frontiers | Frontiers in Sustainable Food Systems

TYPE Original Research
PUBLISHED 14 June 2024
DOI 10.3389/fsufs.2024.1395547

Check for updates

OPEN ACCESS

EDITED BY
Sruthi Narayanan,
Clemson University, United States

REVIEWED BY
Yefan Nian,
Clemson University, United States
Meghnaa Tallapragada,
Temple University, United States

*CORRESPONDENCE
Tapan B. Pathak
tpathak@ucmerced.edu

RECEIVED 04 March 2024
ACCEPTED 24 May 2024
PUBLISHED 14 June 2024

CITATION
Ikendi S, Pinzón N, Koundinya V, Taku-Forchu N, Roche LM, Ostoja SM, Parker LE, Zaccaria D, Cooper MH, Diaz-Ramirez JN, Brodt S, Battany M, Rijal JP and Pathak TB (2024) Climate smart agriculture: assessing needs and perceptions of California's farmers.
Front. Sustain. Food Syst. 8:1395547.
doi: 10.3389/fsufs.2024.1395547

Climate smart agriculture: assessing needs and perceptions of California's farmers

Samuel Ikendi[1,2], Natalia Pinzón[3,4], Vikram Koundinya[1,3], Namah Taku-Forchu[5], Leslie M. Roche[1,6], Steven M. Ostoja[7], Lauren E. Parker[7,8], Daniele Zaccaria[1,9], Mark H. Cooper[3,4], Jairo N. Diaz-Ramirez[1,10], Sonja Brodt[1,11], Mark Battany[1,12], Jhalendra P. Rijal[1,13] and Tapan B. Pathak[1,14]*

[1]University of California Agriculture and Natural Resources, Davis, CA, United States, [2]University of California, Merced, Merced, CA, United States, [3]Department of Human Ecology, University of California, Davis, Davis, CA, United States, [4]Department of Animal Science, University of California, Davis, Davis, CA, United States, [5]Natural Resources Institute, Division of Extension, University of Wisconsin Natural Resources Institute, Madison, WI, United States, [6]Department of Plant Sciences, University of California, Davis, Davis, CA, United States, [7]United States Department of Agriculture California Climate Hub, Davis, CA, United States, [8]Institute of the Environment, University of California, Davis, Davis, CA, United States, [9]Department of Land, Air and Water Resources, University of California, Davis, Davis, CA, United States, [10]University of California: Desert Research and Extension Center, Holtville, CA, United States, [11]University of California Sustainable Agriculture Research and Education Program, Davis, CA, United States, [12]University of California San Luis Obispo County Extension, San Luis Obispo, CA, United States, [13]University of California Integrated Pest Management Statewide Program, Davis, CA, United States, [14]Department of Civil and Environmental Engineering, University of California, Merced, Merced, CA, United States

California is the largest agricultural economy in the United States; however, its current and projected climate risks pose significant challenges. Farmers will need to adapt to climate change in their farming practices. The goal of this needs assessment was to understand farmers' perceptions and experiences with climate change exposures; the risk management practices they currently use; and what tools and resources would assist them in making strategic decisions. A statewide survey was conducted through Qualtrics with farmers ($n = 341$). Results showed that 67% of the farmers *agree (agree + strongly agree)* that climate change is happening, and 53.1% agreed that actions are required. Moreover, historically underrepresented farmers were *very concerned* about climate change-related impacts related to water, temperatures, and natural disasters. Farmers are currently *implementing* adaptation practices related to water management, soil health, and renewable energy and are also seeking insurance and government assistance programs to increase agricultural resilience. They also expressed *interest* and a *high need* for information on those adaptation practices to acquire skills and knowledge to manage various challenges of farming in variable climates. Also, the assessment established that farmers (47.5%) use decision-support tools, mostly weather stations (22.4%); and 51.9% indicated their interest in using online tools designed to translate climate information into forms that support production decision-making. Farmers (60.8%) responded that they would or may attend workshops to learn about adaptation practices. The findings of this needs assessment will inform the development of extension education programs on climate-smart agriculture for farmers in California and elsewhere.

KEYWORDS

needs assessment, extension program development, climate adaptation, climate change, climate-smart agriculture, decision support tools, California farmers

1 Introduction

California is the largest agricultural economy in the United States with a farmgate revenue exceeding $51 billion from farms, ranches, and plant nurseries (California Department of Food Agriculture, 2022). California produces more than 400 commodities including more than 40 specialty crops due to its favorable Mediterranean and unique regional microclimatic zones (Pathak et al., 2018; Rance, 2023). Additionally, more than one-third of vegetables and two–thirds of fruits and nuts in the U.S. are produced in California; 19 of which are not produced anywhere else in the country, including nuts—almonds, walnuts, pistachios; vegetables—artichokes, celery, garlic; dried fruits—prunes, raisins; canned fruits—olives, cling peaches; fresh fruits—nectarines, kiwi, pomegranates, honeydew, figs, plums, table grapes; sweet rice; and lima beans.

However, the current and projected climate change in California (Luedeling et al., 2009; Pathak et al., 2018) poses significant challenges to its agricultural sector due to multiple phenomena that include increased heat waves, temperatures, droughts, wildfires, floods, and variable precipitation. These changes are directly and indirectly impacting agriculture such as declining yield, increases in weed, insect pests, and disease pressures (Matzrafi, 2018; Pathak et al., 2018; Swain et al., 2018; Rijal et al., 2021; Skendžić et al., 2021; Jha et al., 2024), phenology shifts (Pathak and Stoddard, 2018), and declining chill (Luedeling et al., 2009; Zhang et al., 2021). Given the scale of production, such conditions provide a glimpse of a volatile future, which requires multifaceted approaches to address these challenges. Climate-smart agriculture (CSA) is one of the approaches that provides an opportunity to alleviate some of the risks associated with climate change in California (Lewis and Rudnick, 2019). The Food and Agriculture Organization (FAO) describes CSA as an integrated approach that guides actions to transform agrifood systems toward climate-resilient practices, reducing farmer stress from climate impacts [Food and Agriculture Organization of the United Nations (FAO), 2021].

The CSA approach holds particular importance in California, especially for beginning farmers, farmers with limited resources, and socially disadvantaged farmers who may lack access to technical assistance and often have fewer resources for adapting to climate change (Munden-Dixon et al., 2018; Taku-Forchu et al., 2023; Ikendi et al., 2024). These farmers are adversely affected by climate impacts, for instance, the 2012–2016 drought—the worst in 1,200 years (Griffin and Anchukaitis, 2014) greatly impacted the rural communities in the San Joaquin Valley (Howitt et al., 2014; Jasechko and Perrone, 2020). Large-scale farmers also faced challenges, exemplified by abnormally warm winter and spring temperatures in 2015 that resulted in more than $240 million in combined crop indemnity payments to major nut tree and fruit growers (Reyes and Elias, 2019; Parker et al., 2020).

Adaptation to climate change will be crucial in California and farmers will have an increased need for locally relevant and crop-specific information (Jagannathan et al., 2023). Similarly, technical service providers (TSPs) from agencies, extension, private crop consulting, and other boundary-spanning organizations also will be faced with climate change questions from farmers, yet they often lack locally relevant adaptation and mitigation resources to help farmers implement decisions (Grantham et al., 2017; Johnson et al., 2023; Parker et al., 2023). To address the climate and agriculture science knowledge gap in California, a transdisciplinary team of researchers and educators from the University of California designed a multifaceted climate-smart agriculture education project (Figure 1).

The objective of this study was to assess farmers' perspectives, experience, and knowledge on climate change exposures, potential impacts, vulnerabilities and needs for tools, resources, and extension programs, including needs for field demonstration studies for implementing climate-smart agriculture practices. There have been several studies on farmers' needs assessment in California published in the literature (for instance, Jackson et al., 2011; California Department of Food Agriculture, 2013; Surls et al., 2015; Jasperse and Pairis, 2020; Kanter et al., 2021) but to the best of our knowledge, there has been no study published in the literature that is focused on farmers with such diverse cropping systems and their scales of operations. Information from this study will benefit the agricultural community in California and also provide valuable insights to agricultural communities worldwide with similar scales of operations.

2 Methodology

2.1 Research design

This study was part of a statewide survey that adopted an electronic mail communication system through Qualtrics. A participatory and culturally responsive framework was adopted in the design of the survey instrument, taking advantage of the diverse expertise of the research team in climate and agricultural sciences, social sciences, and extension program development and evaluation (Koundinya et al., 2023). The survey was designed according to the guidelines of Dillman et al. (2014) Tailored Design Method (TDM) which emphasizes focusing the questions on the study objectives, systematic design of survey instrument blocks, and effective communication during the survey implementation processes to induce desired social exchange with respondents The survey consisted of seven blocks/sections with 27 questions (Table 1) blended in multiple choices, Likert-type scales, and open-ended capturing an array of information from farmers.

The researchers of this study ensured content validity by exhausting all possible dimensions of the study objectives blended in 27 questions. Face validity was ensured by looking at the questions multiple times and discussing opinions through weekly meetings. Modifications were made including improving the question formatting and reducing the number of questions. The survey instrument was also pilot tested with 18 stakeholders and feedback was incorporated into the final survey.

