoption were more closely tied to cost considerations and uncertainty about performance rather than physical or infrastructural constraints.

Stated investment intentions over the next 5 years mirrored current adoption patterns. Probabilities of future investment were lowest for shade nets and microsprinklers in the pooled sample, suggesting that perceived operational and resource constraints are unlikely to be alleviated in the near term. In contrast, respondents reported substantially higher probabilities of investing in biostimulants, particularly among managers and chemical consultants, indicating stronger near-term adoption potential for technologies that can be integrated incrementally and adjusted across seasons.

Across all three technologies, variation by respondent role highlights differing decision-making contexts within the caneberry and blueberry value chains. Producers' responses reflect direct exposure to capital, labor, and water constraints, whereas advisory roles appear more optimistic regarding adoption of flexible, lower-commitment options. Collectively, these results suggest that adaptation strategies in perennial small fruit systems may be constrained less by awareness of heat risk and more by structural and operational feasibility, with important implications for extension programming and technology development.

Table 5 reports mean expected net returns from heat stress mitigation technologies under two hypothetical heat event scenarios (100% and 50% probability) measured before and after respondents were provided information regarding technology costs and benefits. Results are shown for the pooled sample and disaggregated by respondent role, reflecting heterogeneity in expectations across the PNW and British Columbia.

Across the pooled sample, expected net returns before information provision were higher under a certain heat event than under a 50% probability scenario. After information about costs and benefits was provided, mean expected returns increased under the 100% probability scenario but declined under the 50% probability scenario. This pattern suggested that information enables decision-makers to update their expectations about contingent returns, amplifying perceived benefits under high-risk scenarios while reducing expected profitability when risk exposure is moderate (Marra et al. 2003). The reduction in standard deviations after information provision, particularly in the pooled results, indicated more concentrated

Table 3. Distribution of respondents' socioeconomics characteristics: age, years of experience, education, percent income from raspberry/blueberry operation, and risk profile. Data were pooled by respondent role.

Variable/category	Pool (N = 40)	Owner and lessee (N = 5)	Manager (N = 8)	Chemical consultant (N = 11)	Marketer (N = 1)	Other (N = 11)	Blank (N = 4)
Age (years)							
<25	3 (7.5)[i]	0 (0.0)	1 (12.5)	0 (0.0)	0 (0.0)	1 (9.1)	1 (25.0)
25–34	12 (30.0)	1 (20.0)	5 (62.5)	1 (9.1)	0 (0.0)	3 (27.3)	2 (50.0)
35–44	7 (17.5)	1 (20.0)	0 (0.0)	2 (18.2)	0 (0.0)	3 (27.3)	1 (25.0)
45–54	7 (17.5)	2 (40.0)	0 (0.0)	4 (36.4)	0 (0.0)	1 (9.1)	0 (0.0)
55–64	5 (12.5)	0 (0.0)	2 (25.0)	3 (27.3)	0 (0.0)	0 (0.0)	0 (0.0)
65–74	3 (7.5)	0 (0.0)	0 (0.0)	0 (0.0)	1 (100.0)	2 (18.2)	0 (0.0)
≥75	1 (2.5)	1 (20.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)
Blank/NA	2 (5.0)	0 (0.0)	0 (0.0)	1 (9.1)	0 (0.0)	1 (9.1)	0 (0.0)
Weighted average age (years)	*41.1*	*44.5*	*32.7*	*48.9*	*69.5*	*42.8*	–
Experience (years)							
1–5	6 (15.0)	0 (0.0)	5 (62.5)	0 (0.0)	0 (0.0)	1 (9.1)	0 (0.0)
6–10	4 (10.0)	1 (20.0)	0 (0.0)	1 (9.1)	0 (0.0)	2 (18.2)	0 (0.0)
11–15	1 (2.5)	0 (0.0)	1 (12.5)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)
16–20	2 (5.0)	0 (0.0)	1 (12.5)	1 (9.1)	0 (0.0)	0 (0.0)	0 (0.0)
>20	5 (12.5)	2 (40.0)	0 (0.0)	4 (36.4)	0 (0.0)	1 (9.1)	0 (0.0)
Blank/NA	22 (55.0)	2 (40.0)	1 (12.5)	5 (45.5)	1 (100.0)	7 (63.6)	4 (100.0)
Weighted average experience (years)	*11.6*	*19.0*	*4.7*	*16.1*	–	*12.9*	–
Education							
High school	2 (5.0)	1 (20.0)	0 (0.0)	0 (0.0)	0 (0.0)	1 (9.1)	0 (0.0)
Associate	7 (17.5)	0 (0.0)	2 (25.0)	4 (36.4)	1 (100.0)	0 (0.0)	0 (0.0)
Bachelor	17 (42.5)	3 (60.0)	3 (37.5)	6 (54.5)	0 (0.0)	3 (27.3)	2 (50.0)
>Bachelor	6 (15.0)	1 (20.0)	1 (12.5)	1 (9.1)	0 (0.0)	3 (27.3)	0 (0.0)
Blank/NA	8 (20.0)	0 (0.0)	2 (25.0)	0 (0.0)	0 (0.0)	1 (9.1)	2 (50.0)
Percent of household income from farming							
1% to 24%	2 (5.0)	1 (20.0)	1 (12.5)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)
25% to 49%	2 (5.0)	1 (20.0)	0 (0.0)	1 (9.1)	0 (0.0)	0 (0.0)	0 (0.0)
75% to 100%	3 (7.5)	1 (20.0)	1 (12.5)	1 (9.1)	0 (0.0)	0 (0.0)	0 (0.0)
100%	5 (12.5)	1 (20.0)	3 (37.5)	0 (0.0)	0 (0.0)	1 (9.1)	0 (0.0)
Blank/NA	28 (70.0)	1 (20.0)	3 (37.5)	9 (81.8)	1 (100.0)	10 (90.9)	4 (100.0)
Weighted average (%)	*78.6*	*45.6*	*82.5*	*78.0*	–	*100.0*	–
Risk profile							
Risk-averse	24 (60.0)	1 (20.0)	2 (25.0)	9 (81.8)	1 (100.0)	8 (72.7)	3 (75.0)
Risk-neutral	10 (25.0)	2 (40.0)	2 (25.0)	2 (18.2)	0 (0.0)	3 (27.3)	1 (25.0)
Risk-loving	5 (12.5)	2 (40.0)	3 (37.5)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)
Blank/NA	1 (2.5)	0 (0.0)	1 (12.5)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)

