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California Agriculture

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ORDERS AND SUBSCRIPTIONS

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EDITORIAL

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Research and review articles

COVER: Mowing of winter cover crop with a flail mower in a long-term National Research Initiative study of conservation agriculture systems at the UC West Side Research and Extension Center in Five Points, Calif. Cover cropping is an important soil health management practice that has been monitored at the Five Points site. A recent study of sorghum and garbanzo yields in the San Joaquin Valley examined the effects of cover cropping and no-till techniques versus no cover crop and standard tillage (see Mitchell et al., page 112).

RESEARCH ARTICLE

Silviculture can facilitate repeat prescribed burn programs with long-term strategies

Burn programs to reduce fuel loads in California forests are most effective when stand characteristics and forest structure are considered.

by Robert A. York, Jacob Levine, Daniel Foster, Scott Stephens and Brandon Collins

Online: https://doi.org/10.3733/ca.2021a0016

Abstract

A significant expansion of prescribed fire activity will be necessary to mitigate growing wildfire hazard in California forests. Forest managers can facilitate this expansion by promoting forest structures that allow for more effective implementation of prescribed fire, for both initial-entry and repeat burns. We analyzed changes in surface fuel during a series of three burns in replicated mixed-conifer stands following a period of over 100 years of fire suppression and exclusion. Total fuel load, proportion of pine present, canopy cover and basal area of live trees were relevant forest-structure components that influenced plot-scale fuel consumption. The study highlighted the importance of pre-fire fuel load and the relative proportion of pine in the overstory, which both led to greater amounts of fuel consumption. The initial-entry burn dramatically reduced all fuel categories (fine fuel, coarse wood and duff). Following each burn, fuel recovered until the next burn reduced loads enough to maintain low fuel levels. We apply the results to provide an example of how to determine the timing of prescribed fires.

Over the past century, exclusion of Indigenous and private land burning as well as aggressive fire suppression have drastically altered forest structure in many forest types throughout western North America, including mixed-conifer forests in California (Stephens et al. 2015). In the absence of frequent, low-intensity fires, today's mixed-conifer forests are characterized by greater fuel loads, more horizontal and vertical fuel continuity, increased tree density, smaller average tree diameter and a shift in composition toward shade-tolerant species (Miller and Urban 2000; Scholl and Taylor 2010). The sum effect is a marked increase in the risk of high-severity wildfire (Taylor et al. 2013), resulting in unprecedented timber losses, property damage, injury and human death (Cal Fire 2018).

To reduce these risks, forest managers intentionally set controlled, or prescribed, fires in forests adapted to frequent fire (Fernandes and Botelho 2003; Ryan et al.

By understanding the effects of stand characteristics on fuel consumption, prescribed burns can be prioritized to occur where consumption is expected to be greatest. The burn in this photo was done opportunistically during a dry period in December of 2020. *Photo:* Rob York.

2013). Prescribed fires consume surface fuels, primarily litter, woody debris, small trees, and brush. However, fuel consumption in prescribed fires can be highly variable both within and between burns. The amount of fuel consumed is dependent on two major conditions: weather, including precipitation and resulting fuel moisture, and forest stand characteristics, such as species composition and canopy density. While the influence of weather-dependent conditions on fuel consumption is relatively well understood, the influence of stand characteristics is not (Knapp et al. 2005; Vaillant et al. 2009). Stand structures are highly dependent on past silvicultural practices and on the time that has passed since the last disturbance. By understanding the effects of stand characteristics on fuel consumption, prescribed burns can be prioritized to occur where consumption is expected to be greatest. Likewise, current silvicultural practices can be adjusted to facilitate improved fuel consumption in future burns.

Burn programs: a tiered approach

Conducting initial burns where fire has not occurred for numerous decades is a critical step toward reintroducing the ecological process of fire into California forests, but second- and third-entry burns are necessary to achieve more complete fire restoration (Webster and Halpern 2010). As prescribed fire use increases in California, so will the proportion of prescribed fires that are repeat burns. The results from a series of burns, rather than the effect of any individual burn, will ultimately determine a burn program's success. By burn program, we refer to the decisions regarding the timing, frequency and size of prescribed fires. Depending on the details of these decisions, a number of different fuel-dynamics patterns may occur (fig. 1). Given the considerable amount of surface fuels that have accumulated during the long period without fire in many California forests, it is not clear how fuel consumption in initial-entry burns will differ from that in repeated

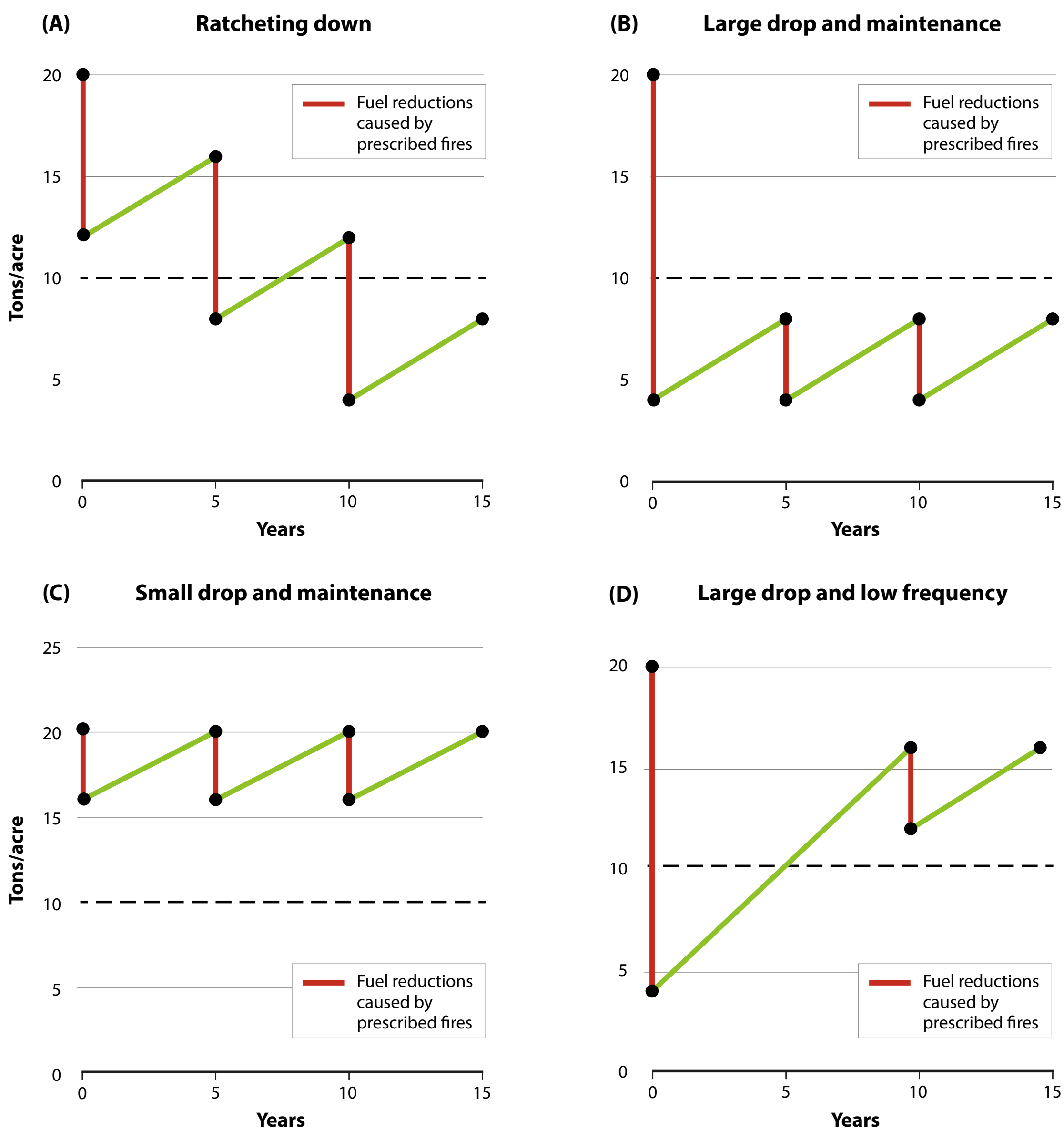


FIG. 1. Potential fuel-load dynamics during a hypothetical prescribed burn program that includes burns in graphs (A), (B) and (C) at years 0, 5 and 10, and burns in graph (D) at years 0 and 10. The horizontal dashed line represents a possible target for desired fuel load, although the actual target will depend on objectives and fire-hazard factors. In these scenarios, graphs (A) and (B) achieve objectives while graphs (C) and (D) do not.

burns on the same site. Clearly, fuel will re-accumulate over time, but the rates of recovery for different sizes of fuel depend on the effects of the initial fire, the forest structural characteristics and the biophysical environment (Keane 2008). Repeated burning could successively reduce fuel loads by a similar amount each time, eventually having a ratcheting-down effect (fig. 1A). Alternatively, especially high consumption in an initial-entry burn could set the stage for repeated maintenance burns that maintain the desired low fuel levels (fig. 1B). Other patterns exist that could result in a burn program that is not effective in meeting reduction targets if, for example, initial burns do not consume enough fuel (fig. 1C) or the burning interval is not frequent enough to keep up with fuel recovery rates (fig. 1D).

The results from a series of burns, rather than the effect of any individual burn, will ultimately determine a burn program's success.

An analysis focused for fire managers

In the work described here, we condense findings reported in a previous study of forest burns (Levine et al. 2020) and analyze the data in a new way to articulate specific management applications. We focus on three objectives: (1) highlight the relative importance of pre-fire fuel load, overstory species composition and large-tree density in driving fuel consumption; (2) profile the measured trends in fuel load by size category across replicated first-, second- and third-entry burns; and (3) provide an example of how the timing of future repeat burns could be scheduled using our results of fuel change over time guided by principles of what we refer to as disturbance-regime–guided silviculture (DReGS).

Blodgett Forest Research Station

Prescribed burns in the Levine et al. (2020) study were done at Blodgett Forest Research Station (BFRS), a University of California–owned mixed-conifer forest located on the western slope of the Sierra Nevada in El Dorado County, California. Prescribed fire research at BFRS began in the mid-1980s and expanded dramatically in the early 2000s. Since 2007, prescribed fires have been conducted annually at BFRS to facilitate research, extension and education. The forest is 2,961 acres (1,199 hectares) in area and is located at approximately 4,400 feet (1,342 meters) in elevation. It is typical of the high-productivity band of mixed-conifer forest that occurs on the western slopes of the Sierra Nevada. Like other high-productivity forests in the range, stands at BFRS are capable of rapidly developing large fuel loads, thus becoming vulnerable to severe wildfires. The study location therefore represents forests that are a high priority for the use of prescribed fire with the specific objective of lowering fuel loads to reduce future wildfire severity.

Fall burns, weather conditions

Initial burns were conducted in three replicated stands in the fall of 2002. Prior to these initial burns, it had been at least 90 years since the last fire. An important context of these burns is that no mechanical treatments (chainsaws or heavy equipment operations) were conducted prior to the burns as a way to "prepare" for burning by altering the forest structure. Each stand was approximately the same size (40 acres [16 hectares]) and contained typical mixed conifer species (Douglas-fir, incense-cedar, ponderosa pine, sugar pine, and white fir). The stands were burned again in 2009 and 2017 — each time in the fall. The exact timing of burns was determined by several factors typical of burning in California related to fall burning: (1) the issuance of a burn permit, (2) conducive weather and fuel conditions, and (3) predictions that fire behavior would meet objectives, that is, consume surface fuel without unacceptable risk of escape from stand perimeters and damage to overstory trees. Because the permitting windows for fall burns are particularly short regardless of the weather-window duration (York et al. 2020), there was extremely limited flexibility in ensuring that all three burns were done under similar conditions.

The amount of pre-burn precipitation plays an important role in driving fire behavior, especially in the fall. Prior to the initial burn, no precipitation had occurred in the BFRS stands. This resulted in low fuel moisture, a situation amenable to effective fuel consumption in forest structures with high tree density and large fuel loads, such as those at BFRS. In 2009 and 2017, precipitation (less than one inch) during the month prior to the burns occurred, causing the burns to be lower intensity. Our experience with burning at BFRS annually for the past 18 years suggests that, as a result of permit restrictions, burning in the fall following precipitation is more feasible than burning without precipitation. The sequence of an initial entry burn during dry conditions, followed by repeat burns under slightly wetter conditions, represents an ideal scenario, but it is dependent on an initial entry burn that could be considered as higher risk since it is on the hotter end of prescription burning. One strategy for managing this risk is to perform initial-entry burns overnight, when temperatures are lower, but this adds another layer of complexity to operations.

Analyses of fuel dynamics

Levine at al. analyzed forest stands prior to and following each burn to quantify changes in forest structure, tree species composition, understory plant cover, understory plant composition and fuel loads. To focus on management implications, we report here the analysis of the results in a digested form, and we add a second analysis that is of particular relevance for the planning of prescribed burn programs.

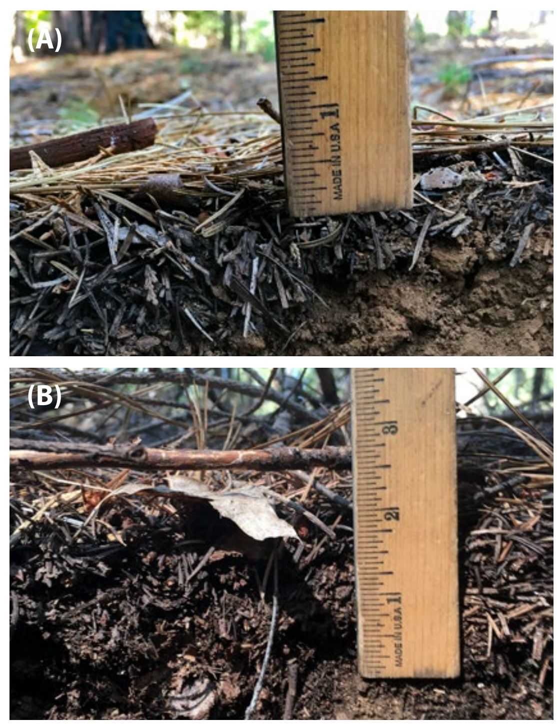
The objective of our first analysis was to determine which of the forest structural and species compositional factors were most important in predicting surface-fuel consumption at fine scales. This focused on the variability between 0.1-acre sample plots that occurred within the 40-acre stands. We selected 11 *a priori* factors that we knew from previous research and experience were most likely to influence surface fuel consumption. We used a model-selection procedure to pare down the 11 factors one at a time, starting with the most comprehensive model and eventually honing in on the model that was the most parsimonious. This iterative approach identifies the "best" model that includes only those factors most important in explaining surface-fuel consumption.

We identified four of the 11 factors that were not only important drivers of fuel consumption but are also controllable from a silvicultural perspective: total fuel load, live-tree basal area, percent canopy cover (percentage of the ground that is covered by tree crowns) and relative abundance of pine species. We also described the effect of burn number (i.e., first-entry versus second- or third-entry) on these factors, and the interaction between burn number and the proportion of live-tree basal area that was in the *Pinus* genus (ponderosa and sugar pine).

In our second analysis, we assessed the between-burn trends in surface fuel across the burns as well as the net change in surface fuel at the end of the burns compared to the beginning. We grouped fuel into three categories according to management relevance (fig. 2). Fine fuels, which is litter and sticks up to three inches in diameter, including fuels that are classified into 1-hour, 10-hour and 100-hour size classes. These are the fuels that are typically considered to be the most important drivers of fire behavior (Albini 1976). The second category, duff, is decomposing organic debris on the forest floor that conventionally has not been considered a strong driver of fire behavior (Burgan and Rothermel 1984). However, it may play a larger role under more extreme burning conditions. Additionally, duff may be of special interest for ecological restoration goals because long-term fire suppression has resulted in especially large accumulations that can influence regeneration, soil processes (Keifer et al. 2006) and mixed-conifer tree mortality (Stephens and Finney 2002). Finally, we considered coarse wood (logs that are more than three inches in diameter), which may be of special interest for wildlife habitat (Knapp 2015).

In our statistical analysis, we used a multivariate repeated measures approach to detect changes in fuel loads over time and to see if the three fuel categories changed in different ways. We considered the net change in fuel, from pre-burn initial conditions to post third burn, as a robust assessment of burning effectiveness. We also assessed the fine-scale changes in fuel over time, including pre- and post-burn measurements of all three burns, in order to more closely profile the drops and recoveries in fuel between burns. We considered time as being significant (i.e., fuel decreased as a result of the burns) if $P < 0.05$, and as being weakly

FIG. 2. A maintenance prescribed fire, occurring in winter. The open, pine-dominated structure in the foreground is allowing for consumption of fine fuels, but the fire is unlikely to consume large amounts of coarse wood and duff. The dense stand in the background requires relatively dry fuel conditions in order to consume the heavy fuels that are present. *Photo*: Rob York.



Profile of surface fuels in a stand burned three times in the past 18 years (A) and a stand with thick duff and woody debris that has not burned in the past 100 years (B). One burn may not consume all of the fuel that is in stand B, but multiple burns may maintain lower fuel levels or progressively reduce fuel over time. *Photos*: Rob York.

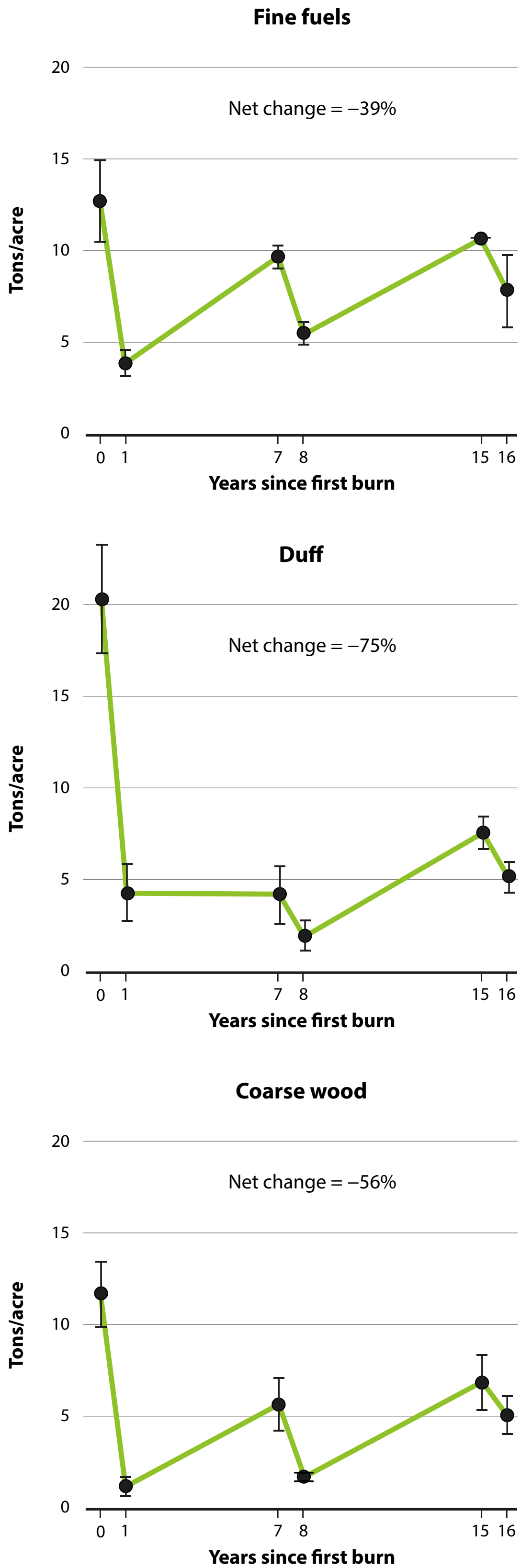


FIG. 3. Actual trends by fuel category across three prescribed burns in stands at Blodgett Forest Research Station. The first burns were not preceded by mechanical preparation treatments. Points are stand-level means; whiskers are standard errors.

significant if $P < 0.10$. We used the same P-value thresholds for the interaction between fuel category and time, an interaction that detected non-parallel trends between fuel categories.