2.2 Data collection

Following the TDM, the main survey was distributed on February 28, 2023, through Qualtrics using 12,933 emails

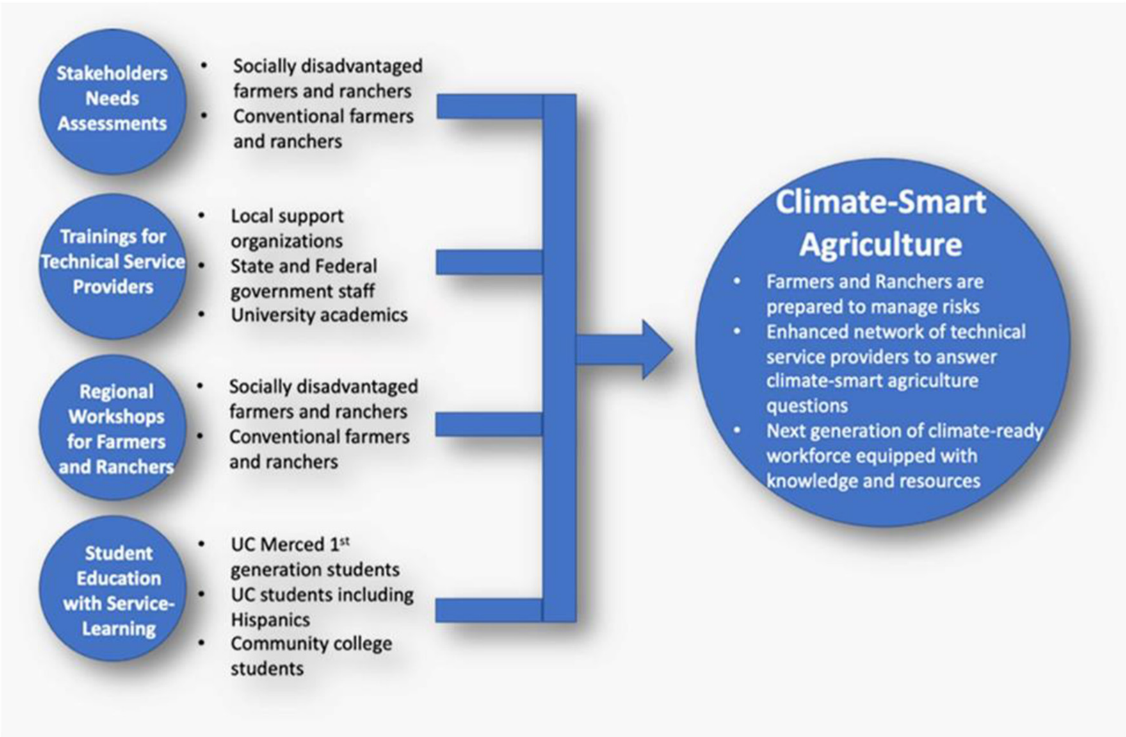

FIGURE 1
Multifaceted pathways to climate-smart agriculture educational project concept in California.

TABLE 1 Composition of the farmers' climate adaptation needs assessment instrument.

Blocks	Questions	Information collected
1	4	Characteristics include land access and use, major crops produced and their relative revenues, and zip codes to determine spatial locations
2	5	Concerns and perspectives of farmers about impacts related to climate on farm operations
3	2	Thoughts on climate adaptation practices farmers are currently implementing or interested in, and nature of information need for practice adoption. And the preferred method(s) to receive information on adaptation practices
4	2	Perceptions of barriers to climate adaptation practices and whether farmers might participate in workshops
5	6	Use of Decision Support Tools that aid decision-making by translating climate and weather information into usable information for farmers
6	2	Farmer climate change perspectives and beliefs
7	6	Farmer demographics including years farming since age 18, gender, age, race/ethnicity, category of farmers–first generation, multigeneration, socially disadvantaged, and/or limited resource farmers

(including both farmers and ranchers) bought from Farm MarketID in California. Recipients (798) started their survey, and five reminders were sent. Overall, 610 recipients completed the survey and 310 were confirmed as farmers after sorting and cleaning the data that of possible AI-generated responses and human fraudulent responses using 31 fraud detection strategies generated by investigators (Pinzón et al., 2023). Additionally, we leveraged the networks of Extension associations in California to distribute the survey using QR codes and anonymous links. Additional cleaned responses from QR (22) and anonymous links (09) were added to the 310 email responses, giving a final total of 341 respondents. Figure 2 provides a distribution of farmers who provided zip codes.

After establishing reliability through a pilot test, it was further determined using Cronbach's alpha (Drost, 2011) on the Likert-scale responses. The extent of concern about climate-related impacts had 15 Likert items; alpha was 0.923. Interest in adaptation practices had 34 Likert items; alpha was 0.899. Need for information on adaptation practices also had 34 Likert items; alpha was 0.949. Perception of barriers to implementing adaptation practices had 23 Likert items; alpha was 0.915. All alpha coefficients were above 0.70, indicating high consistency (McNeish, 2018).

2.3 Data analysis

Data were analyzed using SPSS and presented as measures of dispersions and variability. Also, a chi-square test was employed to

10.3389/fsufs.2024.1395547

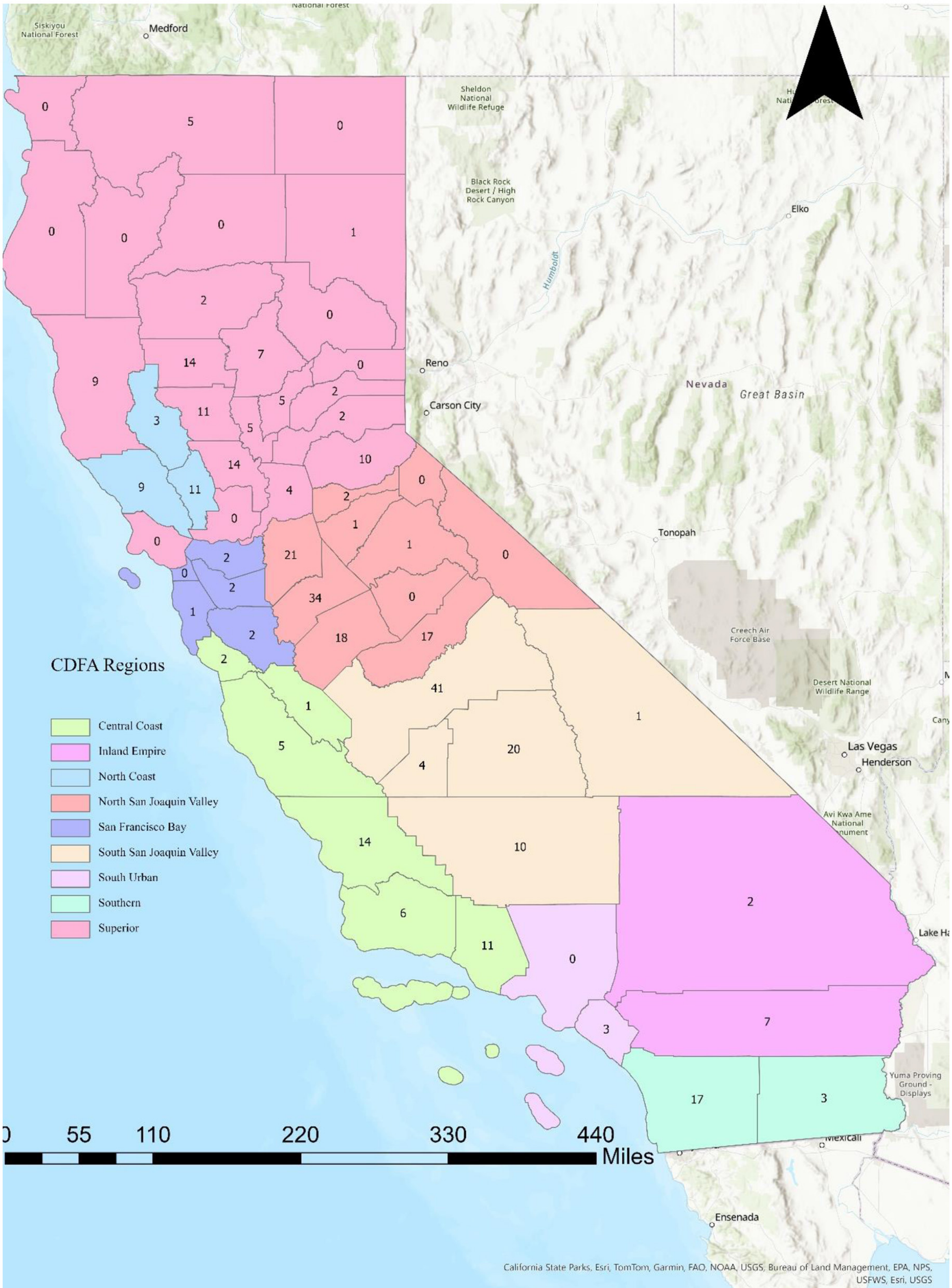

FIGURE 2
Responses by counties and region for farmers who provided California zip codes. Some farmers provided multiple zip codes depending on the location of their farms.

determine the associations between perception variables (concerns, interest, implementation, needs, and barriers to adaptation) and farmer structure and background variables (regions, crops, ethnicity/race, gender, and ethnoracial background). Chi-square tests were also done for crops/regions. The study considered a significance level of $\leq$0.05.

3 Results

3.1 Farmers sociodemographic characteristics

Farmers differed in their demographic characteristics (Figure 3). Of the 294 farmers who responded to the gender question, 82.0% were male, and 16.3% were female. In comparison, California producers as a whole are 62% male and 38% female [United States Department of Agriculture (USDA) – National Agricultural Statistics Service, 2024], in this, our sample underrepresents female farmers. Most of the farmers identified as white (75.5%; $n = 277$), similarly, 80% of California producers identify as white (USDA 2024). Our study identified 52.3%; ($n = 279$) were multigenerational farmers, but these were not available in the agriculture census for comparison. The average age was 60 ± 13.340 years ($n = 277$), with a minimum of 22 years and a maximum of 87 years. Most farmers had farmed for more than 20 years (65.2%; $n = 293$) since age 18, this reflects California producers where the majority (70%) have been farming for more than 11 years (USDA 2024).

3.2 Land tenure types

A total of 330 farmers responded and made use of multiple land tenure types including private land, privately leased, public leased, and/or were hired to manage farms. The majority (71%) used one tenure system; 23.6% used two systems; 5.2% used three and 0.3% used all four systems. Most farmers, 311 (94.2%), farmed on private land, with an average of 341.1 ± 769.745, and a median of 72.0 with a maximum of 6,000 acres. Ninety-two farmers (27.9%) leased land, with an average of 613.2 ± 1,030.633, a median of 200.0 with a maximum of 5,000 acres. Hired farmers 39 (11.8%) managed an average of 6,265.2 ± 31,897.513, and a median of 400.0 with a maximum of 200,000 acres. Only two farmers (0.6%) on publicly leased land for an average of 1,850.0 ± 2,474.874, and a median of 1,850.0 with a maximum of 3,600 acres.