[i] Values are the number of respondents; percentages are shown in parentheses.
NA = not applicable.

expectations and reduced uncertainty once respondents were exposed to concrete economic information (Fiechter et al. 2025; Inoue and Kawasaki 2026).

However, heterogeneity emerges across respondent roles. Owners and lessees reported relatively high expected profits before information provision, especially under both probability scenarios, but they revised expectations downward after receiving cost and return information. This adjustment is consistent with findings in the agricultural economics literature showing that producers often update optimistic priors once investment costs and operational constraints are made explicit. Managers exhibited a similar, but less pronounced, downward revision under the 50% probability scenario while maintaining relatively stable expectations under the 100% probability scenario.

Chemical consultants displayed comparatively moderate expected profits before information provision but revised expectations upward after receiving information, particularly under the 100% probability scenario. This suggested that consultants may initially underestimate the net returns of mitigation technologies and respond positively to formal cost–benefit information, reflecting their advisory role and exposure to technical performance data rather than direct capital costs. Marketer responses, while not generalizable because of the single observation, indicated consistently high expected profits across scenarios, potentially reflecting a downstream perspective that emphasizes supply stability and quality preservation during extreme heat events.

Respondents classified as "other" and those with unspecified roles exhibited intermediate expectations and notable reductions in variability after information provision, again pointing to the role of information in aligning perceptions of economic performance.

Table 4. Use of heat mitigation technologies, reasons for nonuse, investment intentions, and probability of investment in the next 5 years pooled and by respondent role.