Fuel load and pine abundance influence burns

The two most important forest-structure factors driving fuel consumption were fuel load and percent of basal area that was pine. Fuel consumption (as a percentage of pre-fire fuel load) was higher at plots with high initial fuel loads. The percentage of pine basal area, which quantified the relative abundance of sugar pine and ponderosa pine in the overstory versus all other species, was clearly important in driving fuel consumption, but it was also more complex. The interaction between pine basal area and burn number suggested that more pine was associated with *less* consumption during the first burn. But for the second and third burns, the abundance of pine was strongly associated with *more* consumption. Specifically, in burns two and three, a 10% increase in pine basal area was associated with a 9.3% and 6.2% increase in fuel consumption, respectively. In the first burn, a 10% increase in pine basal area was associated with a 4.7% decrease in fuel consumption. The other significant, but less influential, factors were total basal area (the ground area covered by the cross-sectional area of stems at 4.5 feet above the ground) and percent canopy cover. Fuel consumption was slightly greater at the plot level when there was more basal area or lower canopy cover.

As expected, there was a large and statistically significant ($P < 0.001$) net reduction in surface fuel across all fuel size categories at the stand level prior to the first burn and 15 years later following the third burn (fig. 3). The rate of reductions varied across the three different categories (i.e., they were non-parallel), as indicated by a weakly significant ($P = 0.06$) interaction between time and size category. When all measurement times were considered in the analysis (i.e., incorporating finer temporal scale changes between burns and not just before the first burn compared to after the third burn), the effect of time on fuel load was also weakly significant ($P = 0.09$). The fluxes in fuel load between burns decreased the capacity to detect time's significance. Rather than a ratcheting down of fuel, the profile of the trend in fuels indicated a large reduction caused by the first burn, followed by recovery, and then smaller reductions during subsequent burns (most similar to the simplified conceptual model in fig. 1B). There was no evidence that the trends were different among the three fuel categories when including all of the between-burn variability ($P = 0.83$).

Management implications

Even in high-hazard forests with high tree densities and large fuel loads from a century of fire suppression, we demonstrate here that prescribed fire without preceding mechanical preparation treatments can effectively reduce surface fuels. Further, this can be done without excessive damage to canopy trees (e.g., Stephens and Moghaddas 2005). Burning in the late summer or early fall prior to significant precipitation can lead to an initial-entry burn like the one that occurred in this study, which greatly reduced fuel across all size categories. The large drop in fuel from the first burn was a dominant factor in the burn program's eventual success once the third burn occurred.

A significant challenge to this type of first-entry burn, however, is that windows of opportunity for high-consumption fall burning are either narrow or non-existent because of permitting constraints (York et al. 2020). Consequently, managers are forced to burn when fuel is wetter and humidity is higher. Under these marginal fuel-moisture and weather conditions, it becomes even more important to consider the ways in which forest structure can be managed prior to any burn in order to maximize burn effectiveness under a wide range of fuel and logistical conditions.

Relative overstory pine abundance and live-tree basal area were positively related to fuel consumption, while percent canopy cover was negatively related. All three of these factors can be manipulated through silvicultural treatments in the years or decades prior to burning, leading to structures and compositions that are more conducive to fuel consumption. Managing to increase pine in the overstory, especially ponderosa pine, increases "pine straw" litter, which tends to have a lower bulk density (van Wagtendonk et al. 1998) that is easier to burn under wetter conditions. Ponderosa pine needles also dry out faster than other conifer needles (Anderson et al. 1978), increasing the window of opportunity even after significant fall precipitation. Similar to the role of long-leaf pine litter in the southeastern United States (Mitchell et al. 2009), ponderosa pine litter is, in our experience, a dominant factor in conducting successful prescribed fires during wetter fuel conditions in mixed-conifer forests.

Over the long term, the relative abundance of pine can be increased using regeneration harvesting methods. These methods can create distinct canopy openings, the size of which do not necessarily need to be larger than one acre, to maximize recruitment rates in productive forests (York et al. 2004). Planting ponderosa pine, especially on ash substrates created from pile burns (York et al. 2009), can further increase rates of recruitment into the canopy. In the shorter term, during thinning treatments that precede prescribed fires, retention of pine in the overstory is especially important in facilitating future burns. Managing for increased ponderosa pine abundance is co-aligned with historical forest conditions in these forests and is often a stated restoration goal for mixed-conifer forests.

The different effects of live-tree basal area, which was positively related to fuel consumption, and canopy cover, which was inversely related, is not intuitive. Basal area and canopy cover are generally related to each other in a positive but nonlinear way. The stands in this study were dominated by large trees, especially after the second and third burns. Because much of the wood in large trees is heartwood, which is not correlated with leaf area, a stand with low stem density can be high in basal area yet have a somewhat open canopy. For this to occur, the structure must be dominated by sparse but large trees. Integrating the results suggests that stand structures characterized by low-density, large pine trees present the ideal overstory structure for prescribed burning to reduce and maintain low surface fuel.

Determining burn frequency

If prescribed burning becomes more common in mixed-conifer forests, an emerging challenge faced by managers will be to decide which type of burn — initial or repeat — to prioritize during limited burn windows. This study suggests that if conditions are dry and there is an opportunity to burn, it is worthwhile to prioritize first-entry burns. During wetter conditions, resources may be better spent on maintenance burns, or on initial-entry burns where forest structure and composition have been managed specifically to facilitate prescribed burning. Ideally, a manager has all three types of prescribed burns (initial entry, maintenance and burns in stands where the canopy density has been reduced and ponderosa pine favored) ready in each burn season.

A fundamental responsibility for managers of prescribed-burn programs is determining the frequency of follow-up burns. The question of burning frequency is one currently faced by the authors of this study as we consider the timing of a fourth burn in the BRFS stands. A broad objective of future burns for this long-term study is that they represent maintenance burns likely to be prescribed for California forests. However, burn programs that focus on specific objectives, such as timber yield or carbon, versus those that focus on process restoration have different conceptual frameworks and may have different implications for burn frequency. To demonstrate the varied approaches, we discuss below three alternative frameworks for guiding our decision about when to plan the next burn in the BRFS stands.

A fundamental responsibility for managers of prescribed-burn programs is determining the frequency of follow-up burns.

1. *Range of natural variability (RNV).* In terms of fire frequency, RNV is a reconstructed maximum range of fire-return interval that can be used to demonstrate the extent that contemporary forests have departed from those of the past (Battles et al. 2013). The RNV for fire frequency can be used as a target, where management is deemed successful if the fires occur at a frequency that is less than the maximum range that was thought to occur in the past, prior to the current era of fire suppression. The reconstructed fire regime at BFRS suggests a frequency range of from two to 29 years (Stephens and Collins 2004). The benefit of this approach is that it provides a simple and quantitative metric. Further, it provides ample flexibility (in this case, 27 years) for meeting the target. Arguably, however, neither the maximum nor the minimum fire-return intervals are suitable targets for long-run fire frequency. Historically, most fires would have occurred less than 29 (but more than two) years apart. Understanding the distribution frequency of past fire-return intervals may help target a distribution of desired prescribed-fire frequency, but reconstruction studies of fire frequency do not typically provide this level of precision. Further, reconstructions of fire frequency are based only on physical evidence of fire scars that are visible in tree rings. Because low-intensity fires do not necessarily cause a fire scar, RNV is an overestimate of the actual fire frequency that occurred.
2. *Fuel and fire hazard monitoring.* The second approach that we considered is more objective-based, where a decision to burn is triggered by close monitoring of fuels against some management target for wildfire resistance (e.g., Keifer et al. 2006). This requires frequent measurements of fuel and forest structure, using modeling to determine likely severity in the event of a wildfire. This approach includes associated thresholds for modeled overstory mortality under wildfire conditions. For example, managers might decide to burn only if forest structure has

Hemispherical photographs of canopies of (A) a stand that has not been thinned or burned for 100 years, (B) a stand that was burned three times in the past 18 years, and (C) a stand that was thinned and burned twice in the past 18 years. Our data suggest that surface fuel consumption during a prescribed fire is likely to be greatest in stand C and the least in stand A. *Photos*: Rob York.

developed to the point where a wildfire occurring on a hot summer day is predicted to cause more than 50% mortality of overstory trees. While this approach could result in an efficient strategy for reducing wildfire hazard, depending upon the accuracy of its models, it is narrowly focused on a single metric. It does not consider all of the unknown ecological benefits that would come from restoring fire frequency and the complex spatial patterns in forest overstory and understory patterns that have been demonstrated in historical mixed-conifer forests (Collins et al. 2015; Lydersen et al. 2013). Further, this approach requires a high-frequency monitoring program that would likely be cost-prohibitive in most management scenarios.

3. *Disturbance-regime–guided silviculture (DReGS).* This approach takes lessons from disturbance ecology, applying the concept that management should emulate ecosystem patterns and processes as much as possible (e.g., Seymour et al. 2002). While typically applied to timber harvests, this approach could also be applied to prescribed fire, which, like timber harvesting, is a silvicultural practice. Given climatic changes, safety concerns and potential liability realities associated with using fire in California, we highlight the term *guided* in our definition, which is meant to recognize the impracticality of precisely knowing and then mimicking the past disturbance regime given realistic operational constraints. Replicating a target fire frequency with high precision can be especially difficult because planned burns are often delayed (Miller et al. 2020). Use of the term *silviculture* is also essential to the application of this concept because it implies the importance of meeting specific societal or landowner objectives in treating forests. As with RNV, an advantage of this approach is being able to quantify a target for management. By incorporating flexibility for social constraints and by attempting to meet specific objectives, it has the important and added advantage of management flexibility. The downside is the risk of being so flexible and accommodating of logistical constraints that ecological benchmarks no longer apply.

Given the objectives and constraints at the BRFS study location, we decided that the DReGS concept is the most promising approach to use in planning a fourth burn. The median fire frequency in the study area was reconstructed to be less than 5 to 10 years at the stand scale (Stephens and Collins 2004). Applying the concept of DReGS, we would use this 5- to 10-year target as a starting point and then adjust it into an achievable schedule that allows for uncertainty in operational variables (e.g., not being able to get a burn permit because of weather conditions). Using information from our study about fuel recovery between burns, we can also ensure that we meet management objectives (e.g., not allowing fuel to recover to pre-burn levels). In the BRFS stands, which are productive in producing surface fuel and where there is therefore an abundant supply of pine litter input, the data suggest that it is feasible to burn effectively every 5 years in order to maintain low levels of surface fuel. However, it is unlikely that a precise 5-year schedule will actually be attainable because of difficulties in getting permits that coincide in time with low fuel-moisture levels necessary for effective burns. Hence, a burn-frequency plan with a hedge-betting element would be to aim for conducting the next burn after 5 years (specifically, fall of 2022) if conditions are adequate. It is acceptable to burn sooner if conditions are appropriate, or to delay burning a year at a time until a maximum of 10 years after the last burn, which would, in this case, mean burning by the fall of 2026. Further delays would depart unacceptably from the ecosystem's disturbance regime and also risk returning to pre-fire fuel loads, especially in the fine-fuel category. If this were to happen, we would consider the burn program to no longer be effective within the DReGS conceptual framework.

New tools and challenges

As prescribed-burn programs across California develop with time, new silvicultural tools for managing forests to enhance future burn effectiveness will likely be needed. Our study, for example, suggests that guidelines for managing ponderosa pine needle input onto the forest floor could be helpful. Existing information about leaf area in standing trees, needle cast distance and needle input/decomposition rates could be integrated to manage pine-tree density and spatial arrangement so that pine-needle litter on forest floors is maintained or optimized to carry low-intensity prescribed fires. Also important will be the identification of feedbacks that occur between the litter that overstory compositions create and the resulting fire behavior influenced by that litter, and an analysis of how these feedbacks might affect the resulting overstory composition in the future. This "ecology of fuels" concept (Mitchell et al. 2009) could be a useful framework for identifying applied-research needs for prescribed burning in California.

Finally, our study highlights the challenges and importance of being flexible and of taking the long view when developing prescribed-burn programs. Management decisions for the decades preceding burns, being ready to burn during limited periods of conducive weather in all seasons and being adaptive in scheduling future burns are all critical factors that forest managers must consider in planning burn programs that span multiple decades. CA

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RESEARCH ARTICLE

No-tillage sorghum and garbanzo yields match or exceed standard tillage yields

Results from a 4-year trial indicate that garbanzo and sorghum yields under no-tillage practices were similar to or higher than those under standard tillage.

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Abstract

To meet the requirements of California's Sustainable Groundwater Management Act, there is a critical need for crop production strategies with less reliance on irrigation from surface and groundwater sources. One strategy for improving agricultural water use efficiency is reducing tillage and maintaining residues on the soil surface. We evaluated high residue no-till versus standard tillage in the San Joaquin Valley with and without cover crops on the yields of two crops, garbanzo and sorghum, for 4 years. The no-till treatment had no primary or secondary tillage. Sorghum yields were similar in no-till and standard tillage systems while no-till garbanzo yields matched or exceeded those of standard tillage, depending on the year. Cover crops had no effect on crop yields. Soil cover was highest under the no-till with cover crop system, averaging 97% versus 5% for the standard tillage without cover crop system. Our results suggest that garbanzos and sorghum can be grown under no-till practices in the San Joaquin Valley without loss of yield.

Since the advent of irrigation in California with the widespread drilling of wells in the 1930s, several public policy changes affecting surface water allocations, and the proliferation of orchard and vineyard crops during the past two decades, have resulted in total annual water requirements in many irrigation districts exceeding surface water supplies and reliance on groundwater use to make up for the difference, especially during the recent drought. Partly as a consequence, California enacted the Sustainable Groundwater Management Act (SGMA) in 2014 (DWR 2014), which in time will limit withdrawals to sustainable groundwater extractions. Because irrigated agriculture accounts for 40% of all available water supplies, but up to 80% of developed water supplies, especially in the San Joaquin Valley (SJV) (DWR 2018), groundwater use will be restricted in this region to meet the requirements of SGMA. This will have significant economic consequences. With some climate change projections suggesting a potential 20% water availability loss by the middle of the century in California due to global warming (Udall and Overpeck 2017), there is a critical need for strategies with less reliance on irrigation from surface and groundwater sources in crop production.

Post-harvest sorghum residue being rolled down in the no-tillage cover crop system before fall cover crop seeding. Reducing tillage and maintaining surface residues that increase water capture and soil water retention capacities may be a means for improving water use efficiency in crop production systems. *Photo*: Jeffrey P. Mitchell.

Reducing tillage (the physical manipulation of the soil using operations such as plowing, disking and subsoil ripping) in the context of conservation agriculture (see sidebar) offers a currently under-utilized strategy for improving agricultural water use efficiency in California (Bettner 2012; Mitchell et al. 2019). Decreasing soil water evaporation relative to total evapotranspiration (ET) by reducing tillage and maintaining surface residues that increase water capture and soil water retention capacities may be a means for improving water use efficiency in crop production systems. This has been demonstrated under both irrigated (Klocke et al. 2009; van Donk et al. 2020) and rain-fed conditions (Unger 1984; Unger and Baumhardt 1999; Unger and Parker 1976). Crop residues (plant and cover crop material remaining after harvest) reduce evaporation and water loss from wet soils by shading (reducing soil surface temperatures) and by reducing wind erosion effects (Klocke et al. 2009; van Donk et al. 2010). Several studies from both irrigated and rain-fed regions around the United States (some of which also use supplemental irrigation) where no-tillage (NT) is used have reported annual water savings by as much as 4 to 5 inches (Klocke et al. 2009) in crop production systems that typically have 23 to 25 inches of seasonal crop ET (F. Lamm, Kansas State University, personal communication). At Kansas State University's Southwest Research and Extension Center in Garden City, Kan., full-surface residue coverage with corn stover and wheat stubble reduced evaporation by 50% to 65% compared to bare soil with no shading (Klocke et al. 2009). Research in Nebraska showed that tillage operations before planting can dry the soil in the tillage layer with a loss of 0.3 to 0.75 inches of soil moisture per tillage pass (Pryor 2004) in overhead sprinkler irrigated systems. Compared to conventional tillage under overhead irrigation, switching to NT has also been shown to save 3 to 5 inches of water annually with an added savings of $14 to $23 per acre in 2004 US$ from pumping costs (Pryor 2004) in Nebraska.

Several dryland regions around the world are also adopting NT to diversify and intensify annual crop production. In the Canadian prairies, NT enhanced soil health, increased soil water availability in near-surface layers, and allowed the introduction of new crops, including oilseeds and legumes (Lindwall and Sonntag 2010). As a result, the planted area under NT has increased from 5% in 1991 to over 80% in 2011, thus reducing reliance on the traditional summer fallow. In the U.S. central Great Plains, NT has benefited agricultural management and local farm economies by permitting both the intensification and diversification of cropping systems. For example, cropping in this area, sometimes in places with only 15 inches of annual rainfall, has changed from one crop every other year, to two crops every 3 years, to cropping every year (Anderson 2011). NT has also been extensively adopted for cereal production in the southwestern Australia drylands, an area with only about 10 inches of annual

UC Westside Research and Extension Center Superintendent Rafael Solorio stands in a no-tillage no cover crop (NTNO) garbanzo plot. *Photo*: Jeffrey P. Mitchell.

Definition of conservation agriculture

Although currently not widely used in much of California's annual cropland, the core principles and concepts of what are widely and particularly internationally regarded as conservation agriculture (CA) systems may provide an important unifying framework for the development of improved performance crop production systems in the future. CA has three linked principles:

- Continuous minimum mechanical soil disturbance
- Preservation of residues that provide permanent soil cover
- Diversification of crop rotations and emphasis on soil biodiversity

CA is more than avoidance of tillage. It is a farming system that involves changes in cultural practices along with a change in approach that bypasses the use of intense tillage disturbance, focuses on improving soil function, and increases the efficiency of water, energy and nutrient cycling (Mitchell et al. 2019). CA also emphasizes carbon management by focusing on extending the period of crop and residue cover on the soil.

We envision expanded application of CA principles in a variety of California's annual cropping systems for forage and grain, energy, fiber and vegetables as production techniques are further refined. The Conservation Agriculture Systems Innovation (CASI; http://casi.ucanr.edu/) Center works to develop information on locally relevant adaptations of CA systems that include the use of cover crops, integrated pest management, precision irrigation and controlled or limited mechanical traffic on soil and is a resource for farmers interested in learning more about the use of these techniques in California.

rainfall and no irrigation options, which is similar to a sizable portion of the SJV (Ward et al. 2012), where the benefits of surface residues include moisture retention during germination and early growth of the subsequent crop (K. Flower, University of Western Australia, personal communication).

NT and residue preservation have additional benefits, including lower soil temperatures during the summer (Mitchell et al. 2012) and higher water retention (Mitchell et al. 2019; Sposito 2013), increased soil water capture from improved infiltration and retention,

TABLE 1. Measured changes in soil properties and functions in the NRI Project system soils (1999–2018)

Soil property or function	Direction of effect resulting from NT and cover crops	Reference
Soil carbon and nitrogen	+	Mitchell et al. 2017
Soil water infiltration	+	Mitchell et al. 2017
Soil aggregate stability	+	Mitchell et al. 2017
Nematode abundance	+	Zhang et al. 2017
Soil macrofauna diversity	+	Kelly et al. 2021

Experimental no-tillage plots at the UC West Side Research and Extension Center, Five Points, Calif., with sorghum (foreground) and garbanzo stubble (top right). *Photo*: Jeffrey P. Mitchell.