3.3 Crop production profile

The majority (35.5%, $n = 293$) indicated that 76%−100% of their income comes from farming, followed by 29.7% reporting up to 25%, 18.8% reporting 26%−50%, and the smallest percentage (16.0%) indicating 51%−75%. Of the 340 farmers who responded to specific crops produced, the majority participated in the production of fruits (51.2%) and nut trees (44.1%; Figure 4). Relatedly, among farmers ($n = 329$), the majority reported that fruit (37.6%) and nut tree (31.8%) production contributed more than 50% of their annual income.

Chi-square tests revealed statistically significant associations among geographic regions and crops grown. Nut production was associated ($p =< 0.001$) with farmers in the Northern (77.3%) and Southern (55.2%) San Joaquin Valley regions. Fruit production was associated in a statistically significant manner ($p =< 0.001$) with farmers in the North Coast (86.2%), Central Coast (84.2%), San Francisco Bay (83.3%), Southern (73.7%), and the South Urban (66.7%) regions. Production of grains and pulses was associated ($p =< 0.001$) with farmers in the Superior (32.0%) while vegetable production in the South Urban (33.3%) regions. The study also found that first-generation farmers (64.3%) were associated with fruit production ($p = 0.003$) whereas multigenerational farmers (50.3%) with nut production ($p = 0.005$).

3.4 Climate change-related impacts and perceptions

Farmers held varying perceptions regarding climate change and related impacts (Figure 5). Up to 67% *agree (agree+strongly)* that climate change is happening and requires action (53.1%). Also, farmers, 66.8% *agree (agree+strongly)* that climate change is due to natural causes, while 55.7% *agree (agree+strongly)* that climate change is due to human causes. The majority *agree (agree+strongly*; 69.8%) that they are interested in learning more about the impacts of climate change on the agricultural industry. Relatedly, most farmers (59.0%, $n = 339$) expressed that they experienced greater climate change on their farms today than 10 years ago. Similarly, about one-third indicated that the impacts have been *moderate* (31.3%) whereas 27.7% (*slight impact*) 17.1% (*great impact*), 17.1 (*no impact*), and 6.8% experienced a *severe impact* in the last 10 years.

3.5 Concerns about climate change-related impacts

The concerns were categorized into three categories: water, temperature, and disaster-related concerns (Table 2). Farmers were *very concerned* about water-related issues, especially increased uncertainty in water availability for irrigation (58.2%), reduced water availability for irrigation (54.7%), and reduced groundwater availability (51.3%). For temperature, farmers were *very concerned* about increased drought severity (37.4%) and crop damage due to extreme heat (26.5%) while among disasters, farmers were *very concerned* about increased crop loss (23.0%) and farm loss (19.8%).

In a chi-square tabulation of farmers by ethnoracial background, specifically with water-related concerns, the proportions that were very concerned (36% underrepresented vs. 27.9% others) were significantly different ($p = 0.067$). So, there was a significant association between ethnoracial background and concern for water, with more underrepresented farmers being more concerned. Similarly, underrepresented farmers were

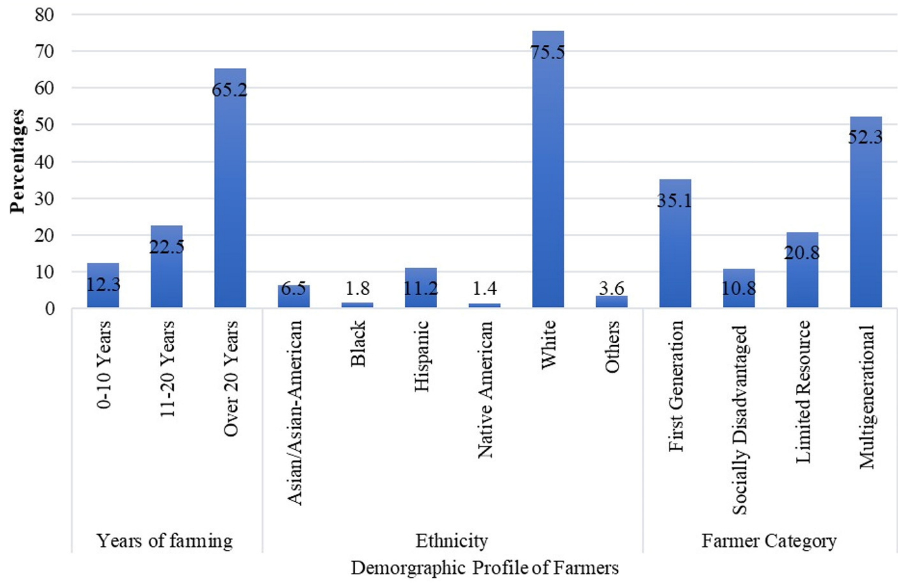

FIGURE 3
Demographic profile of farmers. A socially disadvantaged farmer was defined as a farmer who has been subjected to racial or ethnic prejudices because of their identity as a member of a group without regard to their individual qualities (United States Department of Agriculture – Natural Resources Conservation Service, 2018).

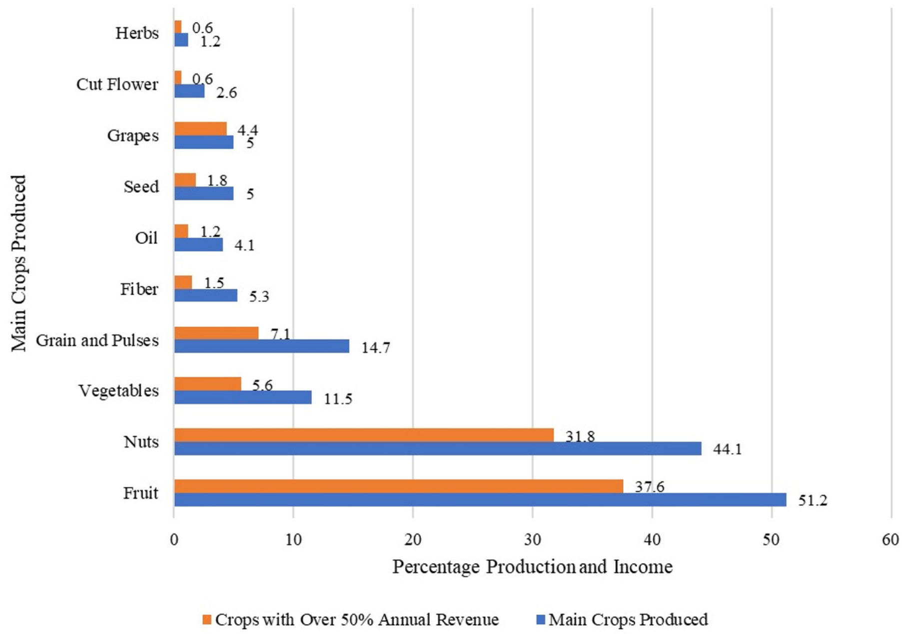

FIGURE 4
Main crops produced and corresponding annual revenue.

17.3% more likely to be *very concerned* with temperature-related issues than 7.4% of other farmers ($p = 0.076$); likewise, 14.7% of underrepresented farmers expressed significant concerns about disasters than 4.9% of other farmers ($p = 0.021$).

We also identified statistically significant differences in primary concerns between farming regions. Farmers in South San Joaquin Valley (71.6%), Central Coast (64.1%), and the Inland Empire (60.0%) were very concerned about reduced groundwater availability ($p = 0.005$). Increased drought severity was a very significant concern ($p = 0.035$) with farmers in the Inland Empire (80.0%), Central Coast (53.8%), and Southern (52.6%) regions. Farmers in the North Coast (39.3%) and Southern

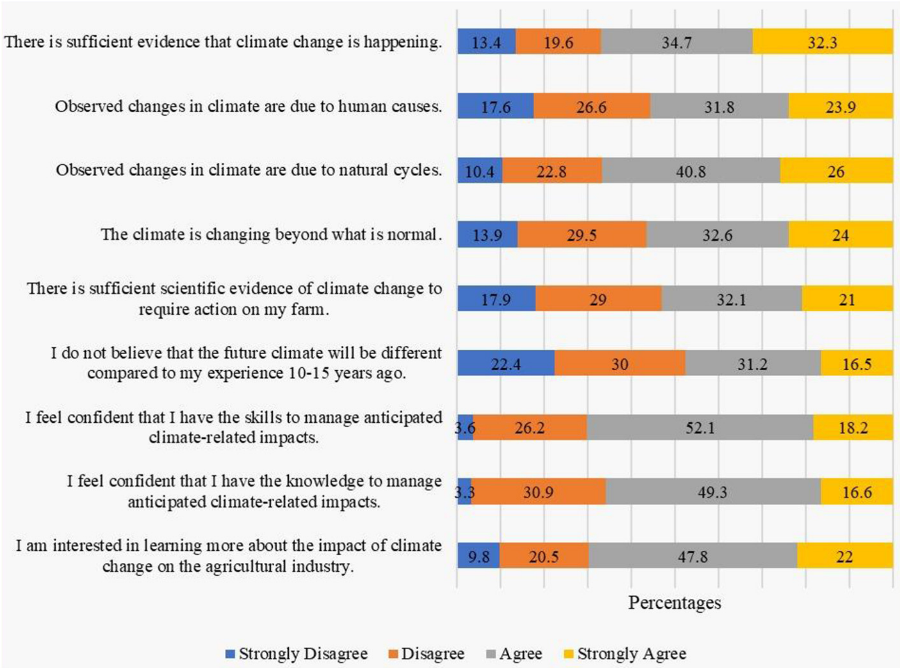

FIGURE 5
Perceptions of farmers about climate change-related impacts on their farms.

(36.8%) were very concerned with increased crop damage due to wildfires ($p = <0.001$).

We also found statistically significant differences in primary concerns among different types of farming operations. Vegetable farmers significantly ($p = 0.044$) expressed more concerns about uncertainty in water availability for irrigation (74.4% *very concerned*). Fruit farmers significantly expressed more concerns regarding increased crop/water stress (38.5% very concerned; $p =< 0.001$), and increased crop damage due to extreme heat (32.8%; $p =< 0.001$). Grains and pulse farmers stood out significantly ($p = 0.022$) in terms of concerns with reduced groundwater availability (59.2%).