Category	Pool (40)	Owner and lessee (5)	Manager (8)	Chemical consultant (11)	Marketer (1)	Other (11)	Blank (4)
Shade net							
Use (2024 or before): yes	2 (5.0)[i]	0 (0.0)	1 (12.5)	0 (0.0)	0 (0.0)	1 (9.1)	0 (0.0)
Use (2024 or before): no	19 (47.5)	5 (100.0)	5 (62.5)	3 (27.3)	1 (100.0)	4 (36.4)	1 (25.0)
Not applicable	15 (37.5)	0 (0.0)	1 (12.5)	6 (54.5)	0 (0.0)	6 (54.5)	2 (50.0)
Blank	4 (10.0)	0 (0.0)	1 (12.5)	2 (18.2)	0 (0.0)	0 (0.0)	1 (25.0)
Shade net: reasons for not using[ii]							
Too costly	1 (2.5)	0 (0.0)	0 (0.0)	1 (9.1)	0 (0.0)	0 (0.0)	0 (0.0)
Negative/unintended consequences	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)
Not worth benefits	3 (7.5)	1 (20.0)	1 (12.5)	1 (9.1)	0 (0.0)	0 (0.0)	0 (0.0)
Unlikely extreme heat	1 (2.5)	0 (0.0)	0 (0.0)	1 (9.1)	0 (0.0)	0 (0.0)	0 (0.0)
Operations difficult	25 (62.5)	5 (100.0)	5 (62.5)	7 (63.6)	1 (100.0)	6 (54.5)	1 (25.0)
Exit industry	2 (5.0)	0 (0.0)	0 (0.0)	2 (18.2)	0 (0.0)	0 (0.0)	0 (0.0)
Not applicable: I use shade nets	5 (12.5)	0 (0.0)	1 (12.5)	0 (0.0)	0 (0.0)	3 (27.3)	1 (25.0)
Probability of investing in the next 5 years (%)[iii]	17.0	17.5	20.0	12.8	55.0	16.0	11.7
Microsprinklers							
Use (2024 or before): yes	5 (12.5)	1 (20.0)	2 (25.0)	1 (9.1)	0 (0.0)	1 (9.1)	0 (0.0)
Use (2024 or before): no	14 (35.0)	2 (40.0)	3 (37.5)	3 (27.3)	1 (100.0)	4 (36.4)	1 (25.0)
Not applicable	14 (35.0)	1 (20.0)	2 (25.0)	5 (45.5)	0 (0.0)	4 (36.4)	2 (50.0)
Blank	7 (17.5)	1 (20.0)	1 (12.5)	2 (18.2)	0 (0.0)	2 (18.2)	1 (25.0)
Microsprinklers: reasons for not using							
Too costly	1 (2.5)	0 (0.0)	0 (0.0)	1 (9.1)	0 (0.0)	0 (0.0)	0 (0.0)
Negative/unintended consequences	14 (35.0)	2 (40.0)	3 (37.5)	4 (36.4)	1 (100.0)	3 (27.3)	1 (25.0)
Not worth benefits	2 (5.0)	0 (0.0)	0 (0.0)	2 (18.2)	0 (0.0)	0 (0.0)	0 (0.0)
Unlikely extreme heat	2 (5.0)	0 (0.0)	0 (0.0)	2 (18.2)	0 (0.0)	0 (0.0)	0 (0.0)
Access to water limitation	13 (32.5)	2 (40.0)	2 (25.0)	4 (36.4)	1 (100.0)	3 (27.3)	1 (25.0)
Exit industry	1 (2.5)	0 (0.0)	0 (0.0)	1 (9.1)	0 (0.0)	0 (0.0)	0 (0.0)
Not applicable: I use microsprinklers	4 (10.0)	1 (20.0)	2 (25.0)	0 (0.0)	0 (0.0)	1 (9.1)	0 (0.0)
Probability of investing in the next 5 years (%)	17.7	5.0	35.0	11.7	5.0	16.0	20.0
Biostimulants							
Use (2024 or before): yes	14 (35.0)	2 (40.0)	3 (37.5)	5 (45.5)	1 (100.0)	3 (27.3)	0 (0.0)
Use (2024 or before): no	7 (17.5)	1 (20.0)	1 (12.5)	2 (18.2)	0 (0.0)	2 (18.2)	1 (25.0)
Not applicable	12 (30.0)	1 (20.0)	2 (25.0)	3 (27.3)	0 (0.0)	4 (36.4)	2 (50.0)
Blank	7 (17.5)	1 (20.0)	2 (25.0)	1 (9.1)	0 (0.0)	2 (18.2)	1 (25.0)
Biostimulants: reasons for not using							
Too costly	11 (27.5)	1 (20.0)	2 (25.0)	4 (36.4)	0 (0.0)	3 (27.3)	1 (25.0)
Negative/unintended consequences	1 (2.5)	0 (0.0)	0 (0.0)	1 (9.1)	0 (0.0)	0 (0.0)	0 (0.0)
Unproven benefits	5 (12.5)	1 (20.0)	1 (12.5)	1 (9.1)	0 (0.0)	2 (18.2)	0 (0.0)
Not worth benefits	4 (10.0)	0 (0.0)	1 (12.5)	1 (9.1)	0 (0.0)	2 (18.2)	0 (0.0)
Unlikely extreme heat	2 (5.0)	0 (0.0)	0 (0.0)	1 (9.1)	0 (0.0)	1 (9.1)	0 (0.0)
Exit industry	1 (2.5)	0 (0.0)	0 (0.0)	1 (9.1)	0 (0.0)	0 (0.0)	0 (0.0)
Not applicable: I use biostimulants	12 (30.0)	2 (40.0)	3 (37.5)	4 (36.4)	1 (100.0)	2 (18.2)	0 (0.0)
Probability of investing in the next 5 years (%)	49.7	39.0	50.0	72.5	45.0	37.7	51.7

[i] Values are numbers with percentages in parentheses calculated using the full column denominator (role-specific N).
[ii] Reasons for nonuse had multiple responses; therefore, percentages do not sum to 100%.
[iii] Probabilities of investing in the next 5 years are weighted averages (%) computed using midpoint values of reported probability intervals (5, 15, …, 95) and exclude "not applicable" and blank responses.