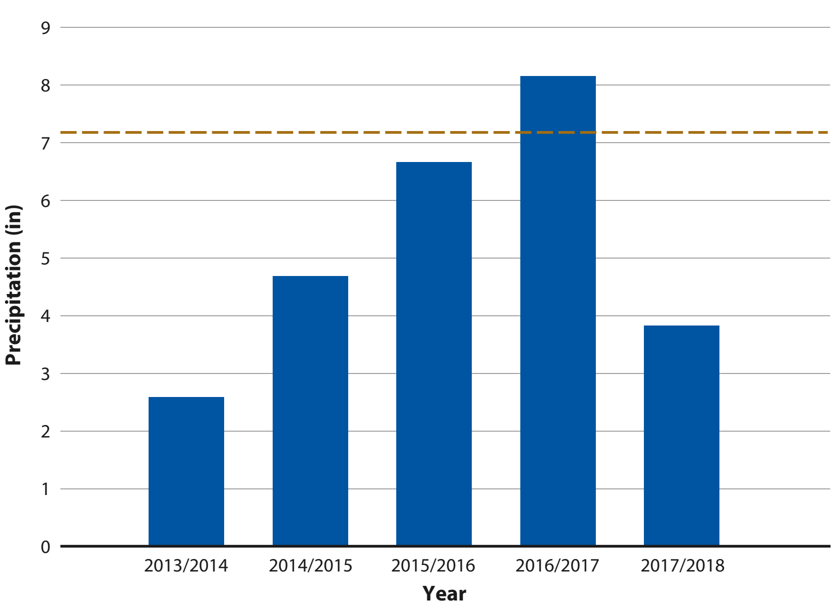


FIG.1. Total annual precipitation (2014–2018) and the 30-year average (represented by the dotted line) at the UC West Side Research and Extension Center in Five Points, Calif.

increased water storage capacity from increased organic matter and changes in pore size distribution (Franzluebbers 2010) for all texture groups (Berman 1994), increased carbon and nitrogen storage (Mitchell at al. 2017) and increased biological activity (Schmidt et al. 2018; Zhang et al. 2018) (table 1). Cost savings of $50 to $150 per acre for a variety of crops in the SJV from NT have been documented (Mitchell et al. 2016; Mitchell, Shrestha, Munk 2016). Compared to ST, NT uses less diesel fuel and requires less labor (Mitchell et al. 2008), and generates less dust (Baker et al. 2005; Madden et al. 2008). Sustained NT coupled with cover crops (CCs) has also been shown to increase soil aggregation, water infiltration and biological diversity compared to ST after 18 years of the practices on a clay loam soil. Generalizing from Mitchell et al. (2012), about 13% (4 inches), of soil water loss from evaporation in a summer crop using 30 acre-inches of water in the SJV could potentially be avoided if reduced disturbance, residue-preserving practices are used on soils with overhead or surface furrow or flood irrigation.

We evaluated the potential for producing sorghum and garbanzo beans — two crops that might be amenable to NT in the SJV — using high residue NT techniques. Sorghum is the fifth most important cereal crop in the world (FAOSTAT 2019). The United States, led by Kansas and Texas, is the world's largest sorghum producer with 16% of the world's production. In California, there is renewed interest in sorghum as a potential replacement for silage corn because of its drought tolerance. Approximately 20% of U.S. sorghum is produced using NT or strip-tillage, a tillage management system that only disturbs the portion of the soil where the seed row will be; however, these practices are uncommon in California and very little is known about their potential locally. Garbanzo beans are a winter planted crop that are grown on about 10,000 acres for the canning industry (CDFA 2018). Garbanzo seed size is similar to soybean, which is NT-planted in several parts of the United States and on over 75% of acreage in Brazil, Argentina and Paraguay.

Study site and tillage systems

In these experiments, we compared grain sorghum and garbanzo yields under NT with no cover crop (NTNO) or with cover crops (NTCC) versus ST with no cover crops (STNO) or with cover crops (STCC). The 8.8-acre study site was in the National Research Initiative (NRI) Project at the University of California's West Side Research and Extension Center (WSREC), Five Points, Calif. (36°20'29"N, 120°7'14"W). The soil type is a Panoche clay loam, which is a very deep, well-drained soil on alluvial fans. Average annual precipitation is about 8.2 inches (fig. 1). Treatments included a factorial arrangement of tillage and CC in a randomized complete block design with four replications. Each plot was 29.9 feet by 270 feet and consisted of six 5-foot beds.

ST consisted of conventional intercrop tillage operations of residue shredding, multiple diskings to incorporate residues, subsoiling to a depth of about 18 inches in the bed shoulder areas to avoid damaging the buried drip tape that was in the center of beds at about 8 inches deep, additional disking to break up soil clods and for the shaping of beds, and incorporation of the surface soil using a cultimulcher (BW Implement, Buttonwillow, Calif.), which is a PTO (power take-off)-powered aggressive tillage operation that pulverized the top 8 inches of soil into a fine, powdery seedbed for both the STNO and STCC systems. These conventional intercrop tillage practices break down and establish new beds following harvest and represent normal operations in the SJV in terms of the intensity, depth and timing of tillage (Mitchell et al. 2017).

The only soil disturbance in the NT systems occurred during seeding and fertilizing in prior years when tomatoes were grown, during shallow cultivations for weed management and for the one-time installation of drip tape in 2012. The tillage and CC treatments were maintained in the same plots during the study. To have both crops in each year, a garbanzo/sorghum rotation was used on half of the plots and a sorghum/garbanzo crop sequence was used on the other half of the plots.

In the CC plots, a mix of triticale (*Triticosecale* Wittm.), cereal rye (*Secale cereale* L.), common vetch (*Vicia sativa*), radish (*Raphanus sativus*) and clover (*Trifolium incarnatum*) was seeded in 7.5-inch rows at 80 pounds per acre (lb/ac) in late October or early November at 20, 20, 30, 5 and 5 lb, respectively. The CCs were not irrigated in the fall of 2013, 2014 or 2015, but received 2 inches of sprinkler irrigation in 2016. In late March of the following year, the CC was cut at the soil line with a stalk chopper and the residue sprayed with 2% glyphosate and left on the surface as a mulch. In the ST system, the residue was disked into the soil. A 0.9-inch diameter drip tape with emitters every 13.8 inches and a flow rate of 0.16 gallons per hour was installed 12 inches deep and 60 inches apart (Netafim Streamline 875 0135F, Netafim USA, Fresno, Calif.) in all plots.

Dry fertilizer (11-52-00) was shank-applied to both crops at 200 lb/ac pre-plant. For weed control, in the sorghum plots, Dual Magnum (S-metolachlor) (24 ounces per acre [oz/ac]) and Clarity (Dicamba diglycolamine salt) at 8 oz/ac were applied pre-plant and post-establishment, respectively, while in the garbanzo plots, Prowl H2O (Pendimethalin) (20 oz/ac) and Chateau (Flumioxazin) (2 oz/ac), were applied post planting, pre-crop and pre-weed emergence for weed control. These materials were all spray-applied and incorporated using sprinkler irrigation.

The grain sorghum hybrids NK7829 (2014), 251 (2015) and K5585 (2016 and 2017) (Sorghum Partners, New Deal, Texas) were seeded on May 7, 2014, May 11, 2015, May 20, 2016, and May 22, 2017, respectively, using a John Deere 1730 six-row NT planter at 72,870 seeds/ac or about 4 seeds per foot of row. Garbanzo beans (AWF-1, 2015 and 2016, and UC27, 2017 and 2018) were inoculated with a crop-specific rhizobia bacteria and seeded using the same planter at 100,000 seeds/ac or about 5 seeds per foot of row on Feb. 5, 2015, Feb. 22, 2016, March 16, 2017, and March 9, 2018. Both crops were established with two sprinkler irrigations of 1 inch each.

Reference ET (ET_o) and crop coefficient (K_c) values were used to generate daily crop ET estimates to determine irrigation timing. ET_o data were acquired from a California Irrigation Management Information System (CIMIS; www.cimis.water.ca.gov) weather station located about 200 yards from the study field. K_c values were based on average crop canopy estimates of both crops (Hanson and May 2005; Hanson and May 2006). Irrigation frequency varied depending on ET demand

Research colleagues from California Ag Solutions, Madera, Calif., assist with John Deere 1730 no-tillage planter adjustments for garbanzo seeding. *Photo*: Jeffrey P. Mitchell.

conditions throughout the season but was typically two to three times per week. No precipitation occurred during any of the summer cropping seasons. Applied water amounts averaged about 20 inches for sorghum and 12 inches for garbanzo, which are close to historical estimates for crop evapotranspiration (ET_c) and commercial application volumes in the region (Long et al. 2019; Steduto et al. 2012) and which are within the bounds of consumptive water use (ET) estimates for well-watered sorghum (Steduto et al. 2012). The same amount of water was applied to all treatments of a given crop in each year. Weekly fertigations (32-0-0) as urea ammonium nitrate were applied to the sorghum crop totaling 165, 166, 185 and 218 lb/ac material in 2014, 2015, 2016 and 2017, respectively. The garbanzo crops were all carefully inoculated with rhizobia each year. No fertigated nitrogen applications were made to the garbanzos as is the custom in commercial fields in the region.

Crop stands were estimated by counting the

Thirty-foot wide combine harvester used for sorghum grain and garbanzo harvests. *Photo*: Jeffrey P. Mitchell.

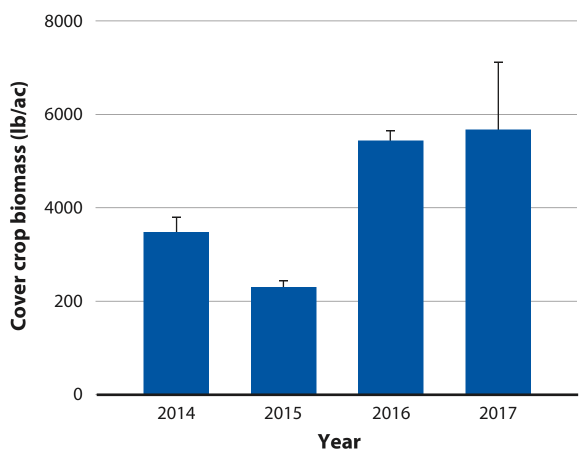


FIG. 2. Cover crop dry biomass (lb/ac) for cover crop systems 2014–2017.

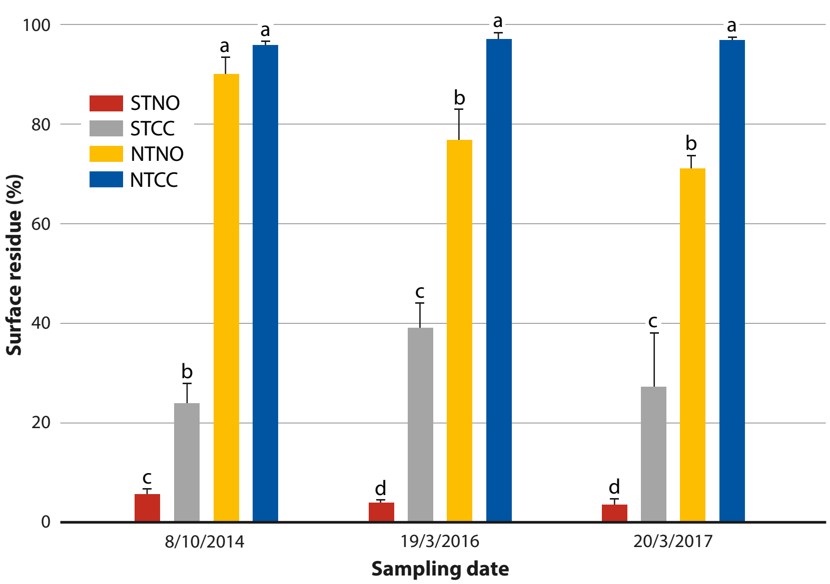


FIG. 3. Surface residue coverage (%) on Aug. 10, 2014, March 16, 2016, and March 20, 2017, as averages. Error bars represent standard errors. Systems with different lowercase letters within a given date are significantly different ($P \leq 0.05$).

number of emerged seedlings along two 100-foot lines within a plot about 2 weeks after planting. Canopy cover, in both crops, was estimated by taking one image per plot using the Canopeo image-analyzing app for iPhones. Final grain yield of sorghum was determined by harvesting 49.2-foot lengths of one row in a representative area in each plot with an 18.1-inch bundle plot thresher (Kincaid Equipment Manufacturing, Haven, Kan.) in 2015 and by harvesting and weighing the grain from an entire plot using a John Deere combine in the other years.

Sorghum harvests were conducted on Oct. 14, Sept. 4, Oct. 12 and Oct. 16 in 2014, 2015, 2016 and 2017, respectively. Garbanzo yields were determined by harvesting the entire plots in all years using a combine. Harvests were done on July 20, July 22, July 28 and Aug. 15 in 2015, 2016, 2017 and 2018, respectively. After harvest and intercrop tillage on Aug. 10, 2014 (post crop harvest), March 19, 2016, and March 20, 2017 (post cover cropping), surface residue was estimated using the line-transect method, which involves counting the number of intersections with surface residue pieces every foot along a 100-foot transect. Data were analyzed using SAS version 9.3 (SAS Institute Inc., Cary, N.C.) using a significance level of 0.05. The ANOVA model included year as a random effect, tillage type and CC system as fixed effects, and interaction between all combinations of year, tillage and CC. Yield data satisfied the assumptions (normality and homogeneity of variance) of ANOVA.

CC biomass production

Over the 5 years of the study that were characterized by recurring drought, a total of 8.4 tons of aboveground dry CC biomass (fig. 2) representing about 358 lb/ac nitrogen and 3.4 tons/ac carbon was produced with a total precipitation of 22 inches and 4 inches of supplemental irrigation in 2016 and 2017 to all plots (plus residual soil moisture following summer crops which is assumed to have been negligible). The CCs were typically seeded by Oct. 15 of each fall and terminated around Feb. 1 of the following spring for garbanzo and March 15 for sorghum, accounting for a growth period of 105 days before garbanzos and 120 days before sorghum. Compared to the systems with no CCs (NO), which were bare during this time, the CC treatments had an additional 90 days annually of actively growing green ground cover and living roots in the soil.

NT increased surface residue coverage

Both ST and CCs affected percentage surface residue (fig. 3). The NT systems had more surface residue than the ST systems and the CC plots had more residue than the no CC (NO) plots (97% for the NTCC, 82% for the NTNO, 30% for the STCC and 5% for the STNO across all sampling dates). Irrigation was provided as needed to all treatments in this trial and differences in soil water content were not measured. But previous work with other crops at the WSREC, work reported elsewhere (Unger and Parker 1976) and well-established micro-meteorological principles (T.C. Hsaio, Department of Hydrology, UC Davis, personal communication; Luo et al. 1992) suggest savings would be possible when irrigation water is limiting. Based on prior work at the WSREC (Mitchell et al. 2012) for a clay loam soil under sprinkler irrigation, approximately 13% (4 inches) of soil water loss from evaporation in a summer crop in the SJV was avoided when reduced disturbance residue-preserving practices were used. Similar responses should apply to all instances where NT management is followed for the production of warm season annual crops.

Sorghum yields similar in NT and ST

There were no significant interactions between year and tillage ($P = 0.91$), year and CC ($P = 0.68$), tillage and CC ($P = 0.18$) or year, tillage and CC ($P = 0.53$) on sorghum grain yield, but year was highly significant ($P < 0.001$). Averaged over the 4 years, the NT (4,757 ± 257 lb/ac) and ST (4,984 ± 278 lb/ac) had approximately similar yields. In analyses by year, there were no significant ($P > 0.05$) interactions between tillage and CC, and no significant tillage or CC effects on yield, implying that the yields were similar in the NT and ST plots (fig. 4). Unger and Baumhardt (1999) reported similar sorghum grain yield under NT and ST systems in Texas; however, our average yields were lower than reported average yields under irrigation (Steduto et al. 2012). We speculate that heavy infestations of the sugarcane aphid (*Melanaphis sacchari*) and observed leaf stickiness late in the season explains the lower yields in 2017 (J. Dahlberg, personal communication). There was no water deficit condition in this study.

CCs had no effect on yield. In arid and semiarid regions, soil moisture depletion by CCs may adversely affect successive crops, particularly if the CCs are allowed to grow into periods of high ET. Previous determinations of soil water depletion of CCs during the same winter period in the SJV indicate relatively small differences — on the order of 2 inches — between cover cropped and bare soil conditions (Mitchell et al. 2015) in the same field with the same soil type. Residues from CCs may also hinder planting and stand establishment, but they did not affect yield here. Also, although the combination of CC and NT was reported previously to improve several soil properties, including water infiltration, aggregate stability (Mitchell et al. 2017) and soil water-holding capacity (Araya et al., unpublished data), we did not see any effect from the CC on sorghum yield.

No-till sorghum seeding on May 22, 2017, into an NTNO (no-till, no cover crop) plot using a 6-row John Deere 1730 no-till seeder. On the lower right, there is an NTNO garbanzo plot. *Photo:* Jeffrey P. Mitchell.

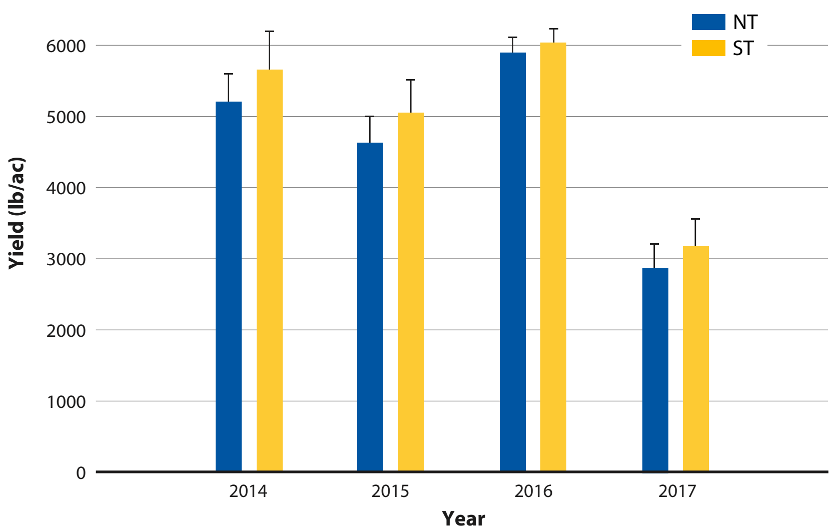


FIG. 4. Sorghum grain yields from 2014 to 2017. NT, no-tillage with and without a cover crop combined; ST, standard tillage with and without a cover crop combined. Data values show means and standard errors. For each year, there were no significant treatment effects or interactions.

Garbanzo yields in NT higher than ST in two of four years

In garbanzo, there was a highly significant year effect ($P < 0.001$), but no interactions between year and tillage ($P = 0.17$), year and CC ($P = 0.31$), tillage and CC ($P = 0.79$), or year, tillage and CC ($P = 0.81$). When each year was analyzed individually, there were no significant ($P > 0.05$) interactions, and no significant CC effects. NT produced greater yields ($P < 0.001$) than ST in 2015 ($P = 0.057$), 2016 ($P < 0.001$) and in 2017 ($P = 0.009$) (fig. 5). Thus, compared to ST, NT matched garbanzo yields in 2018 and surpassed yields in 2015, 2016 and 2017. Averaged over the 4 years, garbanzo yields were

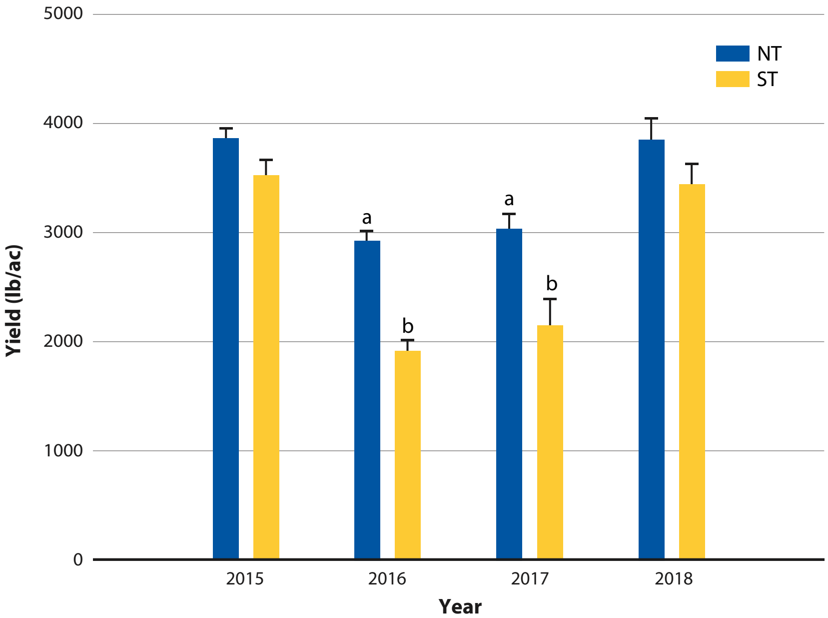


FIG. 5. Garbanzo yields from 2015 to 2018. NT, no-tillage with and without a cover crop combined; ST, standard tillage with and without a cover crop combined. Data values show means and standard errors. There were no significant treatment effects or interactions in 2015 and 2018. In 2016 and 2017, for each year separately, yields in NT were significantly greater than in ST.

approximately 25% greater in the NT compared to the ST plots. Similar to sorghum, CC did not affect yield in any year.