3.6 Implementation, interest, and need for information on climate adaptation practices

The top adaptation practices (Table 3) farmers were implementing included changes in irrigation practices (54.0%), reducing soil disturbance/no-till (47.9%), building soil organic matter/applying manure/compost (46.9%), using cover crops (39.3%), and mulching (39.3%). Mostly, farmers expressed interest in water harvesting (54.5%), transition to renewable energy (48.7%), drought-tolerant varieties (48.5%), reducing dependence on fossil fuels (48.1%), and applying for government assistance (45.8%). The highest information needs were securing access to insurance (21.6%), applying for government assistance (20.6%), transitioning to renewable energy (20.4%), building soil organic matter (19.7%), and water harvesting (19.4%).

3.6.1 Adaptation practices by regions

Seven of the 34 adaptation practices presented in the survey showed statistically significant differences by regions with *implementation:* agroforestry, diversification, cover crops, new crops, fuel load management, windbreaks, and increasing acreage. The use of cover crops was mostly implemented by farmers in the North Coast (66.7%) and Central Coast (51.4%; $p = 0.022$). Farmers significantly implemented agroforestry in South Urban (50.0%; $p = 0.035$) and diversifying production (50.0%; $p = 0.009$). Switching to new crops was significantly ($p = 0.059$) implemented by farmers in Southern (26.3%); and fuel load management in San Francisco Bay (33.3%; $p = 0.033$). Farmers implemented wind breaks significantly in San Francisco Bay (33.3%; $p = 0.001$) and increase acreage in the Inland Empire (40.0%; $p = 0.082$).

As it relates to expressing *interest*, seven adaptation practices showed significant differences by region. Farmers in Superior (40.0%), North San Joaquin Valley (38.2%), Southern (36.8%), and South San Joaquin Valley (36.7%) significantly ($p = 0.009$) expressed interest in diversifying production. The interest in the use of cover crops was significant ($p = 0.022$) in Southern (47.4%), South San Joaquin Valley (44.4%), and Inland Empire (40.0%). Farmers in the Inland Empire expressed significant interest ($p = 0.001$) in adding windbreaks (80.0%) and similarly, agroforestry in the Inland Empire (60.0%), South Urban (50.0%), and North Coast (37.5%; $p = 0.035$); while switching to new crops was significantly ($p = 0.059$) expressed by farmers in South Urban (50.0%) and Superior (40.0%) regions.

TABLE 2 Extent of concern about climate change-related impacts on the future of farmers' operations.

Climate change-related impacts	*n*	Percentage extent of concern			
		Not at all	Somewhat	Concerned	Very
Water-related concerns					
Increased uncertainty in water availability for irrigation	340	8.2	12.6	20.9	58.2
Reduced water availability for irrigation	340	8.8	14.4	22.1	54.7
Reduced groundwater availability	339	11.2	13.9	23.6	51.3
Increased crop/water stress	340	13.5	20.3	30.0	36.2
Increased salinization	338	40.2	26.6	23.7	9.5
Temperature-related concerns					
Increased drought severity	340	12.6	24.1	25.9	37.4
Increased crop damage due to extreme heat	340	18.2	31.2	24.1	26.5
Increased frost damage	339	24.8	37.5	23.6	14.2
Increased pest and disease pressure	336	19.6	36.3	31.8	12.2
Reduced chill accumulations	334	29.9	37.4	23.1	9.6
Disaster-related concerns					
Increased crop loss due to climate-related disaster	339	16.8	30.4	29.8	23.0
Increased farm loss due to climate-related disaster	337	19.3	32.0	28.8	19.8
Increased crop damage due to wildfire/smoke	337	38.3	30.9	16.3	14.5
Increased wildfires severity	337	30.3	35.3	21.1	13.4
Increased flooding	337	38.3	36.2	16.0	9.5

3.6.2 Adaptation practices by farmer demographics

The study found statistically significant differences in *implementation, interest, and need for information* on adaptation practices among different ethnoracial backgrounds. First-generation farmers significantly *implemented* reducing dependence on fossil fuels (14.6%; p = 0.083) and switching to low-chill varieties (11.6%; p = 0.008) compared to other farmers. Similarly, they significantly expressed a *high need* for information about securing access to insurance (32.3%; p = 0.004), changing irrigation practices (24.0%; p = 0.081), and earning off-farm income (18.3%; p = 0.075). In contrast, multigenerational farmers significantly *implemented* altering labor schedules (39.6%; p = 0.031), reduced reliance on groundwater (37.9%; p = 0.036), reduced input use (25.7%; p = 0.017), and rotating crops (23.0%; p = 0.009). Similarly, they significantly expressed *interest* in switching to low-chill varieties (38.8%; p = 0.035) and rotating crops (25.9%; p = 0.009) compared to other farmers.

There was a statistically significant difference in the way limited resource farmers *implemented* earning off-farm income (22.8%; p = 0.009) and changed their market strategy (19.6%; p = 0.005). Similarly, they significantly expressed a *high need* for information with applying for government assistance (42.6%; p =< 0.001), transitioning to renewable energy (36.4%; p = 0.013), securing access to insurance (27.8%; p = 0.005), earning off-farm income (27.3%; p = 0.002), and changing market strategy (21.2%; p = 0.046). Socially disadvantaged farmers statistically significantly *implemented* applying for government assistance (34.5%; p = 0.024). These farmers significantly expressed a *high need* for information with applying for government assistance (55.2%; p =< 0.001), securing access to insurance (48.3%; p = 0.001), transitioning to renewable energy (44.8%; p = 0.006), and reducing dependency on fossil fuels (37.9%; p = 0.005) compared to other farmers.

3.7 Extension education and outreach

Most farmers preferred emails (67.7% n = 294; Table 4); 41.3% (n = 298) indicated that they would attend workshops on adaptation practices and programs if organized, while 39.3% said no, and 19.5 responded 'maybe'.

3.8 Barriers to climate adaptation

In this study, 23 obstacles were presented (Figure 6), of which government regulations (53.1%), high input cost (46.9%), labor access/cost (35.2%), access to water (33.5%), and access to investment capital/funds (32.4%) were the most "*significant barriers*" to adaptation.

TABLE 3 The top 10 climate adaptation practices farmers are currently implementing, interested in, and in need for information.

Climate-smart adaptation practices	Interest and implementation (%)			Need for information (%)		
	Not interested	Interested	Currently implementing	No need	Some need	High need
Secure access to insurance	29.2	45.7	25.1	44.3	34	21.6
Apply for government assistance	33	45.8	21.2	39	40.4	20.6
Transition to renewable energy for farm use	21.7	48.7	29.7	37.2	42.5	20.4
Build soil organic matter	17.8	35.3	46.9	38	42.3	19.7
Water harvesting	34.7	54.5	10.9	39.1	41.5	19.4
Change irrigation practices	18.4	27.6	54	42.3	41	16.7
Reduce dependency on fossil fuels	41.3	48.1	10.6	45.8	38.5	15.7
Use of cover crops	26.9	33.8	39.3	47.7	37.1	15.2
Reduce reliance on groundwater	29.1	38.3	32.6	41.4	44.1	14.5
Use of drought-tolerant varieties	30.3	48.5	21.2	49.5	37.1	13.4
Change market strategy	41.8	42.9	15.3	50.9	36.2	12.9
Mulching	24.4	36.4	39.3	47.5	39.9	12.6
Reduce soil disturbance	24.4	27.7	47.9	51.5	36.2	12.3
Reduce input use	34.6	45.5	19.9	46.5	41.8	11.7
Alter labor schedules to cope with heat	34.1	34.1	31.8	58.6	31.9	9.5
Transition to perennial plants	57.6	13.8	28.6	75.3	20.1	4.7

Most adaptation practices and programs were among the top 10 that are currently being implemented, interested, and in need of information. Supplementary Table S1 provides complete details of all 34 adaptation practices and programs traced in this study.

3.8.1 Significant barriers by regions

Access to locally adapted decision support tools (DSTs) was a *significant barrier* ($p =< 0.001$) to farmers in the Inland Empire (80.0%), and South Urban (50%). Similarly, farmers in the Inland Empire (40.0%), San Francisco Bay (33.3%), North San Joaquin Valley (26.0%), and Southern (23.5%) perceived access to detailed economic information (cost/benefit analysis) as a significant barrier ($p = 0.058$). The risk of implementing new practices was a significant barrier ($p = 0.040$) perceived by farmers in San Francisco Bay (50.0%), Superior (31.1%), Southern (29.4%), and Southern San Joaquin Valley (28.6%).

3.8.2 Significant barriers by farmers' profile

First-generation farmers perceived labor access/cost (44.2% *significant barrier*; $p = 0.028$), access to water (38.5%; $p = 0.092$), and access to appropriate insurance (30.1%; $p = 0.098$). Multigenerational farmers perceived access to locally adapted DSTs (10.8%) as a *significant barrier* ($p = 0.041$) whereas socially disadvantaged farmers perceived access to appropriate equipment to implement climate adaptation practices (33.3%; $p = 0.067$), land ownership (33.3%; $p = 0.005$), and access to locally adapted monitoring tools (26.7%; $p = 0.004$). Limited resource farmers perceived access to investment capital (47.4% *significant barrier*; $p = 0.039$), labor access/cost (41.1%; $p = 0.008$), access to appropriate insurance (34.5%; $p = 0.030$), access to appropriate markets (32.1%; $p = 0.013$), and access to detailed economic information (22.8%; $p = 0.026$).

TABLE 4 Methods to receive information on adaptation practices by farmers.