Summary and conclusions

This study provides a descriptive assessment of caneberry and blueberry industry participants' perceptions, experiences, and expectations regarding heat mitigation technologies in the Pacific Northwest and British Columbia. Using data collected through a multimodal survey administered at an industry conference and via an online instrument, the analysis documented the following: current use of shade nets, overhead microsprinklers, and biostimulants; perceived barriers to adoption; stated investment intentions; risk profiles; and expected profitability under alternative heat event scenarios. The Results are presented as summary statistics disaggregated by respondent role, reflecting heterogeneous decision environments across the small fruit value chain.

A central limitation of the analysis was the small sample size, which constrained both statistical power and external validity. While respondents spanned diverse professional roles, geographic locations across the PCN, and small fruit systems (blueberries, raspberries, mix of berries), the limited

Table 5. Mean and standard deviation of the expected net returns from heat stress mitigation technologies before and after information on costs and benefits assuming 100% and 50% probabilities of a heat event pooled and by respondent role.

Variable	Pooled (N = 40)	Owner and lessee (N = 5)	Manager (N = 8)	Chemical consultant (N = 11)	Marketer (N = 1)	Other (N = 11)	Blank (N = 4)
Profit (100% probability of a heat event)	2,562[i] (1,055)[ii]	3,480 (1,963)	2,625 (446)	2,250 (769)	4,200 (–)	2,291 (922)	2,250 (755)
Profit (50% probability of a heat event)	2,147 (1,268)	3,360 (1,926)	1,650 (769)	2,040 (1,173)	4,200 (–)	1,800 (1,058)	2,250 (1,025)
After information: profit (100% probability of a heat event)	2,846 (865)	2,280 (1,553)	2,850 (621)	2,775 (311)	3,000 (–)	2,940 (957)	3,600 (600)
After information: profit (50% probability of a heat event)	1,749 (802)	1,320 (657)	1,725 (501)	1,680 (738)	4,200 (–)	1,575 (550)	2,400 (1,200)

[i] Mean in $/acre. $/ha = $/acre ÷ 0.404686.
[ii] Standard deviations appear in between parenthesis.

number of observations restricted the ability to capture the full distribution of producer heterogeneity. Consequently, the findings should be interpreted as exploratory and indicative of emerging patterns rather than representative of the broader industry. They provide a useful basis for hypothesis generation and informing the design of larger, more representative surveys that can support causal inference and policy-relevant generalizations.

Overall, the adoption of shade nets and microsprinklers for heat mitigation was limited, with nonuse largely attributed to operational and resource constraints rather than disbelief in climate risk. In contrast, biostimulants exhibited higher reported use and stronger near-term investment interest, consistent with their lower capital requirements and greater management flexibility. Information about technology costs and returns influenced expected profit perceptions, thus reducing uncertainty and prompting role-specific revisions in expectations, particularly among producers and consultants.

The findings indicate that heat mitigation decisions in perennial small fruit systems are shaped less by awareness of climate risk and more by feasibility constraints, including infrastructure requirements, water access, and operational complexity. Structural investments such as shade nets and overhead microsprinklers face substantial barriers to adoption. Conversely, input-based technologies such as biostimulants appear more compatible with existing production systems and decision timelines, resulting in higher adoption and investment interest.

The respondent role plays a central role in shaping perceptions and expectations. Producers' responses reflect direct exposure to capital, labor, and regulatory constraints, whereas advisory roles tend to place greater weight on technical performance and flexibility aspects. Information provision narrowed dispersion in expected profitability across roles, suggesting that transparent cost–benefit information can align expectations but does not necessarily overcome structural barriers to adoption. Because of the limited sample size, the results should be interpreted as a snapshot of current industry perceptions rather than evidence of causal relationships.

These results have several implications for climate adaptation efforts in caneberry and blueberry systems. First, extension programming may be more effective when it differentiates between technologies constrained by physical and regulatory conditions and those that can be adopted incrementally. Emphasizing flexible, low-commitment options may yield higher short-term adoption, while longer-term strategies for structural technologies may require coordinated solutions addressing water availability, infrastructure costs, and operational design. Second, the observed role-specific heterogeneity highlights the value of targeted communication strategies. Producers, managers, and advisors respond differently to economic information, suggesting that extension materials should be tailored to decision authority, risk exposure, and investment capacity.

Finally, the study established baseline descriptive evidence regarding perceptions and investment intentions that can inform future research. As extreme heat events become more frequent, longitudinal data and larger samples will be necessary to evaluate how expectations, adoption behavior, and profitability evolve over time. Integrating an economic analysis with field-level performance data will be critical for identifying cost-effective and scalable adaptation pathways for perennial specialty crop industries.

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