Inconclusive results on garbanzo growth in STCC plot

Early crop stand establishment for both crops across all study years was similar in all treatments. In 2017, garbanzos in the STCC grew significantly less than in the NTNO, NTCC and STNO treatments (fig. 6; this was not observed in other years). To determine whether NT promotes garbanzo growth or the STCC in particular suppressed growth, we investigated whether a fungus was responsible for either decreased growth in the STCC or for enhanced growth in the other treatments. Based on symptoms in mid-May 2017, we initially postulated that a *Fusarium* spp. was a pathogen in the STCC. However, neither pathogenicity tests nor high-throughput DNA sequences from the elongation factor intron-rich region (data not shown) indicated that there was an important pathogenic *Fusarium* spp.

In contrast, the high-throughput ITS rDNA sequences were consistent with the presence of the fungal pathogen *Macrophomina phaseolina* in the field. In the vigorous plants that were sampled from the STCC plots, 11% ± 5% of the sequences were *M. phaseolina*,

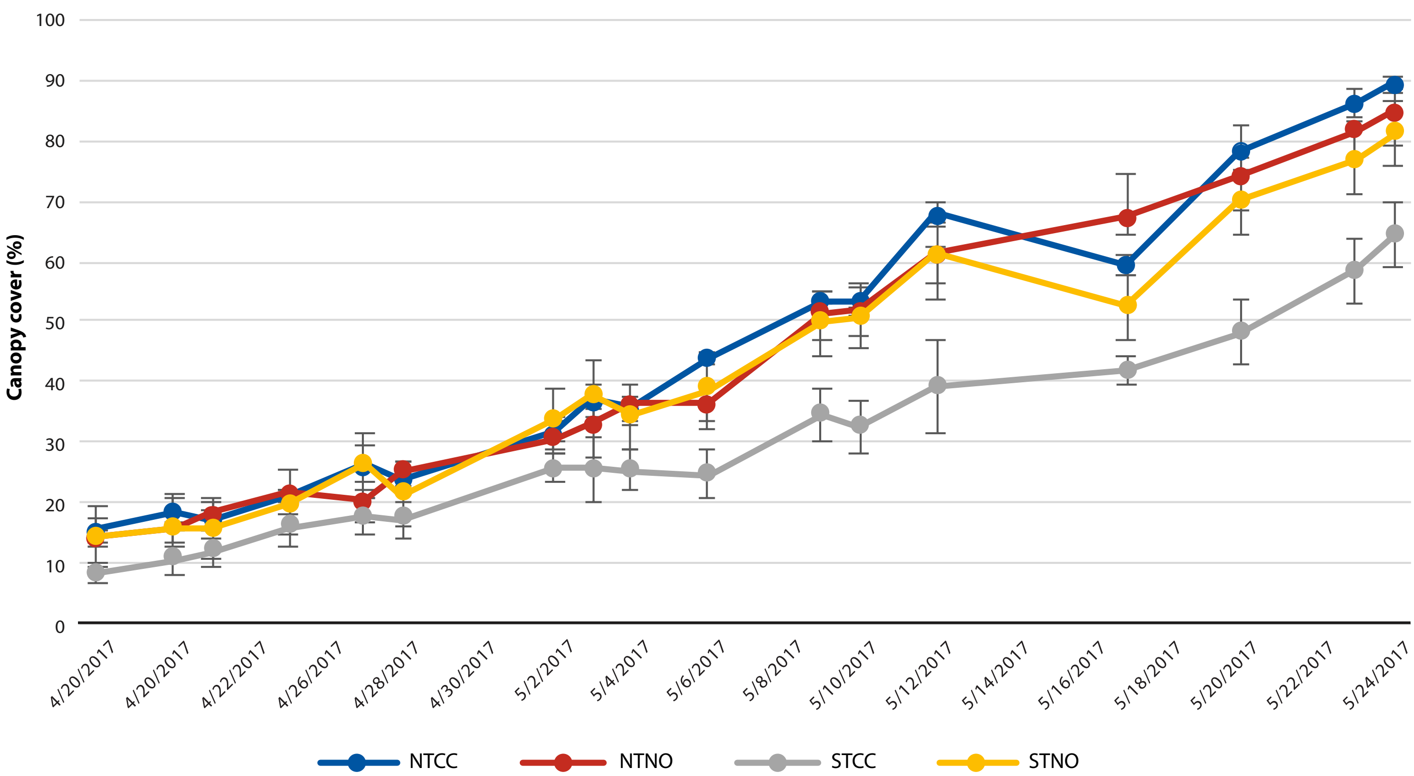


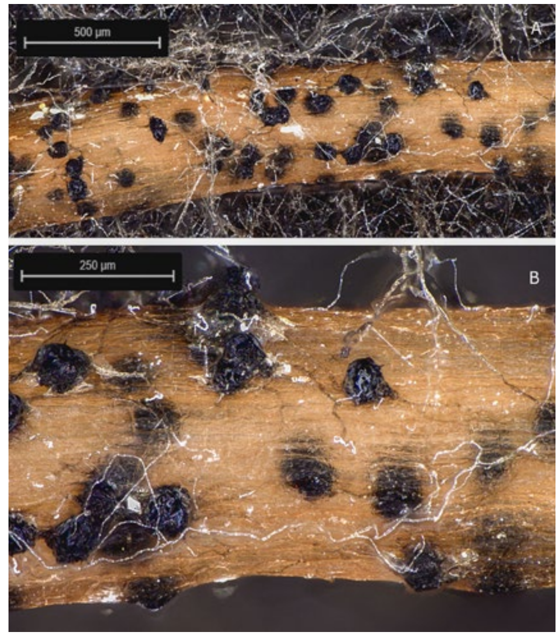
FIG. 6. Percent canopy cover for tillage and CC systems in garbanzo in 2017. NTCC, no-tillage and no cover crop; NTNO, no-tillage with no cover crop; STCC, standard tillage with cover crop; STNO, standard tillage no cover crop. An analysis of the slope of the linear regressions indicated that there was significantly less growth as measured by canopy cover in STCC than in the other treatments ($P = 0.01$), i.e., the CC under ST was harmful to garbanzo growth.

but in the unthrifty plants, 26% ± 18% of the sequences were *M. phaseolina*. Although we did not observe typical charcoal rot symptoms on roots in either 2017 or 2018, in mid-June 2018, we incubated roots and soil in conditions that were suitable for diagnosis and quantification of microsclerotia of *M. phaseolina*. In 2018, there were significantly more *M. phaseolina* microsclerotia in the STNO treatments that had been in garbanzos in the previous year than in the NT plots. Although we did not observe any classic charcoal rot symptoms, when the garbanzo root segments were incubated at a temperature conducive for *M. phaseolina*, the pathogen was readily isolated. Thus, in accordance with Magyarosy et al. (1985), growers should monitor for *M. phaseolina*, which flourishes in warmer temperatures. Because all systems were irrigated similarly throughout the season, it is unlikely that drought — a known factor for increasing the risk of disease in garbanzos — was the reason for lower growth in the STCC system. However, soils with high organic matter, such as perhaps the recently incorporated CC in the STCC system, are also known to increase risk of disease (Light 2018). A final possible explanation for the yield response of the STCC system in 2017 may have resulted from soil water deficit in the CC treatment; however, because rainfall during the winter of 2016–2017 was actually highest and above the 30-year average, this is unlikely.

NT may be a viable and water-efficient option for growing garbanzos and sorghum

ST practices have been used throughout the SJV for nearly 90 years. Using similar inputs and amounts and pest management, we show that a garbanzo and sorghum rotation in NT yielded at least as well as in ST. In our trial, NT yielded an average of 3,417 lb/ac of garbonzos versus ST, which had an average of 2,738 lb/ac. Garbanzo production in California, which is almost all in ST, averages 2,300 lb/ac (Long et al. 2019) statewide, with higher averages of 3,200 lb/ac typically reported in the SJV (L. Kubo, Rhode Stockton Bean LLC, Tracy, Calif., personal communication).

If water costs continue to rise as curtailments on water supply increase, the value of some agricultural land without allocations in California will eventually decline (Hanak et al. 2019), providing more of an economic incentive for using NT for growing a portfolio of crops, such as sorghum and garbanzo, somewhat more amenable to constraints on available water supplies. A review by Richter et al. (2017) of technically credible case studies that could help document the potential water savings attainable by using various strategies or technologies, including NT farming, found that reduced non-beneficial consumption derived from NT may increase water application efficiency and result in reductions in consumptive water use on the order of 3.5 inches per acre in a range of irrigation scenarios and locations compared to ST systems that do not have surface residues. While changes in soil function — including the increases in aggregation, water infiltration (Mitchell et al. 2017), porosity and water holding capacity (Araya 2019) that we documented in the NTCC system — may take several years to be achieved, generating and preserving surface residues as a first step toward transforming annual cropping systems in the ways we describe here can be done in a few cropping cycles. For these reasons, this work may serve as a decision-making tool for growers who are considering producing garbanzos and grain sorghum in the future, especially if there is the opportunity to both reduce management costs and maintain yields (Mitchell et al. 2008; Mitchell et al. 2016; Mitchell, Shrestha, Munk 2016). CA



A segment of an asymptomatic garbanzo root from an infected plant was cultured. These are two magnified images; the size bar is approximately 0.02 inches in (A) and 0.01 inches in (B). The root was infected by the plant pathogenic fungus *Macrophomina phaseolina*, which produces dark, multi-celled microsclerotia, its survival structure. The thin filaments are the fungal hyphae. *Photo*: Lynn Epstein.

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RESEARCH ARTICLE

Addressing organizational climate can potentially reduce sexual harassment of female agricultural workers in California

Assessing antecedents for sexual harassment among California's agricultural workers yields insight into the causes and consequences of this behavior and suggests ways to mitigate it.

by Malcolm Hobbs, Emanuelle Klachky and Monica Cooper

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Abstract

Workplace sexual harassment (SH) has been highlighted as a key issue for female agricultural workers in the United States. This study investigated how workers' descriptive data (age, job experience, attitudes) and specific organizational variables (how work crews are structured) potentially facilitate SH in an agricultural setting. Harassment was reported by 30% of surveyed female viticulture workers in their current jobs. Harassed women tended to be younger, employed seasonally and working in crews where hostile sexist views were prevalent. Harassment affected worker productivity; harassed women and their male co-workers were less satisfied with their jobs and more likely to seek other employment. Efforts to address SH by restructuring at the level of the field crew may be ineffective. Instead, addressing workers' hostile sexist attitudes and the extent to which an organization tolerates SH appears to have the most promise for reducing SH in agricultural industries.

Of the estimated 3 million farmworkers in the United States, approximately 1 million are employed in California, where a well-documented labor crisis (Martin 2017) has been driven by diminishing numbers of male migrant workers. Viticulture is one of many agricultural industries affected. In 2017, Napa County vineyards, which employ 10,000 farmworkers, experienced an estimated 12% shortage of vineyard laborers (Martin et al. 2019; Giovanni Peri, UC Davis Economics Department, personal communication). This labor shortage could have been considerably worse if not for an influx of female workers into the Napa County labor pool. Between 2013 and 2016, the proportion of female seasonal laborers in Napa vineyards increased from 10% to 25%, mirrored by a smaller increase in permanent laborers (Hobbs and Cooper 2017). There are indications that similar gender shifts are occurring in other California regions. The economic motivation is, therefore, stronger than ever for agricultural companies to reduce barriers to the employment and retention of female workers. One such barrier is workplace sexual harassment (SH).

Researchers collected data on sexual harassment, job satisfaction, and turnover from farmworkers in the Napa Valley. *Photo:* Malcom Hobbs.

Studies in the United States estimate that from 40% to 75% of all working women have experienced SH and that rates have not decreased since the 1980s (McDonald 2012). Furthermore, SH rates are higher (70% to 80%) in male-dominated and lower-income jobs (Buchanan et al. 2014; Fitzgerald 2019), categories that include agricultural labor (Arcury et al. 2015; Murphy et al. 2015). California is no exception; in one study, 80% of female farm laborers reported experiencing SH (Waugh 2010) and, in a recent survey of farmworkers in northern California, 44% of women reported SH (Prado et al. 2018).

Defined as "unwanted sex-related behavior at work that is appraised by the recipient as offensive . . . or threatening her well-being" (Fitzgerald et al. 1997), SH of women is one of the most prominent and detrimental barriers to women's career development and satisfaction (Willness et al. 2007). Sexual harassment covers a range of behaviors usually placed on a continuum of severity. One common typology assigns behaviors into three categories: gender harassment, unwanted sexual attention and sexual coercion (Fitzgerald et al. 1997). All of these behaviors have negative consequences for both the victims and the organizations in which they work (Pina and Gannon 2012; Willness et al. 2007). Victims report debilitating effects on their physical and mental well-being (O'Leary-Kelly et al. 2009; Pina and Gannon 2012; Street et al. 2008). In addition, they are less productive, less satisfied with and committed to their jobs and have higher absenteeism and turnover rates (Macdonald 2012; Pina and Gannon 2012). SH may also act as a stressor for entire work teams, with negative impacts on intrateam interactions, cohesion and performance (Raver and Gelfand 2005). All these consequences incur economic costs.

To tackle SH, a company needs to understand the antecedents. For example, it is important for a company to know which workers are at highest risk and in what work scenarios SH is most likely to occur. Organizational studies in other industries have identified multiple antecedent variables of SH over the last 30 years (MacDonald 2012). It was our objective to test these in an agricultural context (Willness et al. 2007), with the aims of improving our understanding of which antecedent conditions are present in agricultural work environments, specifically viticulture, and to assess how they are related to reported incidence of SH and work outcomes, that is, job satisfaction and job retention. In doing so, our goal was to provide practical guidance for the local industry and, by extension, other agricultural industries, as well as to learn which approaches may be effective for addressing SH, a significant barrier to women excelling in the workforce.

Measuring study variables

Our study focused on the organizational level of the work team because agricultural workers spend most of their time working in small groups (field crews). We quantified three categories of antecedent variables based on organizational models (Raver and Gelfand 2005): (1) personal and situational characteristics of female workers, (2) job gender context and (3) organizational climate (see below and table 1). Our primary criterion for selecting each antecedent measure was the likelihood a company could influence that variable if it were linked to SH. These antecedents were compared with a measure of SH, which was then compared to work outcomes as a demonstration of how SH can negatively impact productivity (fig. 1).

Personal and situational characteristics

The personal and situational characteristics we measured were age, employment status, duration of employment in the company, crew size and the presence of relatives on a crew. Previous studies have found that women with temporary employment contracts are more vulnerable to SH than those with permanent fixed contracts (LaMontagne et al. 2009), and that younger women are consistently identified as at greater risk than older women (MacDonald 2012).

TABLE 1. Study measures

Personal and situational	(1) Age: years; (2) crew size: no. members; (3) duration of employment: days worked in company; (4) employment status: seasonal or permanent; (5) number of relatives present in crew
Job gender context	Percentage of female members in vineyard crew
Organizational climate	(1) SH awareness training: participant completion of SH training (yes/no) and the percentage of crew members replied "yes"; (2) hostile sexism: four statements selected from the Ambivalent Sexism Inventory (ASI; Glick and Fiske 1996) based on judged ease of comprehension for the participants and scores totaled on a rating scale from 0 (completely disagree) to 5 (completely agree). Cronbach's alpha = 0.64.
Sexual harassment incidence	Revised Sexual Experiences Questionnaire (SEQ): Nineteen items measuring frequency of SH behaviors on a scale of 0 (never) to 4 (very often). Subscales of gender harassment (GH), unwanted sexual attention (USA) and sexual coercion (SC). The SEQ does not define a time period for participants so they responded only with respect to their current employment. Cronbach's alpha = 0.69.
Work outcomes	(1) Agricultural Job Satisfaction Survey (AJSS; Hobbs, Klachky, Cooper 2020): 32 statements, rated from 0 (completely disagree) to 5 (completely agree). Total scores provide value of overall job satisfaction. Cronbach's alpha = 0.87. (2) Turnover intentions (Abbas et al. 2012): three-statement tool using same scale as AJSS. Cronbach's alpha = 0.71.

Job gender context

Job gender context refers to the "balance of genders in the work environment" (Quick and McFayden 2017). We adopted a common measure: the ratio of male to female members in a crew. Women have consistently been shown to be more vulnerable to SH in male-dominated teams and organizations than they are in gender-balanced or female-dominated contexts (McCabe and Hardman 2005).

Organizational climate

Organizational climate is the extent to which an organization tolerates SH and the effectiveness of any remedies put in place to combat it. A permissive social climate for SH behaviors, as well as failures to properly address complaints by recipients, facilitate SH (O'Leary-Kelly et al. 2009). Awareness training programs are widespread across industries to educate employees on what constitutes SH and appropriate workplace behaviors (Cortina and Berdahl 2008). In California, these training programs are mandatory for supervisors in companies with at least 50 employees, but they are not mandatory for crew members. We took an indirect measure of organizational climate, measuring how many crew members had completed SH awareness training, to assess the impact of training on reported incidence of SH. We also measured hostile sexist attitudes associated with perpetration of, and tolerance for, SH (Begany and Milburn 2002; De Judicibus and McCabe 2001). Hostile sexist attitudes were measured using questionnaire items from the Ambivalent Sexism Inventory that reflect aggressive attitudes to women and opinions that women are inferior (Glick and Fiske 1996).

SH incidence and work outcomes

We measured incidence and severity of SH using the Sexual Experiences Questionnaire (SEQ) (Fitzgerald 1993), which quantifies the three types of SH mentioned previously: gender harassment (offensive comments, jokes or gestures), unwanted sexual attention (physical contact or requests for sexual relationship) and sexual coercion (job-related rewards or reprisals contingent on sexual cooperation). We measured two work outcomes using questionnaires for turnover intentions (thoughts and plans about quitting job), which is an established predictor of actual turnover (Lambert et al. 2001), and job satisfaction, which is negatively linked to turnover (Hobbs, Klachky, Cooper 2020).