Extension education and outreach indicators	Frequencies	Percentages
Emails	199	67.7
Print publications	163	55.4
Extension education events	138	46.9
Face-to-face	73	24.8
Social media	43	14.6
Group texting	17	5.8
Webinars	03	1.0
Farm visits	02	0.6

3.8.3 Significant barriers to crop production

Fruit farmers perceived labor access/cost (38.8% *significant barrier*; $p = 0.036$) and access to appropriate equipment (20.4%; $p = 0.074$) whereas nut tree farmers perceived government regulations (62.1%; $p = 0.048$) and high input cost (55.6%; $p = 0.064$) as significant barriers. Similarly, vegetable farmers perceived time (48.5%; $p = 0.076$), land ownership (42.4%; $p = 0.003$), and access to appropriate insurance (40.6%; $p = 0.021$) as significant barriers whereas grain and pulse farmers perceived access to appropriate markets (37.5%; $p = 0.091$) and land ownership (30.8%; $p =< 0.001$) as their significant barrier to adaptation efforts. Fiber farmers

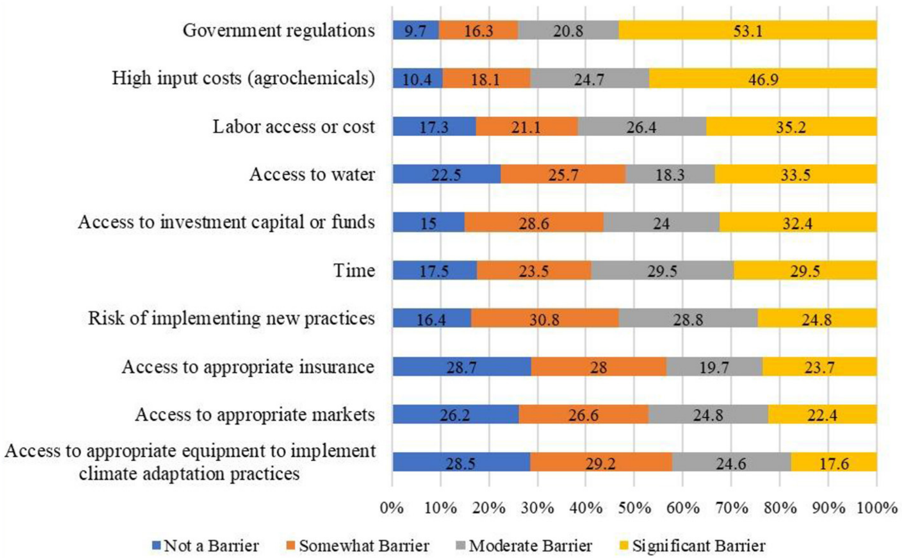

FIGURE 6
Top 10 barriers to implementation of adaptation practices and programs by farmers. Also see Supplementary Table S2 for complete details of all 23 barriers to adaptation.

significantly perceived time (71.4%; p = 0.003), access to water (64.3%; p = 0.097), risk of implementing new practices (64.3%; p = 0.005), access to investment capital/funds (60.0%; p = 0.085), access to appropriate markets (57.1%; p = 0.013), and access to detailed economic information (46.7%; p = 0.006) as *significant barriers*.

3.9 Decision support tools

On farmers' experiences with DSTs, 47.5% 'use' DSTs to aid farming decision-making. Similarly, 56.5% (n = 294) indicated that DSTs are helpful in their farm decision-making; 49.7% (n = 296) indicated using them *within-in-season planning*, 15.5% use them in *long-term planning*; 51.9% (n = 293) expressed their interest in using online DSTs. The study also asked farmers what DSTs they use and weather stations (n = 67), soil moisture sensors (n = 19), California Irrigation Management Information System [CIMIS] (n = 11), ETo (n = 10), and water sensors (n = 8) were most used. Other info and tools utilized included the National Oceanic and Atmospheric Administration (NOAA), eVeg, Jain Logic, IRROMETERS, and Fruition Sciences 360Viti.

4 Discussion

A needs assessment is the initial step toward developing adaptation strategies for farmers by understanding and documenting their perceptions, experiences, and knowledge of exposures, potential impacts, and social vulnerabilities. Also, to know what effective risk management practices they currently use, what tools and resources would assist them in making strategic decisions, what types of extension education activities would help them, and where to find essential resources. These aspects begin with a detailed understanding of stakeholder needs that allows for a focused use and mobilization of resources that are both measurable and trustworthy to decision-makers on the ground (Garst and McCawley, 2015; Donaldson and Franck, 2016). The discussions focus on farmers' climate change perceptions, impacts, concerns, CSA practices, extension education programs, and climate DSTs they currently use to adapt to farming in variable climatic conditions in California.

4.1 Climate change perceptions, impacts, and concerns

Climate change and the associated extreme events, including high temperatures, heatwaves, droughts, wildfires, erratic precipitation, floods, and storms are evident (Swain et al., 2020), increasing the vulnerability of agriculture in California (Pathak et al., 2018; Swain et al., 2018; Parker et al., 2020). Despite the ongoing debate on climate change perceptions across the United States (Sanders et al., 2022), this study established that 67% of respondents *agree (agree+strongly agree)* that climate change is happening and also *agree (agree+strongly agree)* that it is happening due to natural (66.8%) and human (55.7%) causes. Moreover, 38.7% of all impacts were rated *severe* over the past 10 years among historically underrepresented farmers—mostly first-generation, limited resource, socially disadvantaged—who are mainly (42.9%) farming in the San Joaquin Valley.

Underrepresented farmers were overall *very concerned* about climate-change-related impacts in all three categories—water–related (i.e., the increasing uncertainty of available water, reduced underground water, crop/water stress, and salinization); temperature–related (i.e., crop damage due to heat, drought, frost, pest and disease, and reduced chill); and disaster–related (i.e., crop and farm losses, wildfire, smoke, and floods). This study found a connection between farmers' responses and the 2012–2016 drought in California that led to fallowing of thousands of acres, drying of wells in San Joaquin Valley (Howitt et al., 2014; Jasechko and Perrone, 2020); and indemnity payments to nut tree and fruit growers (Reyes and Elias, 2019; Parker et al., 2020).

The future climatic change in California is projected to impact water supply, storage, and reservoir operations; for instance, snowpacks in the Sierras are projected to decrease by 48% and 65% under low and high-emission scenarios respectively (Reich et al., 2018). In the Sierra region, a notable shift has occurred, with a higher proportion of precipitation falling as rain rather than snow, leading to reductions in stored water and time regulation of snow; affecting the substantially irrigated San Joaquin Valley, Sacramento–San Joaquin Delta, and Imperial regions (Mount et al., 2018). We found connections between those assertions with significant *concerns* of farmers which were mainly water-related issues (see Table 2). Specifically, farmers in the South San Joaquin Valley (71.6%) and Central Coast (64.1%) were *very concerned* about reduced groundwater availability. Similarly, vegetable farmers significantly expressed more concerns about uncertainty in water availability for irrigation (74.4% *very concerned*) during spring months. The reduced availability of stored water introduces complexities for farmers, especially for irrigation insurance (Wright, 2014; Maestro et al., 2016; Ghosh et al., 2021).

In temperature, warmer winters are projected to reduce winter chill accumulation, an important decision-making factor in orchards, especially in rootstock and cultivar selection (Parker and Abatzoglou, 2019; Zhang et al., 2021). In some nut species (almond), these aspects are further complicated due to the need to have a main variety and one or two pollinator varieties in the same orchard for cross-pollination. Relatedly, problems of insect pest population and incidence are directly linked to increases in greenhouse gas (GHG) emissions, rising temperatures, and relative humidity. Increased carbon dioxide, for instance, supports plant physiology but also influences insect fecundity, consumption rates, and density (Rijal et al., 2021; Skendžić et al., 2021; Jha et al., 2024), and alters pesticide translocation and metabolism, reducing pesticide availability for target pests (Matzrafi, 2018). Also increases in temperature increase the pest generations and their geographical expansion, like, Naval orangeworm spreading in the Coastal Ranges, Southern Sierra, and San Joaquin Valley (Pathak et al., 2021; Martínez-Lüscher et al., 2022). The impacts that are seen by the scientific community and those perceived by farmers are aligned, regardless of whether they believe the climate changes are natural cycles or human driven.

4.2 Need for information on climate adaptation practices

Farmers are currently *implementing* several climate adaptation practices related to water resource management, soil health, and renewable energy and are also seeking out insurance and government assistance programs to increase agriculture resilience. Farmers expressed *interest* and a *high need* for information on those adaptation practices and programs (see Table 3) to acquire skills and knowledge to manage various challenges of farming in variable climates. Specifically, water resources are among the main issues farmers are *very concerned* about.

It is noted that increasing weather variability will worsen problems for water supply in California (Reich et al., 2018); consequently, water will be limited and more regulated for all users (Mount et al., 2018). According to California Department of Food Agriculture (2022), irrigated cropland in California is 9.4 million acres, of which 6.17 million acres are of annual crops and 3.21 million acres are of perennial crops, mostly fruits, and nut trees led by almonds (Mount et al., 2018) in the San Joaquin Valley which accounts for over 60% of the farmland (Escriva-Bou et al., 2023). Farmers will need cropping systems that use less water and benefit from rainfall and flows captured during the fall and winter months. Additionally, farmers will need high-precision automated irrigation systems to apply water in small amounts at frequent intervals, shifting from surface to Microirrigation, and effectively managing crop stress (Ayars et al., 2024).

Farmers are currently *implementing* several soil health-related adaptation practices, more especially reducing soil disturbance/no-till, building soil organic matter by applying manure/compost, using cover crops, and mulching. This study noted that some of these practices, such as mulching, were of *interest,* and farmers similarly expressed a *high need* for information about these practices for building soil organic matter and using cover crops. Cover cropping is a conservation practice, improving biodiversity, ecosystem services, and yield index, making productionist agrosystems more sustainable and reconnecting human activities to the natural ecological community (Thompson, 2017; Montgomery, 2021; Ikendi, 2023). However, cover crops earlier were not widely adopted in semi-arid western states and are grown on 4.8% of farmland in California (LaRose and Myers, 2019). Nevertheless, an *implementation* rate of 39.3% was established among farmers who participated in this study. The low adoption of cover crops is mainly due to the lack of accurate water-related information i.e., the amount of water necessary to establish and maintain the cover crops as well as the paucity of information on their costs and benefits (DeVincentis et al., 2022). Moreover, access to water was among the top five barriers that farmers perceived as significantly impeding their adaptation endeavors. One of the core aspects of this project (see Figure 1) is to close the information gap through regional and crop-specific workshops (Ikendi et al., 2023).