Data collection

We collected data from male (*n* = 195) and female (*n* = 100) Hispanic vineyard workers from 21 distinct crews across nine companies operating in Napa County. The nine companies consisted of seven contract labor companies (vineyard management or labor contractors) and two estate vineyard companies who employed their crews directly. Each participating company, except one estate vineyard, had more than 50 employees. Eighty-five participants (29% female) reported they were permanent employees, and 198 participants (67% female) reported they were temporary seasonal employees. At the time of the survey (April to July 2018), all workers were engaged in standard crop-production tasks (e.g., canopy management), but not harvest. Questionnaires were presented to workers in groups during their work breaks. Study questions were displayed on a flipchart while a bilingual researcher read them aloud in Spanish. Crew members answered using electronic response pads (Turning Technologies, Youngstown, Ohio), which allowed participants to respond anonymously. Each question also had a "do not wish to respond" option so that participants could opt out of responding to specific items. All questions except the SEQ were presented to all participants, both male and female, within their work crews. After they finished the questionnaires, the male employees returned to work, out of sight and hearing range, and the female workers were taken aside in small groups (with a maximum of six participants) to conduct the SEQ. All female workers agreed to participate in the SEQ, but some participants chose not to answer all items.

Incidence of SH

Gender harassment was reported by 30% of female crew members, of which 9% also reported unwanted

FIG. 1. Summary of theoretical models and variables investigated. Measures were selected from existing models (e.g., O'Leary-Kelly et al. 2009). Antecedents may influence the probability of sexual harassment occurring, which in turn impacts work outcomes.

sexual attention and 1% reported sexual coercion. The relative prevalence of these SH categories mirrored the pattern in prior California studies, although the rates of workers reporting SH in our study were considerably lower than the rates (44% to 80%) reported in those studies (Prado et al. 2018; Waugh 2010). This may be explained by regional and crop-specific differences. For example, working conditions in Napa vineyards are generally considered better than those in other agricultural sectors, with workers offered above-average wages and benefits (Hobbs, Herrero et al. 2020; Hobbs, Klachky, Cooper 2020). Additionally, we considered harassment only at a worker's current company, not throughout the worker's overall agricultural or working career, which could have resulted in a lower reporting rate compared to previous studies.

The low rates of unwanted sexual attention and sexual coercion in our study were far lower than those found in other studies. Such low rates reflect well on the Napa industry, but they may also, despite the anonymity of responses, indicate a reluctance among women to admit severe harassment when participating alongside co-workers and in a study coordinated as we did this one. The small number of women reporting unwanted sexual attention or sexual coercion meant we were not able to consider an analysis of the relationship between the severity of SH with the other variables measured. Instead, we focused on two types of group comparison based on the presence or absence of SH: (1) women reporting any type of harassment versus women reporting no harassment, and (2) crews where SH was reported (SH+) versus crews where SH was absent (SH–). We analyzed average scores or counts except for crew gender ratio, SH awareness training and relatives in crew. For these three variables, we classified female participants into additional groups based on the percentage of females in a crew, the percentage of crew members that were SH-trained and the presence or absence of relatives in a crew. Thus, female participants were assigned either to a low-female (7% to 40%) group or a high-female (44% to 100%) group and either to a low-SH-trained group (18% to 63%) or to a high-SH-trained group (75% to 100%), using a median split.

Characteristics of harassed vs. non-harassed women

Descriptive data for harassed and non-harassed female participants (table 2) show that harassed women in our study differed on two antecedent variables. As in other industries (Street et al. 2008), harassed women were significantly ($P = 0.001$) younger than non-harassed women; women under 40 years of age accounted for two-thirds of reported harassment cases in our study. Second, 89% of women reporting the more severe categories of harassment (unwanted sexual attention, sexual coercion) were seasonal employees. More female seasonal workers (33%) than permanent workers (22%) reported gender harassment, although this relationship was not statistically significant ($P = 0.28$). Harassed and non-harassed women did not differ significantly in the presence of relatives on their crews, the duration of their employment, crew size, crew gender ratio or the number of members in their crew that had received SH awareness training (all *P*s = ns, not

TABLE 2. Descriptives comparing harassed and non-harassed female crew members

	Non-harassed (*n* = 70)	Harassed (*n* = 30)		
		GH (*n* = 30)	USA (*n* = 9)	SC (*n* = 1)*
Personal and situational characteristics				
Age range (years)	20–68	18–47	21–47	—
Mean (+SD) age	40.8 (9.9)	32.7 (9w.5)	31.3 (10.0)	25
Crew size range	6–32	8–20	16–20	—
Mean (+SD) crew size	15.0 (6.0)	16.4 (3.3)	18.1 (1.5)	19
Mean (+SD) employment time (days)	431 (777)	634 (832)	545 (840)	21
Employment status (perm./seas.)	24/44	7/22	1/8	Seasonal
Family present/absent in crew	32/38	13/17	3/6	Absent
Job gender context and organizational climate				
Crew gender ratio (low/high)	33/37	13/17	4/5	Low
Crew SH training (low/high)	33/37	18/12	5/4	High
Work outcomes				
Mean (+SD) turnover intentions	3.1 (4.0)	5.97 (4.7)	6.3 (5.1)	12
Mean (+SD) overall job satisfaction	104.6 (26.3)	91.3 (25.6)	92.3 (36.1)	—

*Actual values for woman reporting sexual coercion.
GH = gender harassment; USA = unwanted sexual attention; SC = sexual coercion; SD = standard deviation.

significant). Harassed women had significantly higher turnover intentions ($P = 0.002$) and lower overall job satisfaction ($P = 0.033$) compared to non-harassed women, supporting prior research (Pina and Gannon 2012) on the negative impact of SH on morale and worker productivity.

Comparing crews with SH vs. no harassment

We compared descriptive data for SH+ and SH– crews (table 3) on hostile sexism (aggregated across all crew members, both men and women) and male work outcomes. Mean scores for hostile sexism were significantly higher ($P < 0.000$) in SH+ crews compared to mean scores in SH– crews, supporting the theory that sexist attitudes contribute to a climate of SH tolerance (Begany and Milburn 2002). This complemented our finding of a higher incidence of gender harassment over other types of SH. The hostile sexism questionnaire can thus be considered an attitudinal measure of the behavioral gender harassment component of the SEQ, as hostile sexist attitudes appeared to be enacted as behavioral harassment towards women workers. Turnover intentions for male members of SH+ were significantly higher ($P = 0.024$) and job satisfaction was lower ($P = < 0.000$) than they were for males in SH– crews. We could not determine whether dissatisfied male workers were more likely to perpetrate SH or if witnessing SH adversely affected male workers; however, the latter has previously been concluded in other research (Miner-Rubino and Cortina 2007).

Implications for companies

We identified several variables associated with the presence of SH in agricultural work crews, and we demonstrated that SH is associated with a decline in work outcomes. The type of design we employed in this study cannot verify causation between variables, only association. However, these statistical associations, together with consideration of the literature on SH in other industries, provides grounds for healthy speculation as to how agricultural companies might address SH among their workers.

High-risk workers

Young women were clearly identified as high-risk targets for SH. The oldest woman reporting SH was 47; most harassed women in this sample were 40 years or younger. Despite the lack of statistical differences in SH incidence between seasonal and permanent female workers, the severe forms of SH were overwhelmingly reported by seasonal workers. While recognizing that all workers are at risk of SH, companies should therefore be especially vigilant of the risk to young and seasonal female workers.

Structure of work crews

Changing the structure of work crews is unlikely to reduce SH. In our study, harassed women worked in crews that were large and small, with or without relatives, and with considerable variation in gender ratio. Harassed women were just as likely to be working on crews with a high percentage of females (44% to 100%) as on crews with a low percentage of females (7% to 41%). This was unexpected, as meta-analyses have demonstrated gender ratios to be a significant predictor of SH (Willness et al. 2007). However, the gender ratio effect may be small, and as SH occurs in a range of organizational settings (McCabe and Hardman 2005), the characteristics of SH perpetrators may be more important. For example, perpetrators in male-dominated workplaces tend to be co-workers, whereas perpetrators in female-dominated workplaces are more likely to be supervisors (Pina and Gannon 2012). The questionnaire we used in our study did not ask women about the perpetrators, but the unimportance of crew gender ratio indicates the possibility that SH may have originated not only from inside the crews but from outside, such as from supervisors or other company employees. Our presumption that the crew level is the most relevant company unit for SH was too optimistic. We often observed multiple crews working in the same vineyard, and they often mixed during work breaks; SH could therefore have originated from other crews, especially as the SH reported in our study was primarily verbal and gestural in nature. Crew membership was also probably more fluid than our study design conceived. Women were asked about SH only during their current employment, but these women did not necessarily work continually in the same crew configuration. If gender ratio is an important antecedent of SH in agriculture, we predict it will be at the level of the company rather than at the level of the work team.

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Organizational climate

Our results, as supported by the literature (Russell and Trigg 2004), indicate that an improvement in organizational climate is a more effective method for tackling SH than a restructuring of work crews. The hostile sexist attitude of both men and women in a crew was significantly associated with the presence of SH. Companies can expect to reduce SH by changing or neutralizing these attitudes. However, shifting these attitudes may be difficult to accomplish, as indicated by our finding that previous SH awareness training was not related to a decrease in reported SH. Similar

TABLE 3. Descriptives comparing SH– and SH+ crews and male work outcomes

	SH– crew	SH+ crew
Mean (+SD) male turnover intentions	4.9 (5.2)	6.6 (5.2)
Mean (+SD) male overall job satisfaction	108.6 (24.4)	88.7 (26.7)
Mean (+SD) crew hostile sexism	9.2 (2.4)	12.9 (2.4)

poor efficacy of SH awareness training has been reported in prior research (Quick and MacFayden 2017), suggesting that improvements are needed to the structure and administration of awareness training for agricultural workers. Unless these changes are made, other organizational climate variables, such as the internal management of complaints and the overall social climate of a company (Jiang et al. 2014; Quick and MacFayden 2017), are more likely to be effective in reducing SH. There is still value in conducting training, as it has been shown to make women more likely to report SH and it makes workers more aware of what is (un)acceptable behavior (MacDonald 2012; Quick and MacFayden 2017). Since we did not collect details on which training programs the workers received, we cannot comment on the efficacy of one training program over another.

S[exual] h[arassment] has the potential to significantly affect the stability of the labor pool in a time of labor shortage . . .

SH and company performance

Harassed females reported lower job satisfaction and higher intention to quit their jobs, illustrating that SH is likely resulting in companies losing female workers and experiencing other negative effects (e.g., lower performance) associated with poor worker satisfaction. The same reduced outcomes were reported by male workers in crews where harassment was occurring, suggesting that SH may be impacting not only the targets but also the co-workers. Dissatisfaction among men as a result of SH thus also has the potential to negatively affect company performance.

The challenge of SH

The current study demonstrated that workplace sexual harassment of female vineyard workers affects the well-being and retention of all workers in an agricultural sector where there is a paucity of quantitative data on the issue. Furthermore, this study illustrated that female workers in entry positions to the industry (young, seasonal) are most at risk of SH, illustrating that SH is

The study's results indicate that an improvement in organizational climate is a more effective method for tackling sexual harrassment than a restructuring of work crews. *Photo:* Monica Cooper.

a barrier for women seeking to enter the agricultural workforce. Thus, SH has the potential to significantly affect the stability of the labor pool in a time of labor shortage and to incur economic costs not only for workers but also for agricultural organizations seeking to train and retain stable work crews.

Incidence of SH in our study was lower than that previously reported for farmworkers, but our results should be treated with some caution; there may have been some underreporting due to our method of data collection and our relatively small sample size. This study also measured SH in one region (Napa County, Calif.) and one crop only, and incidence rates may not generalize to other agricultural regions and sectors. Workplace policies and practices that reduce or eliminate hostile sexist attitudes appear to have the most promise for reducing SH in agriculture. However, accomplishing these goals with limited resources and within a company's traditional organizational structure may be challenging. Future studies may seek to consider in more detail how organizational climate can be effectively addressed in the agricultural sector, the effectiveness of different SH awareness programs and the characteristics of perpetrators of SH towards women. CA

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RESEARCH ARTICLE

Biological and chemical pruning wound protectants reduce infection of grapevine trunk disease pathogens

Identifying fungicides that protect grapevines from multiple grapevine trunk diseases is vital in maintaining California's vineyard economy.

by Robert Blundell and Akif Eskalen

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Abstract

Grapevine trunk diseases (GTDs) are currently considered some of the most important challenges for viticulture, curtailing vineyard longevity and productivity in nearly every raisin, table and wine grape production region in California and worldwide. Pruning wounds provide the main entry point for fungal pathogens responsible for these diseases; pathogens enter the wounds following precipitation events. The aim of this study was to evaluate the efficacy of selected chemical and experimental biological fungicides for protection of pruning wounds against two of the most common and virulent fungal pathogens causing GTDs: *Eutypa lata* and *Neofusicoccum parvum*. This study was conducted on sauvignon blanc at the UC Davis Department of Plant Pathology Field Station. Results showed that several chemical and biological fungicides, notably the chemical fungicide Luna Sensation, the biofungicide Vintec and a combination of the biofungicides Bio-Tam and CrabLife Powder, provided significant protection against at least one of the two canker pathogens used in this study. However, the majority of products tested did not provide simultaneous control of both *E. lata* and *N. parvum* pathogens, highlighting the continuing challenge of controlling GTDs.

Cultivated for over 7,000 years, grapevines are today one of the most extensively grown and economically important woody fruit crops in the world. In 2018, approximately 18.3 million acres (7.4 million hectares) of grapevines were cultivated and 77.8 million tons of fruit were harvested around the globe (OIV 2019). In the United States, California leads the way in grape production; in 2019, grapevine cultivation totaled 918,000 acres (37,000 hectares) (CDFA and USDA NASS 2019). *Vitis vinifera* (common grapevine) cultivars are the most widely planted in California and elsewhere, yielding a high commercial value for fresh table grape, dried fruit and wine production (Gramaje et al. 2018; Mullins et al. 1992).

However, *V. vinifera* is susceptible to infection by a large variety of pathogenic microorganisms, including fungi, oomycetes, viruses and bacteria (Gaulon-Brain et al. 2007). Among the most destructive infections are the grapevine trunk diseases (GTDs). Caused by a broad range of taxonomically unrelated fungi, GTDs present a major threat to the economic sustainability

Results from a UC Davis field trial of sauvignon blanc indicate that *Trichoderma*-based biological fungicides can protect against both *E. lata* and *N. parvum*, but the majority of treatments tested were not effective in controlling both pathogens simultaneously. *Photo:* Robert Blundell.

of table and wine grape productions worldwide (Trouillas et al. 2010). They cause serious economic losses due to a significant reduction of both yields and quality of grapes; they also increase crop management costs for cultural and chemical preventative measures (Bertsch et al. 2013; Gubler et al. 2005; Kaplan et al. 2016; Siebert 2001). Important GTDs include Eutypa dieback, Botryosphaeria dieback, Esca, and Phomopsis cane and leaf spot. In this study, we tested two of the most prevalent GTD fungal pathogens found in California crops, *Eutypa lata* and *Neofusicoccum parvum*, which are causal agents of Eutypa dieback and Botryosphaeria dieback, respectively (Gramaje et al. 2018; Moller and Kasimatis 1980).

Fungal entry points

Infection of grapevine by GTDs occurs after precipitation events, when spores of fungal pathogens (sexual and asexual) become airborne and colonize exposed pruning wounds resulting from winter pruning (Eskalen et al. 2007; Petzoldt et al. 1983; Rooney-Latham et al. 2005; Úrbez-Torres et al. 2008). Following pruning, grapevine wounds remain susceptible to infection by canker pathogens for several weeks (Eskalen et al. 2007; Munkvold and Marois 1995; Úrbez-Torres et al. 2008). During this time, the plants can become infected multiple times with one or more pathogens. Because several pathogens are frequently isolated from old cankers, GTDs are often referred to as a complex (Gramaje et al. 2018; Larignon and Dubos 1997; Rolshausen et al. 2004; Úrbez-Torres et al. 2006). Several years after infection occurs, grapevine yields can decline due to formation of wood cankers and/or plugging of the xylem and phloem vessels in the trunk or cordon, resulting in impaired translocation of water and nutrients. When the affected vineyards are no longer profitable, growers have no alternative but to remove the infected vines and replant.

Control of grapevine trunk diseases

Complete control of GTDs is virtually unattainable because of the high number of pruning wounds made on individual grapevines and the extended period of wound susceptibility, but there are options for minimizing the impact of these diseases. Previous studies evaluated

Botryosphaeria dieback is also known as black dead arm. *Photo*: Akif Eskalen.

Botryosphaeria canker. *Photo*: Akif Eskalen.

Stunted shoots are common symptoms of Eutypa dieback. *Photo*: Akif Eskalen.

Wedge-shaped Eutypa dieback canker. *Photo*: Akif Eskalen.

a range of chemical fungicides for their ability to prevent infection of grapevine pruning wounds by *E. lata*. The most effective were carbendazim, tebuconazole, pyrimethanil, fluazinam and pyraclostrobin. However, these chemicals were applied to the wounds at rates greater than those currently registered for other diseases of grapevines (Sosnowski et al. 2008; Sosnowski et al. 2013), and some have been banned because of health and safety concerns (Bertsch et al. 2013).

Commercial chemical fungicide treatments available in the United States, such as a combination of Rally and Topsin M (active ingredients myclobutanil and thiophanate-methyl, respectively), have also been shown to be effective in controlling fungi associated with GTDs (Rolshausen and Gubler 2005; Sosnowski et al. 2008). In addition to chemical fungicides, biofungicides (for bio control without chemicals) have generated considerable interest as pruning wound protection strategies. Beneficial microorganisms are known to reside inside roots, stems and leaves of plants; these microorganisms help protect the plants from a range of infections (Lodewyckx et al. 2002). Biofungicides contain several of these beneficial microorganisms, including *Trichoderma* spp. and *Bacillus* spp., which have been shown to provide protection against GTDs (John et al. 2005; Kotze et al. 2011; Mutawila et al. 2016). In this study we sought to evaluate the efficacy of commercially available and experimental chemical and biological fungicides against *E. lata* and *N. parvum* infection on pruning wounds of grapevine under field conditions.

Field trial design

We conducted our field trial in an 8-year-old sauvignon blanc vineyard at the UC Davis Plant Pathology Field Station in Yolo County. Grapevines in the vineyard had been trained to bilateral cordons (the "arms" of the vine) on a horizontally divided trellis with typically 10 spurs per cordon. In early March 2019, we pruned the spurs so that each bore three, 1-foot-long buds. Within 24 hours of pruning, we sprayed liquid formulations of each treatment onto the exposed pruning wound until run off. The treatments were prepared according to commercial label recommendations (table 1) and applied with 1-liter handheld plastic spray bottles. Unless otherwise shown in table 1, the pruning wounds were artificially inoculated within 24 hours of spraying with a 20-μl aqueous spore suspension (approximately 1,000 spores per wound) of each fungal pathogen.

In this study, we inoculated a total of 10 grapevines per treatment. We applied a treatment combination (one pathogen + one fungicide) to two pruning wounds on each grapevine, organized in a random block design. We selected treatments based on varying groups or types of active ingredients and modes of action. In the control treatment, we applied sterile distilled water to wounds and then inoculated the wounds with the same spore concentration of each pathogen as we used in the fungicidal treatments.

Preparation of fungal inocula

We collected dead wood from grapevine trunks naturally infected with stromata of *E. lata* in a vineyard in Lodi, California. After releasing fruiting bodies (ascospores) from 5-centimeter-long wood segments (as described by Carter 1991), we adjusted the ascospore concentration to 2.5×10^4 ascospores/mL. We also collected dead grapevine wood with fruiting bodies (pycnidia) of *N. parvum* from naturally infected grapevine trunks in the same Lodi vineyard, and we adjusted the concentration to equal that of *E. lata*: 2.5×10^4 pycnidiospores/mL. We added a 0.05% solution of Tween 20 as a surfactant to both pathogen inocula. Prior to inoculation, we confirmed the viability of inoculum suspensions by plating on potato dextrose agar medium (PDA).

Fungal inocula were applied to pruning wounds following application of liquid treatments. *Photo*: Akif Eskalen.

Calculating efficacy of pathogen control

Treated spurs were allowed to stand for 6 months before collection and laboratory analysis. After we collected the spurs, we split each one with a knife longitudinally and then cultured six small tissue pieces (three from the pith and three from the margin of the dead wood or from any area exhibiting discoloration) on PDA amended with tetracycline at 100 mg/L (PDA-T). After incubating the tissues at room temperature for 7 to 14 days, we recorded the recovery of the fungal pathogens by means of their morphological characteristics. We confirmed the identity of isolates by sequencing the ITS region of the isolates' rDNA, and we calculated the efficacy of the protectants controlling the GTDs as the mean percent of infection (MPI). We used the following formula for the MPI calculation:

$$(\text{Number of GTD-infected spur samples} / \text{number of total samples}) \times 100.$$

We calculated the mean percent disease control (MPDC) on the basis of the MPI of the inoculated control treatment, using the formula (100 × (1 − (MPI treatment / MPI inoculated control))). Means comparisons were made using Dunnett's test $\alpha = 0.05$. We performed all data analysis using JMP software version 14 (SAS Institute, Cary, N.C.).

Differences in *E. Lata* and *N. parvum* responses

Both *E. lata* and *N. parvum* colonized the pruning wounds in our treated samples, but they had different infection rates (figs. 1 and 2). Treatments overall protected pruning wounds against *E. lata* infection more effectively than they protected against *N. parvum*.

TABLE 1. Fungicide pruning wound treatments evaluated in Yolo County field trial, 2019

Treatment	Active ingredient	Regulatory status	Class	Manufacturer	Pathogen interval	Rate
Inoculated control	N/A*	N/A	N/A	N/A	N/A	N/A
Spur Shield	Polymer of cyclohexane	Registered	Barrier†	Miller	Within 24 hrs of pruning	1.5 qt/A‡
Vitiseal	Acrylic co-polymer	Registered	Biological	VitiSeal International LLC	Within 24 hrs of pruning	0.5 gal/A
Vitiseal + EMP Polymer	Acrylic co-polymer + co-polymer emulsion	Registered	Biological + barrier	VitiSeal International LLC + Gemm Ag Solutions	Within 24 hrs of pruning	0.5 gal/A
EMP Polymer	Co-polymer emulsion	Registered	Barrier	Gemm Ag Solutions	Within 24 hrs of pruning	1%
Terramera (experiment B)	Proprietary information	Experimental	Biological	Terramera Inc.	Within 24 hrs of pruning	2.4 (% v/v)
Terramera (experiment B) + EMP Polymer	Proprietary information	Experimental	Biological + barrier	Terramera Inc. + Gemm Ag Solutions	Within 24 hrs of pruning	2.4 (% v/v) + 1%
Luna Sensation	Fluopyram/ trifloxystrobin	Registered	Chemical	Bayer CropScience	Within 24 hrs of pruning	5.0 fl oz/A
Luna Experience	Fluopyram	Registered	Chemical	Bayer CropScience	Within 24 hrs of pruning	6.0 fl oz/A
Rally + Topsin M + organosilicone surfactant	Myclobutanil + thiophanate-methyl	Registered	Chemical + chemical	DOW AgroSciences LLP	Within 24 hrs of pruning	2.25 oz + 1.25 lb/A
Rally + organosilicone surfactant	Myclobutanil	Registered	Chemical	DOW AgroSciences LLP	Within 24 hrs of pruning	2.25 oz + 1.25 lb/A
Rally + Spur Shield	Myclobutanil + polymer of cyclohexane	Registered	Chemical + barrier	DOW AgroSciences LLP	Within 24 hrs of pruning	2.25 oz + 2 qt/A
Rally + Topsin M + Spur Shield	Myclobutanil + thiophanate-methyl+ polymer of cyclohexane	Registered	Chemical + barrier	DOW AgroSciences LLP	Within 24 hrs of pruning	2.25 oz + 1.25 lb + 2 qt/A
Rally + Vitiseal	Myclobutanil + acrylic co-polymer	Registered	Chemical + biological	DOW AgroSciences LLP	Within 24 hrs of pruning	2.25 oz + 2 qt/A
Bio-Tam + CrabLife Powder	*Trichoderma asperellum* + *Trichoderma gamsii* + a blend of crab and lobster shell powder	Experimental	Biological	Isagro USA + Conchazul de Mexico	7 days after pruning	2.0 lb/100 ga + 0.5 lb/100 ga
Bio-Tam	*Trichoderma asperellum* + *Trichoderma gamsii*	Experimental	Biological	Isagro USA	7 days after pruning	2.0 lb/100 ga
CrabLife Powder	A blend of crab and lobster shell powder	Experimental	Biological	Conchazul de Mexico	7 days after pruning	0.5 lb/100 ga
GCM (spray fermented product at wound)	*Bacillus velezensis*	Experimental	Biological	N/A	Within 24 hrs of pruning	12 fl oz/A
Lalitha 21 (spray on wound)	*Trichoderma* spp. + *Bacillus subtilis* + *Azospirillium brasilense*	Registered	Biological	Acela Biotek	Within 24 hrs of pruning	12 fl oz/A
Vintec	*Trichoderma atroviride*	Experimental	Biological	Bi-PA	Within 24 hrs of pruning	0.7 oz/A

* N/A = not applicable.
† A barrier provides a physical layer of protection against pests and pathogens.
‡ A = acre.

Of 20 treatments 16 controlled *E. lata* at least 50% more effectively than the inoculated controls did, and six of these treatments had an MPDC higher than 90% (table 2). For *N. parvum*, only Vintec and Rally + Topsin M + Spur Shield resulted in an MPDC of at least 50% (table 2). A total of eleven treatments limited the MPI of *E. lata* to under 20% and were significantly different ($P < 0.05$) from the MPI of the inoculated control treatment, but only Vintec and Rally + Topsin M + Spur Shield significantly reduced *N. parvum* infection compared to the inoculated control (figs. 1 and 2). The treatments EMP Polymer, Vitiseal, Rally + Spur Shield, and Rally + Vitiseal had an MPDC of 0% for *N. parvum* (table 2). These treatments in fact resulted in a higher MPI of *N. parvum* compared to that of the inoculated control, with the inoculated control yielding 78% MPI. The highest MPI for *N. parvum* was Rally + Vitiseal, yielding 90% (fig. 2). The low control rate of *N. parvum* versus *E. lata* can likely be attributed to *N. parvum*'s more aggressive nature and faster colonization of woody tissue (Galarneau et al. 2015).

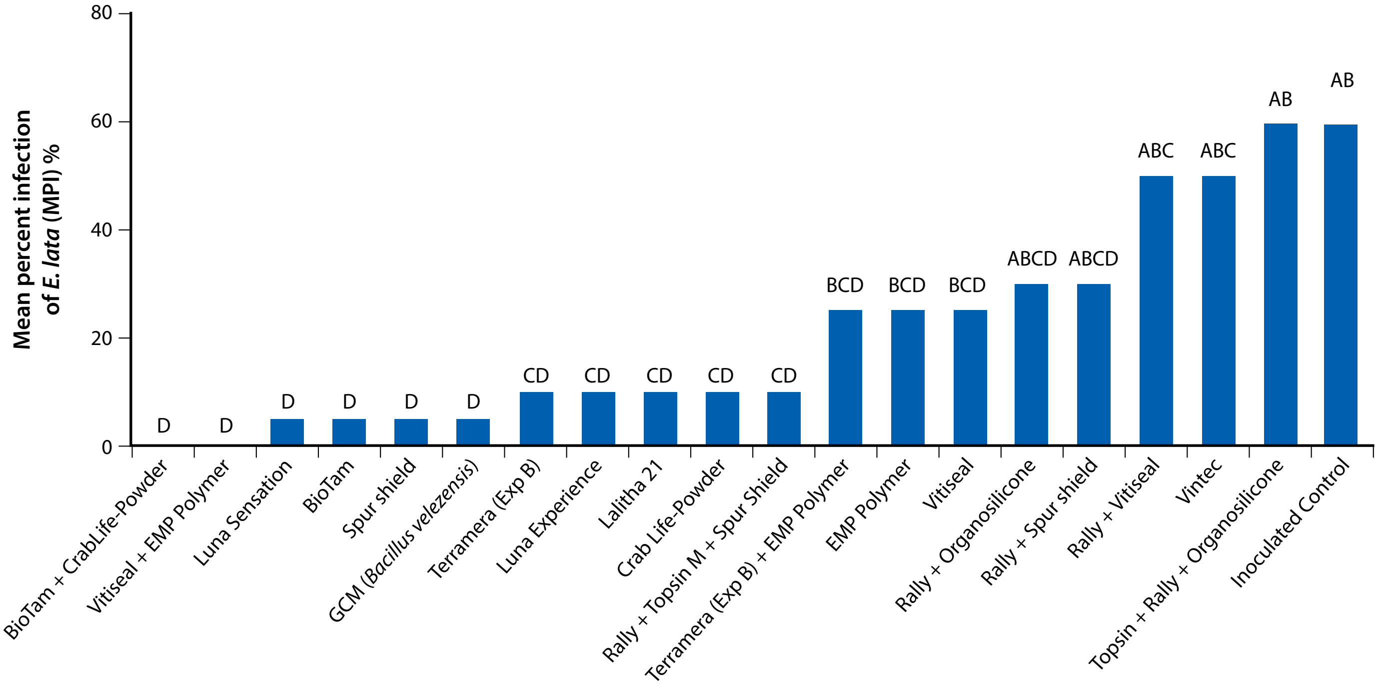

FIG. 1. Evaluation of pruning wound treatments mean percent infection (MPI) rates with *E. lata* located at UC Davis Plant Pathology Field Station, 2019. Bars represent the least square means of percent infection. Bars with a different letter are different according to Dunnett's test ($P = 0.05$).

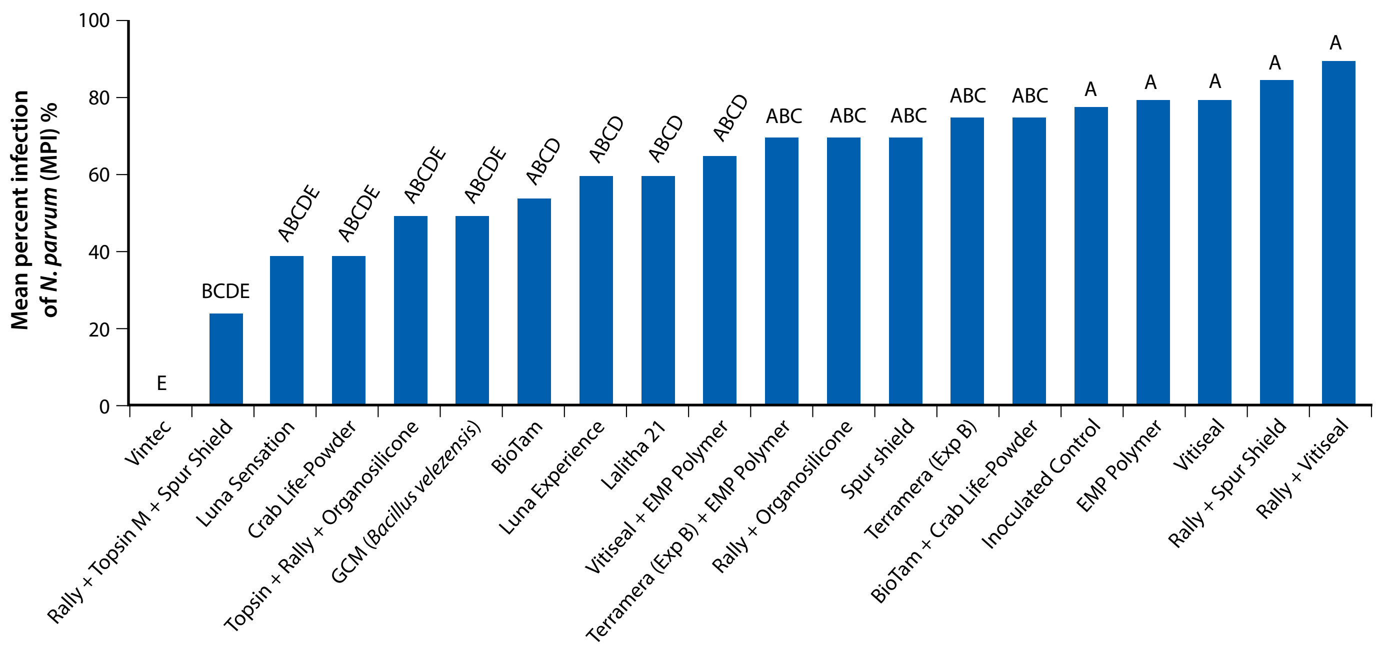

FIG. 2. Evaluation of pruning wound treatments mean percent infection (MPI) rates with *N. parvum* located at UC Davis Plant Pathology Field Station, 2019. Bars represent the least square means of percent infection. Bars with a different letter are different according to Dunnett's test ($P = 0.05$).

Higher than natural pathogen pressure

To ensure significant infection of control spurs, we inoculated pruning wounds with a significantly higher number of spores than that estimated to infect a pruning wound naturally (Carter and Moller 1971). Sosnowski and Mundy (2019) showed that MPI from noninoculated controls was 3% to 6% for *E. lata,* and 12% to 17% for *N. luteum*. In contrast, the MPI for our inoculated controls was 65% for *E. lata* and 78% for *N. parvum* (fig. 2). Similar results were reported by other researchers using high spore-count treatments. Rolshausen et al. (2010) reported that the inoculated control treatment for a Botryosphaeriaceae pathogen had an MPI of 90%, and Sosnowski and Mundy (2019) reported an MPI of 59% for *E. lata* averaged over multiple years. The high MPI rates in our inoculated controls are therefore likely the result of the large spore concentrations we applied to the pruning wounds. In future studies, it may be prudent to compare the effectiveness of treatments under both high and moderate-to-low disease pressure. For example, Sosnowski and Mundy (2019) in New Zealand showed that when disease pressure was moderate (i.e., 40% to 60% recovery of pathogens from inoculated controls), fungicide efficacy was far greater than when the disease pressure was high (greater than 60%). Under the high disease pressure in our study (greater than 60%), the majority of treatments performed well as pruning wound protectants against *E. lata,* but this might not be the case under natural conditions.

Trichoderma-based biological fungicides

In this study, *Trichoderma*-based biological fungicides performed the best against both of the fungal pathogens we investigated, with Vintec performing the best against *N. parvum* and Bio-Tam + CrabLife Powder performing the best against *E. lata* (figs. 1 and 2). It may be prudent in future studies to combine Vintec and Bio-Tam + CrabLife Powder in a single application to see if they can provide effective pruning-wound protection against multiple GTD pathogens. Interestingly, Bio-Tam was more effective than Bio-Tam + CrabLife Powder against *N. parvum,* which suggests that CrabLife Powder might have an inhibitory effect on the *Trichoderma* spp. that are the active ingredients in Bio-Tam. The commercial success of biocides containing *Trichoderma* spp., representing more than 60% of registered biocides, is based on the benefits they confer. Depending on the strain, *Trichoderma* species can stimulate plant growth, suppress pathogens by direct competition for nutrients and space, exhibit antibiosis and induce systemic resistance (Harman 2006; Mukherjee et al. 2013). Other pruning-wound studies have also shown that *Trichoderma* spp. can provide effective control against fungal pathogens associated with GTDs (Berbegal et al. 2020; John et al. 2005).

Simultaneous control of pathogens is necessary

Identifying pruning wound treatments that can control multiple GTD pathogens will be essential for mitigating GTD infections. In our study, some treatments provided effective control of both *E. lata* and *N. parvum,* including Luna Sensation, Rally + Topsin M + Spur Shield, CrabLife Powder, Bio-Tam and GCM (*Bacillus velezensis*). Rally + Topsin M + Spur Shield had a high efficacy against both *E. lata* (MPDC of 84.62%), and *N. parvum* (MPDC of 67.95%). While we found that *Trichoderma*-based biological fungicides are capable of protecting wounds with high efficacy, it should be highlighted that some biofungicides in this trial were not effective in controlling both pathogens. For example, Bio-Tam + CrabLife Powder had 100% disease control of *E. lata*, yet this combination only had 3.85% MPDC of *N. parvum* (table 2). Inversely, Vintec had 100% disease control of *N. parvum* but only 23% MPDC of *E. lata*. Similar results were reported by Rolshausen et al. (2010) where biopaste was very efficient in controlling *E. lata* but did not control species in the Botryosphaeriaceae family.

Grapevine spur positions were pruned to three 1-foot-long buds in early March 2019. *Photo:* Akif Eskalen.

TABLE 2. Pruning wound treatments mean percent disease control (MPDC) of *E. lata* and *N. parvum*

	MPDC	
	E. lata	*N. parvum*
Bio-Tam + CrabLife Powder	100.00	3.85
Vitiseal + EMP Polymer	100.00	16.67
Luna Sensation	92.31	48.72
Bio-Tam	92.31	29.49
Spur Shield	92.31	10.26
GCM (*Bacillus velezensis*)	92.31	35.90
Terramera (Exp B)	84.62	3.85
Luna Experience	84.62	23.08
Lalitha 21	84.62	23.08
CrabLife Powder	84.62	48.72
Rally + Topsin M + Spur Shield	84.62	67.95
Terramera (Exp B) + EMP Polymer	61.54	10.26
EMP Polymer	61.54	0.0
Vitiseal	61.54	0.0
Rally + organosilicone	53.85	10.26
Rally + Spur Shield	53.85	0.0
Rally + Vitiseal	23.08	0.0
Vintec	23.08	100.00
Topsin + Rally + organosilicone	7.69	35.90
Inoculated control	0.0	0.0

Testing of various cultivars and pathogens needed

While our results are encouraging, the climatic conditions at our experimentation site and the cultivar we used for this study likely differ from those of other grapevine-growing regions. Further research should evaluate these promising fungicides against GTDs pathogens in diverse conditions, including various geographical locations and cultivars. The susceptibility of pruning wounds to fungal pathogens may also vary depending on the fungal isolate used in a specific study (Sosnowski et al. 2007). Future studies on fungicide efficacy should include multiple isolates of a specific pathogen species.

In conclusion, our study has shown that several chemical and biological fungicides can provide efficient protection of pruning wounds against at least one canker pathogen, and some are effective at controlling both. The combination of Luna Sensation with Rally + Topsin M + Spur Shield, for example, offered simultaneous control of both *E. lata* and *N. parvum*. Remaining challenges include improving accurate diagnoses of GTDs and identifying additional treatment products efficacious against a broad diversity of fungal canker pathogens. CA

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RESEARCH ARTICLE

Proposed changes to the H-2A program would affect labor costs in the United States and California

This article explores how the H-2A visa program is used in the United States, especially in California, and how proposed changes to the program would affect labor costs.

by Philip Martin and Zachariah Rutledge

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Abstract

The H-2A visa program allows farmers in the United States to be certified by the U.S. Department of Labor to recruit and employ guest workers, usually for a maximum of 10 months, when they are unable to find enough workers living in the United States (including U.S. citizens, other legally authorized workers, and workers not authorized to work in the United States). We analyzed U.S. and California H-2A job certification data to determine how the program is currently used and how a proposed H-2A wage freeze would likely affect future farm labor costs. Our analysis suggests that changes in the H-2A visa program would likely expand the program while reducing labor costs in California and elsewhere.

Since 1952, the H-2 (and, since 1986, the H-2A) visa programs have allowed farmers in the United States who anticipate a shortage of workers in the United States (U.S. citizens, other legally authorized workers, and workers who do not have U.S. government–issued work authorization credentials, hereafter referred to as undocumented workers) to fill seasonal farm jobs with workers from other countries (guest workers). Employers seeking to recruit and hire H-2A workers must first be certified by the Office of Foreign Labor Certification (OFLC) of the U.S. Department of Labor (DOL). The certification process requires that an employer satisfy three major criteria each year to hire seasonal guest workers: (1) try (and fail) to recruit U.S. workers, (2) offer free and approved housing to both H-2A workers and out-of-area U.S. workers and (3) pay an adverse effect wage rate (AEWR), which varies by state. (The AEWR for California was $14.77 an hour in 2020, 14% more than the state's $13 minimum wage.) Once employed, H-2A guest workers are tied to their employers by contracts and reside in the United States for an average of 6 months.