This study established that farmers (29.7%) are transitioning to renewable energy and many are expressing interest in transitioning to renewable energy (48.7%) and reducing dependence on fossil fuels (48.1%), which were both among the top adaptation practices identified. Despite their *interest*, there is a knowledge gap expressed by a *high need* for information on transitions and the reduction of dependency on fossil fuels. The Senate Bill (SB100 2018) laid out a decarbonization program with a vision for a zero-carbon economy by 2045 (California Air Resources Board, 2020; Heidi et al., 2022). The 2022 GHG inventory report shows that between 2000–2020, the proportions of emissions by sector were transportation

(38%), industrial (23%), in-state electricity (11%), agriculture and forestry (9%), residential (8%), commercial (6%) and imported electricity (5%) which all together emitted an estimated amount of 369.2 MMT CO_2e (California Air Resources Board, 2022). Also, California is hydrologically engineered with water conveyance systems spanning from the north with large distributions to central to southern California that entail increasing electricity demands.

Most irrigation takes place in the San Joaquin Valley, creating implications for the environmental footprint of nut crops (Marvinney and Kendall, 2021), as well as the energy demand for water conveyance and groundwater pumping (Heidi et al., 2022). Moreover, energy rates for agriculture have been increasing, with an estimated 65% rise over the past decade. In addition, the rate for 2023 was estimated to rise by 16.4%, increasing the operational costs. Investing in automated irrigation systems (Ayars et al., 2024), and renewable energy and creating opportunities for optimal power generation and usage in agriculture can help the electricity system be decarbonized (Governor Gavin Newsom, 2023). California is on a trajectory to zero carbon with statistics showing 59% of electricity already coming from renewable and zero-carbon resources.

Given the current variability of climate and its projected volatility to the end of the century, farmers are consistently looking toward securing access to insurance and/or seeking information about insurance programs. Multigenerational farmers are statistically significantly *accessing* insurance, whereas underrepresented farmers statistically expressed significant *interest* and a *high need* for information on access to insurance and this is expressed as the *highest need* overall. California had its worst drought ever recorded in 1,200 years between 2012–2016 based on paleoclimate reconstructions (Griffin and Anchukaitis, 2014) which caused severe crop losses and drying of wells especially in the San Joaquin Valley. However, there are Multiple Peril Crop Insurance products available to farmers in the San Joaquin Valley, especially covering losses caused by failure of the irrigation systems (Wright, 2014; Maestro et al., 2016).

Nevertheless, there are complexities involved in insurance that require thorough education of farmers to understand what alternatives benefit best (Wright, 2014; Ghosh et al., 2021). For instance, insurance bases its expected water availability on how much water is available in reservoirs, levels of soil moisture and snow packs, and crop season precipitation; making it difficult given the fact that snow packs are projected to decrease, and more precipitation falls as rain in the Sierras instead of snow reducing the stored water (Reich et al., 2018). Moreover, insurance does not cover crop losses due to non-natural causes like repurposed water allocations, for instance, environmental regulations (Escriva-Bou et al., 2023) limiting water supplies and usage in agriculture.

This study found that most farmers expressed *interest* in and *a high need* for information on government assistance programs, especially indicated by underrepresented farmers. Adapting to adverse climate requires government intervention and California has several assistance programs related to water resources, renewable energy, and soil health at the federal, state, and county levels (Lewis and Rudnick, 2019). Since 2006, California has been enacting Acts in response to global warming and subsequently providing funds to move forward the CSA policy framework (p. 4). Federal assistance programs helping farmers include the Environmental Quality Incentives Program (EQIP), which promotes conservation practices to improve soil health, water quality, and irrigation efficiency (United States Department of Agriculture Natural Resource Conservation, 2023). At the state level, the California Department of Food and Agriculture (CDFA) offers several CSA grant programs including, but not limited to, the Healthy Soils Program (HSP), which increases soil organic matter and decreases GHG emissions (California Department of Food and Agriculture, 2023a); State Water Efficiency and Enhancement Program (SWEEP), which increases water use efficiency and decreases GHG emission (California Department of Food and Agriculture, 2023b). The California Energy Commission has the Renewable Energy for Agriculture Program that supports the installation of renewable energy technologies on-site in agricultural operations (California Energy Commission, 2023). At the county level, California has, for instance, San Joaquin Valley Air Board with the Agriculture Burn Alternatives Grant Program (San Joaquin Valley Air Pollution Control District, 2023) and Zero Footprint Grants including Compost Connector Grants and Restore Grants, which together support farmer adaptation and resilience to climate change. Despite the availability of several government assistance programs, the study found an information gap as expressed by farmers in the high need for information related to those programs, indicating a need to educate farmers through regional and crop-specific extension education workshops (Ikendi et al., 2023).

4.3 Use of climate decision support tools

Information on climate change is one of the most valuable resources for adaptation planning. Climate scientists have a strong understanding of climate trends and have developed many trend and impact models (Laloyaux et al., 2018; Swain et al., 2020). Despite progress at both ends of the spectrum, DSTs that combine climate trends and impact analyses for specific contexts are still in their infancy (Haigh et al., 2018; Ranjan et al., 2020; Lu et al., 2021). Our study corroborates this statement, with 50% of respondents reporting using DSTs and mostly used weather stations. However, the greatest hope is the high level of acceptance that DSTs are useful and the high expression of interest in using online DSTs designed to translate climate information into forms that support production decision-making.

The USDA had earlier echoed the need to transform technical climatic information into forms that farmers can use [United States Government Accountability Office (USGAO), 2014]. Farmers need specific information on their unique crops for decision-making (Jagannathan et al., 2023; Taku-Forchu et al., 2023; Ikendi et al., 2024), especially in California with more than 400 commodities (Pathak et al., 2018) including high-value specialty crops that are highly sensitive to climate-related impacts (DeVincentis et al., 2022; Parker et al., 2022; Ikendi et al., 2024; Jha et al., 2024). In response, a team of researchers (Pathak et al., 2023) from CalAgroClimate embarked on designing online DSTs. The team currently has five tools that project: frost and heat using high-resolution PRISM data within 800 m and 4 km grids, pests, crop phenology, and historical data. Tools like this have value only if they are utilized in farming decisions. For that purpose, tools like CalAgroClimate and

10.3389/fsufs.2024.1395547

other web-based portals need to be illustrated and disseminated to farmers in ways to address their specific needs.

5 Conclusions

Farmers in California who participated in this study had varying perceptions and experiences regarding climate change and related impacts. However, we found that 67% *agree* that climate change is happening due to natural (66.8%) and/or human (55.7%) causes; moreover, 59.0% expressed that they experienced greater climate change on their farms today than 10 years ago. Importantly, 69.8% *agree* that they are interested in learning more about the impacts of climate change on the agricultural industry, providing a platform for climate and agriculture science researchers and educators to develop extension education programs to meet the needs of the farmers.

Generally, farmers were *very concerned* about water-related issues, specifically increased uncertainty in water availability for irrigation, reduced water availability for irrigation, and reduced groundwater availability. Closely related were temperature-related issues especially increased drought severity and crop damage due to extreme heat. The study found statistically significant associations between ethnoracial background and concern for water, temperature, and disaster-related issues with more underrepresented farmers expressing greater concerns and these farmers especially first-generation farmers were statistically significantly participating in fruit production. The study also identified statistically significant differences in primary concerns between farming regions with farmers in South San Joaquin Valley and Central Coast expressing greater concerns about reduced groundwater availability. Relatedly, increased drought severity was a significant concern with farmers in the Inland Empire, Central Coast, Southern, and North Coast regions whereas farmers in the North Coast and Southern were very concerned with increased crop damage due to wildfires and/or wildland fire smoke. Additionally, vegetable farmers significantly expressed greater concerns about uncertainty in water availability for irrigation while fruit farmers significantly expressed more concerns regarding increased crop/water stress and increased crop damage due to extreme heat.

This needs assessment also found that farmers were implementing several climate adaptation practices related to water resource management, soil health, and renewable energy and are also seeking out insurance and government assistance programs to increase their agricultural resilience. We found a connection between the farmers' current adaptation practices and expression of interest in those practices, for instance, water harvesting, transition to renewable energy, drought-tolerant varieties, reducing dependence on fossil fuels, and applying for government assistance. We also found that among the top 10 climate change adaptation practices that farmers were *implementing* and also expressed *interest* in are the same practices they expressed a *high need* for information. These practices included securing access to insurance, applying for government assistance, transitioning to renewable energy, building soil organic matter, and water harvesting. However, the greatest obstacles to farmers' adaptation efforts that they perceived as *significant barriers* included government regulations, high input cost, labor access/cost, access to water, and access to investment capital/funds. These findings will potentially inform the development of extension education programs on climate-smart agriculture for farmers in California.

Data availability statement

The original contributions presented in the study are included in the article/Supplementary material, further inquiries can be directed to the corresponding author.

Ethics statement

The studies involving humans were approved by University of California Davis under Institutional Review Board Number 1841798-2. The studies were conducted in accordance with the local legislation and institutional requirements. The participants provided their written informed consent to participate in this study.

Author contributions

SI: Data curation, Formal analysis, Investigation, Methodology, Project administration, Software, Validation, Visualization, Writing – original draft, Writing – review & editing. NP: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Software, Validation, Visualization, Writing – review & editing. VK: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Project administration, Resources, Software, Supervision, Writing – review & editing, Visualization. NT-F: Data curation, Formal analysis, Investigation, Methodology, Visualization, Writing – review & editing, Validation. LR: Conceptualization, Data curation, Investigation, Methodology, Project administration, Resources, Supervision, Validation, Visualization, Writing – review & editing, Formal analysis, Software. SO: Conceptualization, Data curation, Investigation, Methodology, Project administration, Resources, Supervision, Validation, Writing – review & editing, Formal analysis. LP: Conceptualization, Data curation, Investigation, Methodology, Validation, Writing – review & editing, Formal analysis. DZ: Conceptualization, Data curation, Investigation, Methodology, Resources, Supervision, Writing – review & editing, Formal analysis, Project administration. MC: Conceptualization, Investigation, Methodology, Project administration, Resources, Writing – review & editing, Data curation, Formal analysis, Supervision. JD-R: Investigation, Methodology, Validation, Writing – review & editing, Conceptualization. SB: Investigation, Methodology, Validation, Writing – review & editing. MB: Investigation, Methodology, Validation, Writing – review & editing. JR: Investigation, Methodology, Validation, Writing – review & editing. TP: Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Software, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing.

Funding

The author(s) declare that financial support was received for the research, authorship, and/or publication of this article. The study was funded by the U.S. Department of Agriculture—National Institute of Food and Agriculture, Grant Number: 2022-68017-36358.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fsufs.2024.1395547/full#supplementary-material

References

Ayars, J. E., Zaccaria, D., and Bali, K. M. (2024). *Microirrigation for crop production: design, operation, and management.* Cambridge, MA: Elsevier Science.

California Air Resources Board (2020) *California Air Resources Board vision and roadmap: Clean Air for all Californians.* Sacramento, CA. Available online at: https://ww2.arb.ca.gov/sites/default/files/2021-01/CARB_vision_roadmap_0121.pdf

California Air Resources Board (2022). *Current California GHG emission inventory data: 2000-2020 GHG inventory (2022 Edition).* Sacramento, CA. Available online at: https://ww2.arb.ca.gov/ghg-inventory-data (accessed November 10, 2023).

California Department of Food and Agriculture (2013). *Climate change consortium for specialty crops: Impacts and strategies for resilience.* Sacramento, CA. Available online at: https://www.cdfa.ca.gov/oefi/climate/docs/CCC_Report.pdf

California Department of Food and Agriculture (2022). *California agricultural statistics review 2021-2022.* Sacramento, CA. Available online at: https://www.cdfa.ca.gov/Statistics/PDFs/2022_Ag_Stats_Review.pdf

California Department of Food and Agriculture (2023a). *Healthy Soils Program.* Sacramento, CA. Available online at: https://www.cdfa.ca.gov/oefi/healthysoils/ (accessed December 30, 2023).

California Department of Food and Agriculture (2023b). *State Water Efficiency and Enhancement Program.* Sacramento, CA. Available online at: https://www.cdfa.ca.gov/oefi/sweep/?mf_ct_campaign=yahoo-synd-feed (accessed December 30, 2023).

California Energy Commission (2023). *Renewable Energy for Agriculture Program.* Sacramento, CAStates. Available online at: https://www.energy.ca.gov/programs-and-topics/programs/renewable-energy-agriculture-program (accessed November 10, 2023).

DeVincentis, A., Solis, S., Rice, S., Zaccaria, D., Snyder, R., Maskey, M., et al. (2022). Impacts of winter cover cropping on soil moisture and evapotranspiration in California's specialty crop fields may be minimal during winter months. *Calif. Agric.* 76, 37–45. doi: 10.3733/ca.2022a0001

Dillman, D. A., Smyth, J. D., and Christian, L. M. (2014). *Internet, Phone, Mail, and Mixed-mode Surveys: The Tailored Design Method.* Hoboken, NJ: John Wiley and Sons.

Donaldson, J. L., and Franck, K. L. (2016). *Needs Assessment Guidebook for Professionals.* Knoxville, TN: University of Tennessee Extension.

Drost, E. A. (2011). Validity and reliability in social science research. *Educ. Res. Persp.* 38, 105–124. Available online at: https://www.researchgate.net/publication/261473819

Escriva-Bou, A., Hanak, E., Cole, S., and Medellín-Azuara, J. (2023). *The future of agriculture in the San Joaquin Valley: Policy brief.* San Francisco, CA: Public Policy Institute of California. Available online at: https://www.ppic.org/wp-content/uploads/policy-brief-the-future-of-agriculture-in-the-san-joaquin-valley.pdf

Food and Agriculture Organization of the United Nations (FAO) (2021). *Climate-smart agriculture case studies 2021 – Projects from around the world.* Rome: Italy. doi: 10.4060/cb5359en

Garst, B. A., and McCawley, P. F. (2015). Solving problems, ensuring relevance, and facilitating change: the evolution of needs assessment within Cooperative Extension. *J. Hum. Sci. Exten.* 3, 25–47. doi: 10.54718/FLSF2021

Ghosh, P. N., Miao, R., and Malikov, E. (2021). "Crop insurance premium subsidy and irrigation water withdrawals in the western United States," in *The Geneva Papers on Risk and Insurance-Issues and Practice, Vol. 48* (London: Palgrave Macmillan), 968–992. doi: 10.1057/s41288-021-00252-4

Governor Gavin Newsom (2023). *Building the electricity grid of the future: California's clean energy transition plan.* Sacramento, CA. Available online at: https://www.gov.ca.gov/wp-content/uploads/2023/05/CAEnergyTransitionPlan.pdf

Grantham, T., Kearns, F., Kocher, S., Roche, L., and Pathak, T. (2017). Building climate change resilience in California through UC Cooperative Extension. *Calif. Agric.* 71, 197–200. doi: 10.3733/ca.2017a0045

Griffin, D., and Anchukaitis, K. J. (2014). How unusual is the 2012–2014 California drought. *Geophys. Res. Lett.* 41, 9017–9023. doi: 10.1002/2014GL062433

Haigh, T., Koundinya, V., Hart, C., Klink, J., Lemos, M., Saylor Mase, A., et al. (2018). Provision of climate services for agriculture: public and private pathways to farm decision-making. *Bull. Am. Meteorol. Soc.* 99, 1781–1790. doi: 10.1175/BAMS-D-17-0253.1

Heidi, J., Garcia, C., Neumann, I., Rednam, A., Bailey, S., and Gee, Q. (2022). *Final 2021 integrated energy policy report, volume IV: California energy demand forecast.* San Francisco, CA: California Energy Commission. Available online at: https://www.energy.ca.gov/data-reports/reports/integrated-energy-policy-report/2021-integrated-energy-policy-report (accessed November 10, 2023).

Howitt, R., Medellín-Azuara, J., MacEwan, D., Lund, J., and Sumner, D. (2014). *Economic analysis of the 2014 drought for California agriculture*. University of California, Davis, Center for Watershed Sciences. Available online at: https://www.circleofblue.org/wp-content/uploads/2014/07/Economic_Impact_of_the_2014_California_Water_Drought_0.pdf

Ikendi, S. (2023). Ecological conservation, biodiversity, and agricultural education as integrated approaches for envisioning the future of sustainable agriculture in North America. *Int. J. Sustain. Dev. World Ecol.* 30, 152–163. doi: 10.1080/13504509.2022.2127032

Ikendi, S., Koundinya, V., Bergren, C., Taku-Forchu, N. C., Parker, L., Pinzon, N., et al. (2023). "Communicating climate-smart agriculture to tree nut growers in the San Joaquin Valley of California (Poster presentation)," in *Western Region of the American Association for Agricultural Education Conference: The Crossroads of Food, Agriculture and Innovation* (Logan, UT): Available online at: https://www.researchgate.net/publication/374153295

Ikendi, S., Koundinya, V., Mosase, E. N., Holmquist, H., Spaniel, E. N., Zabronsky, H. M., et al. (2024). "Pathways to climate smart agriculture in the San Diego region of California (Poster presentation)," in *National American Association for Agricultural Education Conference: Cultivating a Brighter Future in Agricultural Education, Leadership, Communications and Extension* (Manhattan, KS): Available online at: https://www.researchgate.net/publication/380880946

Jackson, L. E., Wheeler, S. M., Hollander, A. D., Orlove, B. S., Six, J., Sumner, D. A., et al. (2011). Case study on potential agricultural responses to climate change in a California landscape. *Clim. Change* 109(Suppl 1), 407–427. doi: 10.1007/s10584-011-0306-3

Jagannathan, K., Pathak, T. B., and Doll, D. (2023). Are long-term climate projections useful for on-farm adaptation decisions? *Front. Clim.* 4:1005104. doi: 10.3389/fclim.2022.1005104

Jasechko, S., and Perrone, D. (2020). California's Central Valley groundwater wells run dry during recent drought. *Earths Future* 8:e2019EF001339. doi: 10.1029/2019EF001339

Jasperse, L., and Pairis, A. (2020). *Climate change consortium for specialty crops: Southern California Region.* Sacramento, CA: California Department of

Food and Agriculture, Climate Science Alliance. Available online at: www.climatesciencealliance.org/resilient-roots-resources (accessed November 10, 2023).

Jha, P. K., Zhang, N., Rijal, J. P., Parker, L. E., Ostoja, S., and Pathak, T. B. (2024). Climate change impacts on insect pests for high value specialty crops in California. *Sci. Total Environ.* 906:167605. doi: 10.1016/j.scitotenv.2023.167605

Johnson, D., Parker, L. E., Pathak, T. B., Crothers, L., and Ostoja, S. M. (2023). Technical assistance providers identify climate change adaptation practices and barriers to adoption among California agricultural producers. *Sustainability* 15:5973. doi: 10.3390/su15075973

Kanter, J., Clark, N., Lundy, M. E., Koundinya, V., Leinfelder-Miles, M., Rachael, L., et al. (2021). Top management challenges and concerns for agronomic crop production in California: identifying critical issues for extension through needs assessment. *Agron. J.* 113, 5254–5270. doi: 10.1002/agj2.20897

Koundinya, V., Taku-Forchu, N., Pinzon, N., Parker, L., Cooper, M., Ostoja, S., et al. (2023). "Collecting needs assessment data using participatory and culturally responsive strategies for a climate-smart agriculture project (Poster presentation)," in *American Evaluation Association Annual Conference: The Power of the Story* (Indianapolis, IN). Available online at: https://www.researchgate.net/publication/374842286

Laloyaux, P., de Boisseson, E., Balmaseda, M., Bidlot, J. R., Broennimann, S., Buizza, R., et al. (2018). CERA-20C: a coupled reanalysis of the twentieth century. *J. Adv. Model Earth Syst.* 10, 1172–1195. doi: 10.1029/2018MS001273

LaRose, J., and Myers, B. (2019). *Adoption of soil health systems based on data from the 2017 U.S. census of agriculture. Metrics include cover crop and no-till production practices*. Morrisville, NC: Soil Health Institute. Available online at: https://soilhealthinstitute.org/app/uploads/2021/11/Soil-Health-Census-Report.pdf