The original H-2 program was created in the 1952 Immigration and Nationality Act as a means to recruit temporary workers in post-WW II America. During

H-2A guest workers make up almost 3% of employment in California crop agriculture. In fiscal year 2020, California had 25,453 jobs certified to be filled with H-2A workers; 94% of those jobs were certified to crop or crop support employers. *Photo:* Danny Magno, Driscoll's.

the 1950s, fewer than 10,000 agricultural jobs were filled by H-2 workers each year, predominantly in the Florida sugarcane industry. In contrast, the separate Bracero program — initiated in 1942 to recruit mostly Mexican guest workers — was much larger, peaking at 450,000 admissions a year in the mid-1950s. After the Bracero program ended in 1964, the DOL made it difficult for agricultural employers to switch seamlessly from Braceros to H-2 workers and, during the 1970s, H-2 certifications stayed low, confined primarily to the harvesting of sugarcane in Florida and apples in northeastern states (Martin 2009). The H-2 program was still relatively small in 1986 when the Immigration Reform and Control Act (IRCA) separated the program into two parts: H-2A for agricultural seasonal guest workers and H-2B for nonagricultural workers.

The IRCA included two legalization programs, including one for undocumented workers that granted legal status to 1.1 million individuals and imposed federal sanctions or fines on employers who knowingly hired undocumented workers. Many people expected legalized agricultural workers to move into higher-paying, nonagricultural jobs, and, as agricultural employers presumably sought to avoid fines for hiring undocumented workers, an upsurge in H-2A guest workers (Martin and Luce 1988). However, unauthorized migration of undocumented individuals increased in the 1990s, as some workers learned to provide false work-authorization credentials when hired. The IRCA did not require employers to determine the validity of worker documents, and the Immigration and Naturalization Service did not vigorously enforce the new employer sanctions law (Commission on Agricultural Workers 1992).

The H-2A program remained small in the 1990s because workers with false documents were readily available. After the Florida sugarcane harvest was mechanized in the mid-1990s, the locus of H-2A employment shifted from Florida sugarcane to North Carolina tobacco and to vegetable and apple farms in the Northeast (Martin 2009).

Since 2000, the H-2A program has quadrupled in size, and California has become one of the top five H-2A states (fig. 1). During fiscal year 2020 (FY20, from October 1, 2019, to September 30, 2020), California employers submitted 713 of the 13,549 applications submitted to the DOL's OFLC for H-2A certification. We analyzed all of these applications, as well as the 8,935 job offers that resulted from them, including 223 from California employers. (Some employers submitted several applications.) We found that California H-2A job offers promised each worker an average of $14,400 for approximately 26 weeks of work, more than the $12,500 average for 24 weeks of work by a U.S. worker (at an average wage of $13/hour). This examination of U.S. and California H-2A job offers provides a guide as to how the H-2A program would likely evolve under several proposed changes.

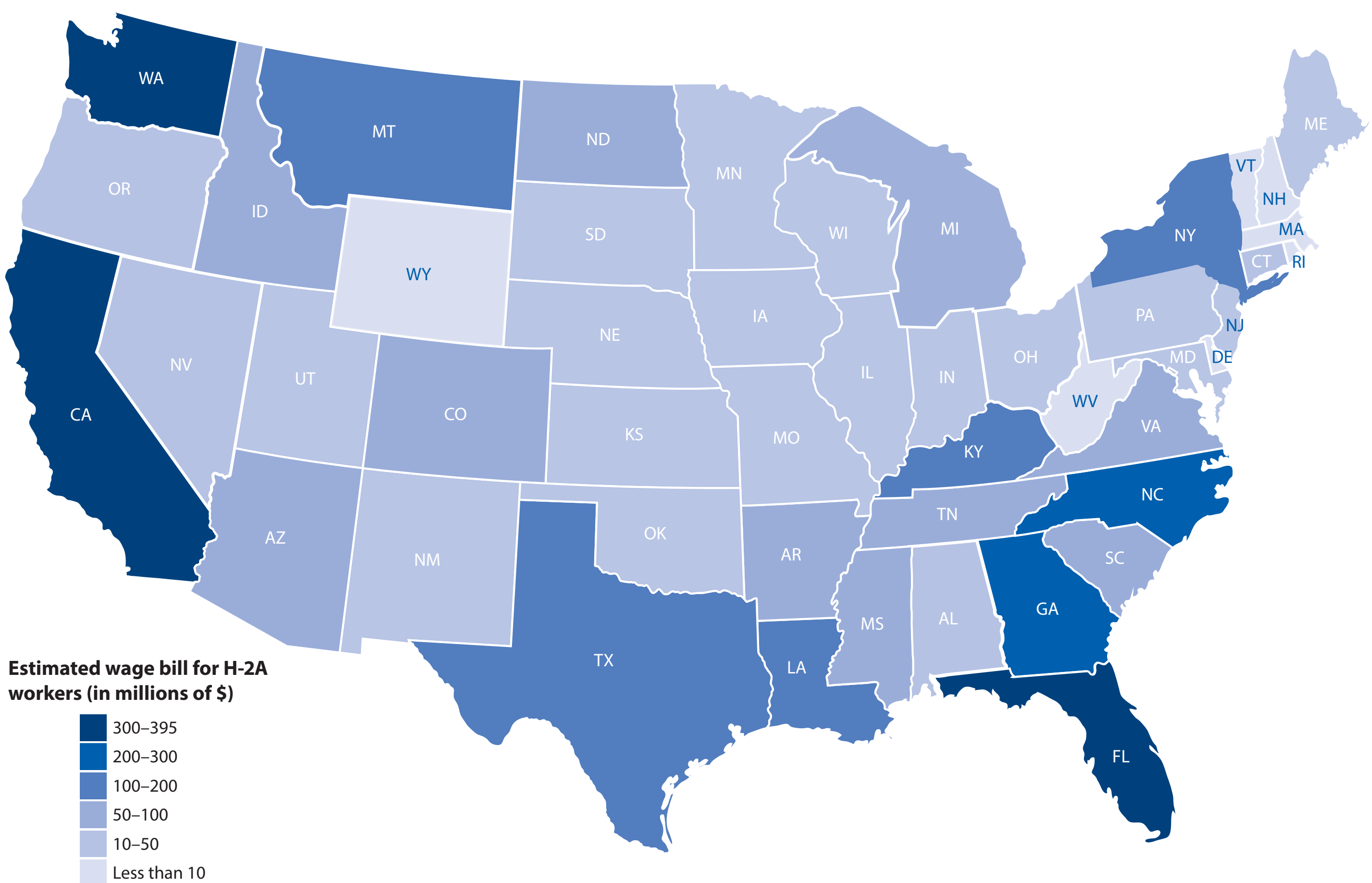

FIG. 1. H-2A wage bills by state (FY20). *Source:* OFLC Disclosure Data.

U.S. statistics and trends

The 2008–2009 recession slowed the entry of undocumented workers into the U.S. labor force. As a result, U.S. employers began to request more H-2A workers. The U.S. Immigration and Customs Enforcement (ICE) agency stepped up audits of the I-9 forms signed by newly hired guest workers and their U.S. employers (DOL OFLC 2021). ICE audits made employers aware of undocumented employees. In response, some employers formed associations to recruit and transport H-2A workers to their farms so that they would have employees with legal documents.

From 2010 to 2020, the number of certified H-2A jobs in the United States more than tripled, from 75,000 in FY10 to over 275,000 in FY20 (DOL OFLC 2021). Not all of the certified H-2A jobs are filled by such workers, and some H-2A visa holders are able to fill two or more certified jobs, as when an employer association moves a worker from one farm to another. In FY20, the number of H-2A visas issued was 213,000, 77% of the number of jobs certified (fig. 2).

Today, there are 1.5 million year-round or full-time equivalent (FTE) jobs in U.S. agriculture, including 1.1 million in crop cultivation and 400,000 in animal agriculture. California accounts for 425,000, almost a third, of these jobs, most of them (390,000, or 90%) in crop cultivation (BLS 2021). H-2A workers reside in the United States an average of 6 months, so two H-2A guest workers are equivalent to one full-time U.S. worker. H-2A workers thus account for almost 10% of average employment in U.S. crop agriculture and almost 3% of employment in California crop agriculture (BLS 2021; DOL OFLC 2021). California is one of six states that each had more than 10,000 H-2A jobs certified in FY20 (table 1). These six states collectively accounted for 55% of all U.S. H-2A certifications. Florida had 14% of H-2A jobs certified, Georgia and Washington had 10% each, California had 9%, North Carolina had 8% and Louisiana had 4%. H-2A workers play a much larger role in crop agriculture in southeastern states, such as Florida and Georgia, than in California and Washington, because more jobs are certified for H-2A workers and these states have less employment in crops.

All employers are exempt from paying federal unemployment insurance (UI) taxes on the wages of H-2A workers, and half of all states exempt H-2A workers from state UI taxes as well, including the states in the southeastern United States. California and Washington do not exempt H-2A wages from state UI taxes, so the Quarterly Census of Employment and Wages (QCEW) data approximate a census of agricultural employment and wages in these states.

The average number of H-2A jobs per certified U.S. application was 20 in FY20. The average duration of job offers or contracts was 168 days (24 weeks), and employers offered guest workers an average of 39.3 hours of work per week (943 total hours) (table 2). At an average U.S. AEWR wage of $13.29 an hour,

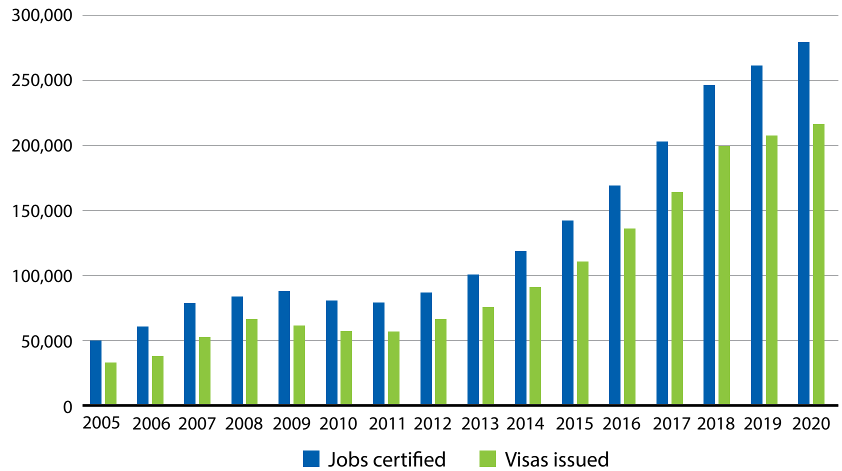

FIG. 2. U.S. H-2A jobs certified and visas issued, FY05–FY20. *Sources:* DOL OFLC 2021; U.S. Department of State 2020.

TABLE 1. H-2A jobs and FTEs certified by state (FY20)

State	H-2A jobs	H-2A FTE jobs	Average annual crop employ (NAICS 111 + 1151)	H-2A FTEs/ QCEW
Florida	39,064	19,532	56,687	34%
Georgia	27,614	13,807	13,523	102%
Washington	26,832	13,416	89,544	15%
California	25,453	12,727	387,319	3%
North Carolina	22,052	11,026	13,588	81%
Louisiana	11,332	5,666	4,873	116%
U.S. total	275,430	137,715	888,268	16%

Source: OFLC disclosure data and 2019 QCEW annual employment data.

Average annual crop employment in column three is employment covered by unemployment insurance. States such as California and Washington require all agricultural employment to be covered by UI, while southeastern states do not, which is why full-time equivalent H-2A employment can exceed average UI-covered employment in Georgia and Louisiana.

TABLE 2. H-2A average job offers in the United States, California and Florida (FY20)

	United States	California	Florida
Total jobs certified	275,430	25,453	39,064
Average number of jobs per certified application	20	36	67
Average length of employment: days	168	183	164
Average length of employment: weeks	24	26	23
Average anticipated hours per week	39	38	37
Average earnings ($): U.S. AEWR $13.29, Calif. $14.77, Fla. $11.71	$12,711	$14,738	$10,119

Source: OFLC disclosure data.

a typical H-2A contract during FY20 was thus worth $12,711, and the total H-2A wage bill for the country was $3.5 billion. Almost half of this total wage bill was paid in the top five H-2A states (fig. 1): Florida ($395 million), Washington ($386 million), California ($375 million), North Carolina ($275 million) and Georgia ($228 million).

The value of H-2A job offers and thus H-2A wage bills by state are approximate for several reasons. First, only 80% of certified job orders result in the issuance of H-2A visas. Second, workers could earn less than 100% of the contract value if a job finishes early. (Employers must satisfy the three-fourths guarantee in these cases, meaning that they must guarantee at least three-fourths of the pay specified in a job offer.) On the other hand, workers could earn more than 100% of a contract's value if they work more hours than promised, if they work under piece-rate wage systems and earn more than the AEWR or if they earn overtime wages and bonuses. There are no data on H-2A worker earnings, but analysis of payroll data from some employers suggests that our estimates are a lower bound since most H-2A contracts offer less than 40 hours of work a week and many H-2A workers are employed more than 50 hours.

Florida had the most jobs certified to be filled with H-2A workers in FY20, an average of 67 per application. Florida's average contract length was 23 weeks with an average of 37 hours per week, so that the average contract was worth $10,119 at the state's AEWR of $11.71. In California, the number of jobs per certified application averaged 36 in 2020. The average duration of California H-2A contracts was 183 days, or 26 weeks, and the average hours offered per week was 38; thus, an H-2A worker who was paid the state's AEWR of $14.77 an hour would have earned $14,738. In FY20, California had three of the 10 largest H-2A employers in the United States, and all were farm labor contractors (FLCs), including two that operated in both California and Arizona (table 3). (The largest California H-2A employer, Fresh Harvest, is based in Imperial County but also has operations in Yuma, Arizona.) California's three largest H-2A employers accounted for a third of all H-2A jobs in the state in FY20 and offered contracts whose value ranged from $8,700 to $16,300, putting California FLC contracts near the low and high ends of the spectrum among the top H-2A employers.

California statistics and trends

Although California is today one of the top users of the H-2A program, California farmers have been reluctant to use it for several reasons (Martin 1994). First, some employers feared that union supporters might respond to the job offers they were required to make to U.S.

TABLE 3. Contract value for top 10 U.S. H-2A employers (FY20)

Employer	Employer state	Jobs certified to employer in state	Total jobs certified by employers in state	Employer's share of total jobs certified to employers in state	Average number of weeks per contract	Average hours of work per week per job in contract	Estimated average value of contract per job
The North Carolina Grower's Association, Inc.	North Carolina	10,639	19,739	54%	28	40	$14,020
Fresh Harvest, Inc.	California	4,445	27,707	16%	21	35	$10,922
Fresh Harvest, Inc.	Arizona	881	6,168	14%	22	35	$10,140
Wafla	Washington	4,358	26,186	17%	24	37	$14,409
Foothill Packing, Inc.	California	2,280	27,707	8%	28	40	$16,252
Foothill Packing, Inc.	Arizona	919	6,168	15%	23	42	$12,320
Farm Op Kuzzens H2A, LLC	Florida	2,998	60,124	5%	18	36	$ 7,851
Rancho Nuevo Harvesting, Inc.	California	2,864	27,707	10%	17	35	$ 8,651
Peri & Sons Farms, Inc.	Nevada	2,608	3,164	82%	20	44	$12,593
Overlook Harvesting Company, LLC	Florida	2,418	60,124	4%	14	37	$ 7,192
Temp Labor, LLC	Florida	2,252	60,124	4%	33	35	$13,456
Zirkle Fruit Company	Washington	2,206	26,186	8%	24	35	$13,225

Source: OFLC disclosure data.

Note: Employer names varied in the database, so that the same employer could be listed as, for example, "Wafla," "WAFLA" and "wafla," and employers could operate in multiple states, as with "Peri & Sons Farms Inc." and "Peri & Sons Farms of California, LLC." We combined data for employers whose names changed, and we used only the in-state jobs of employers who were certified to employ H-2A workers in multiple states.

workers in order to be certified, potentially opening the door to a union election and bargaining obligation. Second, some employers objected to paying an AEWR that exceeded the state's minimum wage and did not have the free housing that must be offered to H-2A workers. Third, because all H-2A employers are required to make their job offers public, some employers feared that they would become the targets of investigations by labor law enforcement agencies, who could quickly compare employer promises to actual wages and working conditions.

In FY20, California had 25,453 jobs certified to be filled with H-2A workers, including 24,015 jobs, or 94%, certified to crop or crop support employers. Nine counties in California each had more than 1,000 certified H-2A jobs (fig. 3), but the distribution of H-2A certifications by county differed from the distribution of agricultural employment by county. The top five California counties for H-2A jobs — Monterey, Santa Barbara, San Luis Obispo, Ventura and Fresno — accounted for 55% of the H-2A certified jobs, even though these five counties accounted for only 38% of the state's crop and crop support employment. Monterey County was California's leading H-2A employer in FY20, with 6,394 certified jobs, followed by Santa Barbara County with 2,668 certified jobs, and San Luis Obispo, Ventura and Fresno counties, each with more than 1,500 certified jobs.

Most California H-2A jobs in FY20 were with crop and crop support employers (NAICS 111 and 1151). In Monterey County, 6,155, or 96%, of the H-2A jobs were with crop and crop support employers. These contracts offered an average of 222 days of work, which means that H-2A workers filled 3,748 FTE jobs, or 7% of average crop and crop support employment. The 2,513 H-2A crop and crop support jobs certified in Santa Barbara County offered an average 209 days and comprised 1,438 FTE jobs, or 6%, of the county's average crop and crop support employment. San Luis Obispo County contracts averaged 239 days, so the 1,774 crop and crop support jobs represented 1,164 FTE jobs, or 25%, of county crop and crop support employment. Ventura County had 1,667 jobs, with an average length of 127 days representing 578 FTE jobs, or 2%, of county crop and crop support employment. Fresno County had 1,457 jobs, with an average duration of 104 days and represented 414 FTE jobs, or 1% of county crop and crop support employment.

H-2A jobs are concentrated in coastal counties that tend to have high wages and high housing costs. Half of California agricultural employment is in the San Joaquin Valley, where there have been relatively few H-2A job certifications because U.S. workers are available.

Proposed H-2A changes

The H-2A program is an efficient mechanism to obtain just-in-time guest workers who are tied to employers by contracts, providing labor insurance to producers of perishable commodities at the cost of paying for worker housing and transportation of perishable commodities. There have been many efforts to modify the program, and on July 26, 2019, the DOL's OFLC proposed major changes. Among them was a shift from the current practice of setting one AEWR per state to setting separate AEWRs for each occupation or job title. The OFLC proposed to use earnings data from the U.S. Department of Agriculture's (USDA) Farm Labor Survey (FLS) to set AEWRs for most farm jobs. However, they proposed the use of the DOL's Occupational Wage and Employment Statistics (OWES) program to set AEWRs for farm-related jobs, such as those in construction and transportation, for example, for workers who build farm structures and haul commodities.