Lewis, J., and Rudnick, J. (2019). The policy enabling environment for climate smart agriculture: a case study of California. *Front. Sustain Food Syst.* 3:31. doi: 10.3389/fsufs.2019.00031

Lu, J., Singh, A. S., Koundinya, V., Ranjan, P., Haigh, T., Getson, J. M., et al. (2021). Explaining the use of online agricultural decision support tools with weather or climate information in the Midwestern United States. *J. Environ. Manag.* 279:11758. doi: 10.1016/j.jenvman.2020.111758

Luedeling, E., Zhang, M., and Girvetz, E. H. (2009). Climatic changes lead to declining winter chill for fruit and nut trees in California during 1950–2099. *PLoS ONE* 4:e6166. doi: 10.1371/journal.pone.0006166

Maestro, T., Barnett, B. J., Coble, K. H., Garrido, A., and Bielza, M. (2016). Drought index insurance for the Central valley project in California. *Appl. Econ. Perspect. Policy* 38, 521–545. doi: 10.1093/aepp/ppw013

Martínez-Lüscher, J., Teitelbaum, T., Mele, A., Ma, O., Frewin, A. J., and Hazell, J. (2022). High-resolution weather network reveals a high spatial variability in air temperature in the Central valley of California with implications for crop and pest management. *PLoS ONE* 17:e0267607. doi: 10.1371/journal.pone.0267607

Marvinney, E., and Kendall, A. (2021). A scalable and spatiotemporally resolved agricultural life cycle assessment of California almonds. *Int. J. Life Cycle Assess.* 26, 1123–1145. doi: 10.1007/s11367-021-01891-4

Matzrafi, M. (2018). Climate change exacerbates pest damage through reduced pesticide efficacy. *Pest Manag. Sci.* 75, 9–13. doi: 10.1002/ps.5121

McNeish, D. (2018). Thanks coefficient alpha, we'll take it from here. *Psychol. Methods* 23, 412–433. doi: 10.1037/met0000144

Montgomery, D. R. (2021). "Soil health and the revolutionary potential of conservation agriculture," in *Rethinking Food and Agriculture,* eds. A. Kassam and A. L. Kassam (Cambridge, MA: Woodhead Publishing), 219–229.

Mount, J., Hanak, E., Lund, J., Ullrich, P., Baerenklau, K., Butsic, V., et al. (2018). *Managing drought in a changing climate: Four essential reforms*. San Francisco, CA: Public Policy Institute of California. Available online at: https://www.ppic.org/wp-content/uploads/managing-drought-in-a-changing-climate-four-essential-reforms-september-2018.pdf

Munden-Dixon, K., Tate, K., Cutts, B., and Roche, L. (2018). An uncertain future: climate resilience of first-generation ranchers. *Rangeland J.* 41, 189–196. doi: 10.1071/RJ18023

Parker, L. E., and Abatzoglou, J. T. (2019). Warming winters reduce chill accumulation for peach production in the Southeastern United States. *Climate* 7:94. doi: 10.3390/cli7080094

Parker, L. E., Johnson, D., Pathak, T. B., Wolff, M., Jameson, V., and Ostoja, S. M. (2023). "Adaptation resources workbook for California specialty crops," in *USDA California Climate Hub Technical Report CACH-2023-1*. Available online at: https://www.climatehubs.usda.gov/hubs/california/topic/adaptation-resources-workbook-california-specialty-crops (accessed November 10, 2023).

Parker, L. E., McElrone, A. J., Ostoja, S. M., and Forrestel, E. J. (2020). Extreme heat effects perennial crops and strategies for sustaining future production. *Plant Sci.* 295:110397. doi: 10.1016/j.plantsci.2019.110397

Parker, L. E., Zhang, N., Abatzoglou, J. T., Ostoja, S. M., and Pathak, T. B. (2022). Observed changes in agroclimate metrics relevant for specialty crop production in California. *Agronomy* 12:205. doi: 10.3390/agronomy12010205

Pathak, T. B., Maskey, M. L., Dahlberg, J. A., Kearns, F., Bali, K. M., and Zaccaria, D. (2018). Climate change trends and impacts on California agriculture: a detailed review. *Agronomy* 8:25. doi: 10.3390/agronomy8030025

Pathak, T. B., Maskey, M. L., and Rijal, J. P. (2021). Impact of climate change on navel orangeworm, a major pest of tree nuts in California. *Sci. Total Environ.* 755:142657. doi: 10.1016/j.scitotenv.2020.142657

Pathak, T. B., Ostoja, S., Jha, P. K., Parker, L., Feirer, S., and Johnson, R. (2023). *CalAgroClimate.org-Web-based decision support system for managing agriculture under weather and climate risks*. San Francisco, CA: American Geographical Union. Available online at: https://calagroclimate.org/

Pathak, T. B., and Stoddard, C. S. (2018). Climate change effects on the processing tomato growing season in California using growing degree day model. *Model. Earth Syst. Environ.* 4, 765–775. doi: 10.1007/s40808-018-0460-y

Pinzón, N., Koundinya, V., Galt, R., Dowling, W., Boukloh, M., Taku-Forchu, N., et al. (2023). *AI-powered fraud and the erosion of online survey integrity: an analysis of 31 fraud detection strategies*. Charlottesville, VA: Center for Open Science. doi: 10.31235/osf.io/95tka

Rance, H. (2023). *19 crops that are grown only in California*. California Grown Blog. Available online at: https://californiagrown.org/blog/only-in-california/ (accessed September 20, 2023).

Ranjan, P., Duriancik, L. F., Moriasi, D. N., Carlson, D., Anderson, K., and Prokopy, L. (2020). Understanding the use of decision support tools by conservation professionals and their education and training needs: an application of the reasoned action approach. *J. Soil Water Conserv.* 75, 387–399. doi: 10.2489/jswc.75.3.387

Reich, K. D., Berg, N., Walton, D. B., Schwartz, M., Sun, F., Huang, X., et al. (2018). *Climate change in the Sierra Nevada: California's water future*. University of California, Los Angeles, Center for Climate Science. Available online at: https://www.ioes.ucla.edu/wp-content/uploads/UCLA-CCS-Climate-Change-Sierra-Nevada.pdf

Reyes, J. J., and Elias, E. (2019). Spatio-temporal variation of crop loss in the United States from 2001 to 2016. *Environ. Res. Lett.* 14:074017. doi: 10.1088/1748-9326/ab1ac9

Rijal, J., Joyce, A., and Gyawaly, S. (2021). Biology, ecology, and management of hemipteran pests in almond orchards in the United States. *J. Integr. Pest Manag.* 12:26. doi: 10.1093/jipm/pmab022

San Joaquin Valley Air Pollution Control District (2023). *Agriculture Burn Alternatives Grant Program*. Modesto, CA. Available online at: https://ww2.valleyair.org/grants/ag-burn-alternatives-grant-program/ (accessed November 10, 2023).

Sanders, C. E., Gibson, K., and Lamm, A. J. (2022). Perceived government control and its influence on climate change knowledge and perceptions: applications for effective communication. *J. Appl. Commun.* 106:6. doi: 10.4148/1051-0834.2441

Skendžić, S., Zovko, M., Živković, I. P., Lešić, V., and Lemić, D. (2021). The impact of climate change on agricultural insect pests. *Insects* 12:440. doi: 10.3390/insects12050440

Surls, R., Feenstra, G., Golden, S., Galt, R., Hardesty, S., Napawan, C., et al. (2015). Gearing up to support urban farming in California: preliminary results of a needs assessment. *Renew. Agric. Food Syst.* 30, 33–42. doi: 10.1017/S1742170514000052

Swain, D. L., Langenbrunner, B., Neelin, J. D., and Hall, A. (2018). Increasing precipitation volatility in twenty-first-century California. *Nat. Clim. Change* 8, 427–433. doi: 10.1038/s41558-018-0140-y

Swain, D. L., Singh, D., Touma, D., and Diffenbaugh, N. S. (2020). Attributing extreme events to climate change: a new frontier in a warming world. *One Earth* 2, 522–527. doi: 10.1016/j.oneear.2020.05.011

Taku-Forchu, N., Ikendi, S., Koundinya, V., Dahlquist-Willard, R., Thaoxaochay, L., Vong, M., et al. (2023). "Climate change related impacts and experiences among Hmong farmers in the San Joaquin valley, California (Paper presentation)," in *National Association of Extension Program and Staff Development Professionals Annual Conference: Extension elevated* (Salt Lake City, UT).

Thompson, P. B. (2017). *The spirit of the soil: agriculture and environmental ethics*. New York, NY: Routledge

United States Department of Agriculture – Natural Resources Conservation Service (2018). *Historically underserved farmers and ranchers*. Available online at: https://www.nrcs.usda.gov/getting-assistance/underserved-farmers-ranchers (accessed November 10, 2023).

United States Department of Agriculture (USDA) – National Agricultural Statistics Service (2024). *2022 census of agriculture: Summary and State data*. Washington DC: United States. Available online at: https://www.nass.usda.gov/Publications/AgCensus/2022/Full_Report/Volume_1,_Chapter_1_US/usv1.pdf (accessed November 10, 2023).

United States Department of Agriculture and Natural Resource Conservation, S.ervice (2023). *Environmental Quality Incentives Program – California*. Sacramento, CA. Available online at: https://www.nrcs.usda.gov/programs-initiatives/eqip-environmental-quality-incentives/california/environmental-quality

United States Government Accountability Office (USGAO) (2014). *Climate change: USDA's ongoing efforts can be enhanced with better metrics and more relevant information for farmers*. Washington DC: United States. Paper presentation https://www.gao.gov/assets/gao-14-755.pdf

Wright, B. D. (2014). Multiple peril crop insurance. *Choices* 29, 1–5. Available online at: http://www.jstor.org/stable/choices.29.3.06

Zhang, N., Pathak, T. B., Parker, L. E., and Ostoja, S. M. (2021). Impacts of large-scale teleconnection indices on chill accumulation for specialty crops in California. *Sci. Total Environ.* 791:148025. doi: 10.1016/j.scitotenv.2021.148025