On September 30, 2020, before the DOL issued final regulations to implement these proposed changes, the USDA cancelled the FLS. However, a federal judge intervened and ordered the USDA to resume the program

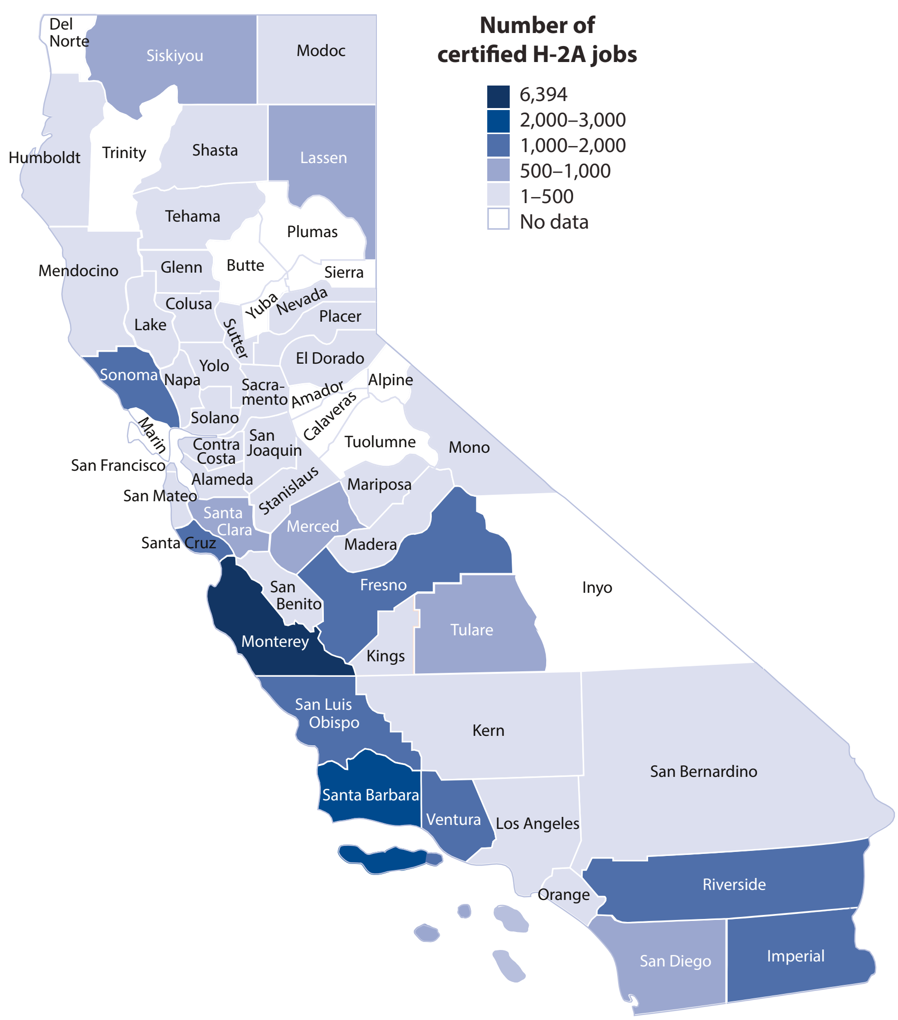

FIG. 3. California H-2A job certifications by worksite county (FY20). *Source:* FY20 OFLC disclosure data.

From 2010 to 2020, the number of certified H-2A jobs in the United States more than tripled, from 75,000 to over 275,000. A proposal to freeze the adverse effect wage rate could speed the growth of the H-2A visa guest worker program even further. *Photo*: Danny Magno, Driscoll's.

and collect the farmworker earnings data used by the DOL to set AEWRs. Meanwhile, on November 5, 2020, the DOL published a final regulation that froze AEWRs for 2021 and 2022 at their 2020 levels and ended reliance on the FLS to adjust these AEWRs in the future. The same federal judge who ordered the USDA to resume the FLS program earlier in the year blocked the DOL from implementing this final regulation, which was withdrawn by the Biden Administration on January 20, 2021.

The new AEWRs for 2021 rose an average 4.3% across the United States and 8.7% in California, bringing California's AEWR to $16.05 an hour, 15% above the state's $14 minimum wage. Rising AEWRs have not slowed California or any U.S. employer requests for H-2A workers. The number of U.S. farm jobs certified to be filled by H-2A guest workers in FY21 continues to increase, likely topping 300,000 for the first time (Rural Migration News Blog 2021b).

In March 2021, the U.S. House of Representatives approved the bipartisan Farm Workforce Modernization Act (FWMA, or HR 1603) on a 247–174 vote. The FWMA would turn many of the DOL's July 2019 AEWR proposals into law, including setting AEWRs by job title, freezing AEWRs and limiting annual increases in AEWRs. (The FWMA is included in the more-comprehensive U.S. Citizenship Act [USCA] of 2021, which would provide an 8-year path to U.S. citizenship for 11 million undocumented workers. The USCA also includes the American Dream and Promise Act [HR 6], which provides citizenship for children who arrived in the United States before age 16.)

The FWMA, which can be enacted separately, has three titles, one for legalization, one for H-2A streamlining and one for verification. Title 1 would allow undocumented farmworkers to become certified agricultural workers (CAWs) if they performed at least 180 days of farm work over the previous two years. CAW status would be extended indefinitely for those who do at least 100 days of farm work a year. The spouses and minor children of CAW status holders would also receive work and residence visas and would not have to do farm work to maintain their status (Rural Migration News Blog 2021a). CAW workers who have performed at least 10 years of agricultural work in the United States could become permanent or legal immigrants if they perform at least 100 days of farm work for four additional years, while those who have performed fewer than 10 years of agricultural work in the United States would have to do eight more years of farm work to become permanent or legal immigrants.

Title 2 would streamline the H-2A program in four ways: (1) make the application process and job ads electronic, (2) introduce 3-year visas, (3) allow 20,000 H-2A workers a year to be admitted for employment in year-round dairy and other farm jobs and (4) add funding to build housing in agricultural areas. AEWRs would be set by job title and frozen for a year, after which increases would be capped at 3.25% a year for the next 9 years. A Portable Agricultural Worker (PAW) pilot program would allow up to 10,000 farm guest workers to be free agents in the U.S. farm labor market for 3 years. PAW visa holders could only work for farm employers, and they would maintain their legal status by not being unemployed more than 60 days a year; their freedom to change employers would presumably protect PAWS from exploitative employers.

Finally, Title 3 would require all farm employers to use electronic verification (a program called E-Verify) once the legalization and H-2A streamlining changes are implemented. In addition, if the FWMA is enacted, USDA and DOL would be required to study whether the employment of H-2A workers has depressed the wages of U.S. farmworkers, whether the AEWR is necessary to protect the wages of U.S. farmworkers and whether any changes are warranted in the methodologies used to calculate AEWRs.

AEWRs rose by an average 4% a year between 2010 and 2020. Freezing the estimated $3.5 billion wage bill of H-2A workers in 2020 would save employers of H-2A workers $140 million a year. Farms that employ H-2A workers also employ an estimated 50,379 U.S. workers in corresponding employment alongside H-2A workers, and their wages would also be frozen, saving H-2A employers an additional $29 million and making the total savings of an AEWR wage freeze at least $169 million a year (table 4).

The savings from an AEWR wage freeze could be larger if employers request more H-2A workers as a result of stable wages or if an AEWR freeze slows the growth in wages of the non-H-2A workers who fill 90%

TABLE 4. U.S. Workers in corresponding employment with H-2A workers

State	QCEW crop and crop support worker wages (in millions $)	Percent of total QCEW crop and crop support worker wages	Estimated number of non-H-2A workers directly subject to 2020 AEWR	Estimated wage bill for non-H-2A workers directly subject to 2020 AEWR (in millions $)
California	13,741	44%	4,885	$66
Washington	2,789	9%	13,867	$177
Florida	1,811	6%	2,618	$36
Oregon	1,302	4%	454	$9
Texas	1,101	4%	1,382	$29
Arizona	680	2%	1,030	$21
Top 6 total	21,424	69%	24,236	$339
U.S. total	31,099	100%	50,379	$719

Source: OFLC disclosure data.

Note: The number of non-H-2A workers subject to the AEWR is calculated by taking the difference between the number of worker applicants requested and the number of jobs certified by DOL for H-2A workers. The average number of weeks and hours worked are based on state-level calculations that are weighted by the number of certified jobs in the state.

of the jobs in U.S. crop agriculture. The number of H-2A jobs has been increasing despite the rising AEWR, so a stable AEWR could accelerate H-2A expansion. The links between AEWRs and the wages of U.S. workers are uncertain, but a frozen AEWR could reduce the growth in the U.S. wage bill, which in 2020 was $21.6 billion for crop farms and $12.1 billion for crop support services — a total of $33 billion.

H-2A expansion in California

While the number of U.S. jobs certified to be filled by H-2A workers has tripled over the past decade, the number of H-2A jobs rose even faster in California. Several factors have influenced this increase in H-2A employment in California, notably the expansion of labor-intensive agriculture and a decrease in unauthorized migration (mainly due to tighter border control and improved conditions in Mexico). The proposal to freeze the AEWR could speed the growth of the H-2A visa guest worker program even further and return California to a 1950s-style farm labor market, when California had the most Mexican Braceros of any state (Rural Migration News Blog 2020a).

There are several differences between 1950s Braceros and 21st century H-2A workers. First, employer associations recruited and employed many of the Braceros, while the leading employers of H-2A workers today are FLCs. Second, most Braceros worked cotton, sugar beets and other field crops through the mid-1950s, while most H-2A workers today are employed in fruit and vegetable crops. Third, most Braceros lived in employer-operated camps on farms, while many H-2A workers are housed in urban motels where the furniture is replaced by bunk beds.

Several factors will influence the expansion of H-2A employment in California agriculture. Rising labor costs encourage labor-saving mechanization even as rising consumer demand for fresh berries and other commodities increases the employment of hand workers until machines are perfected. Meanwhile, increased imports are narrowing windows of profitable production for some fresh fruits and vegetables, increasing incentives for California growers to save on rising labor costs (Rural Migration News Blog 2020b). CA

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RESEARCH ARTICLE

Vineyard-specific climate projections help growers manage risk and plan adaptation in the Paso Robles AVA

Fine-scale resolution climate change projections help communicate risk and facilitate adaptive responses among viticulturalists in the Paso Robles AVA.

by Nicholas Babin, Jazlyn Guerrero, Diego Rivera and Ajay Singh

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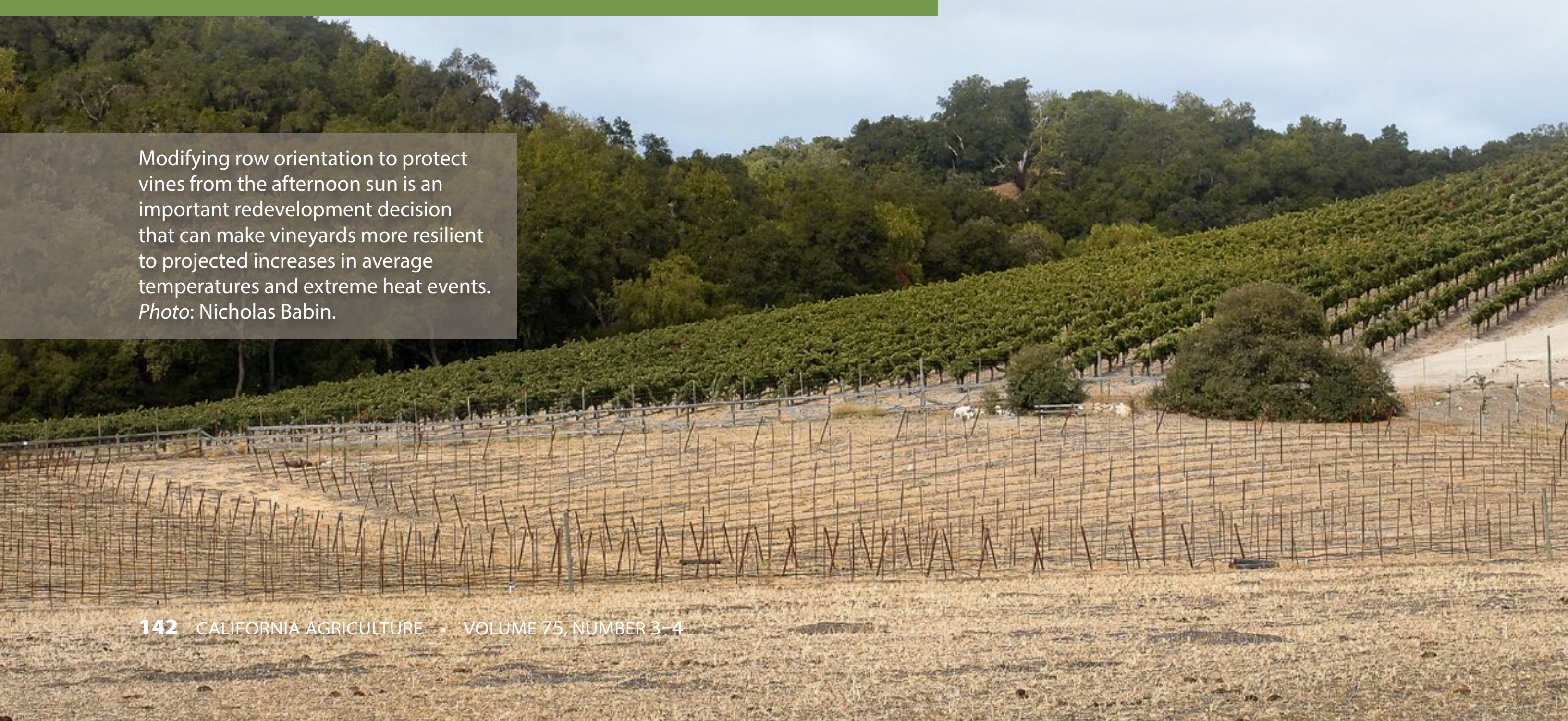
Abstract

California's wine grape growers will face increasing challenges under a changing climate as most production occurs near the boundaries of current varieties' climatic thresholds. As part of this study, we developed a method for transforming downscaled climate information from the publicly available Cal-Adapt database into useful and useable climate projections for vineyard managers and advisors in the Paso Robles American Viticultural Area. We shared vineyard-specific projections during interviews of 20 managers and advisors. Overall, interviewees expressed trust in the projections and found them helpful in reducing their psychological distance from climate change. The projections prompted consideration of strategies for managing future climate risk and planning adaptation, with the majority of adaptations associated with long-term decisions such as row orientation, variety selection, dry farming, crop diversification and relocation. Agri-climatic decision support tools such as the one prototyped here may prove especially helpful for incorporating climate adaptation into the long-term business planning and vineyard redevelopment decisions facing managers and advisors in the near future. This approach could be extended to other California wine grape regions or to other perennial crops with expected vulnerabilities to climate change.

The Paso Robles American Viticultural Area (AVA) features approximately 40,000 planted acres and over 200 wineries that generate US$1.9 billion in total annual output value and provide over 13,000 jobs in northern San Luis Obispo County (Matthews and Medellin-Azuara 2016). The AVA is known for high-quality red wine production dominated by the varieties cabernet sauvignon, merlot and zinfandel. Climate change will affect both yield and quality of wine grape production in the Paso Robles AVA. Impacts on grape yields are projected to be relatively low compared to other major California commodities, with an estimated 10% yield reduction by 2100 (Pathak et al. 2018). However, impacts on grape quality will be more severe, as projected water shortages, prolonged heat waves and increasing average growing-season temperatures will likely damage harvests and shift the ripening potential beyond a threshold for many of the varieties currently being grown in the region (Jones et al. 2005). Adaptation to climate change is thus increasingly recognized as crucial for the sustainability of the Paso Robles AVA and other California wine grape growing sectors (Nicholas and Durham 2012).



Modifying row orientation to protect vines from the afternoon sun is an important redevelopment decision that can make vineyards more resilient to projected increases in average temperatures and extreme heat events. *Photo*: Nicholas Babin.

The production span for wine grapes is 20 to 50 years, meaning that planning, designing and implementing adaptation measures may benefit from climate change decision support systems (CCDSSs), which Palutikof et al. (2019) define as "knowledge resources that facilitate decision-making for adaptation to climate change." CCDSSs can provide useful and usable climatic projections for agriculture (Prokopy et al. 2017). The goal of this study was to evaluate the potential of Cal-Adapt, a web-based CCDSS, as an aid in communicating risk and developing adaptation strategies for the changing climate in the Paso Robles AVA.

Climate change and agriculture

Research on farmer perceptions of climate change reveals deep differences depending on locale and cropping system. While 66% of Midwestern U.S. corn producers believe climate change is occurring, only 22% believe it is a threat to agriculture (Arbuckle et al. 2013). Meanwhile, 53% of New Zealand wine grape growers believe climate change is occurring but fully 32% believe it is a threat to agriculture (Niles et al. 2015). One potential explanation for these divergent perceptions is that different cropping systems, climates and national contexts have rendered some groups more psychologically distanced from the impacts of climate change than others. The theory of psychological distance asserts that the more geographically and temporally distant the perceived impacts of an event, the less willing individuals are to make personal decisions addressing the issue (Spence et al. 2012). Based on this theory, risk communication techniques, including CCDSSs, have been developed that effectively reduce psychological distance and increase public engagement with issues related to climate change (Jones et al. 2017).

While extensive effort has been dedicated to develop CCDSSs specific to the needs of Midwestern grain farmers (Angel et al. 2017), these tools have been under-exploited in other U.S. agricultural sectors, including viticulture (Mase and Prokopy 2014). Where CCDSSs have been utilized, boundary organizations that mediate between CCDSS producers (scientists) and users (farmers) have been identified as key in increasing usability (Lemos et al. 2012; Prokopy et al. 2015). Relevant boundary organizations within the California agriculture sector include the Natural Resource Conservation Service (NRCS), resource conservation districts (RCDs) and UC Cooperative Extension. Viticulturalists might be especially willing to utilize CCDSSs; a survey of European wine grape growers found that 93% desired more information on the projected future impacts of climate change on wine grapes (Battaglini et al. 2009). Additionally, a survey of Australian grape growers found that 72% indicated that the uncertainty surrounding future climate change would not stop them from considering climate change when making decisions about adapting their practices (Dunn et al. 2015).

Cal-Adapt is a publicly accessible, web-based CCDSS maintained by the University of California, Berkeley, that provides localized climate projections produced by California's scientific and research community (Cal-Adapt 2021). Cal-Adapt provides historical climate data as well as projection tools, including "Extreme Heat," "Sea Level Rise," "Annual Averages" and "Extended Drought" to help guide local adaptation decisions. Projections can be made over any time interval between current day and 2099, can utilize either low (representative concentration pathway [RCP] 4.5) or high (RCP 8.5) emission scenarios, can employ any combination of ten global climate models and can be generated at multiple spatial scales from the level of an entire county down to a grid measuring 6 kilometers by 6 kilometers. This fine scale of spatial resolution makes the tools much more useful for viticultural adaptation than the coarser resolution projections generally available, as wine-producing regions often feature extensive topographical and microclimatological variability (Mosedale et al. 2016).

While the potential of the Cal-Adapt tool for reducing psychological distance and promoting adaptation in viticulture is high, past usage has focused on city and regional planning efforts and not the agricultural sector (Deas 2015). This study evaluated the potential of the Cal-Adapt tool for risk communication and climate adaptation among viticulturalists. Specifically, we addressed the following questions:

1. What short-term general risks (1 to 2 years), long-term general risks (3 to 20 years), and climatic-specific risks to viticulture are most important to vineyard managers and advisors in the Paso Robles AVA?
2. What climate change risks and adaptations are considered by managers and advisors after reviewing a vineyard-specific projection generated from Cal-Adapt?
3. How can the Cal-Adapt decision support system be improved for viticulturalists?

Interview framework

The Paso Robles AVA of northern San Luis Obispo County is characterized by a hot-summer Mediterranean climate and is relatively dry; since 1942, the city of Paso Robles has had an average annual rainfall of 14.2 inches (Paso Robles Water Division 2020). Groundwater is the main source of irrigation water in the AVA, and the majority of planted acres lie within a groundwater basin classified by the Sustainable Groundwater Management Act (SGMA) as high priority and critically overdrafted (Battany and Tindula 2018). We compiled an initial interviewee list of three vineyard managers and three advisors in consultation with a local grape grower organization, and we used a snowball sampling method to identify additional subjects (Schutt 2014). The managers we interviewed were owner-operators, estate employees or management

The production span for wine grapes is 20 to 50 years, meaning that planning, designing and implementing adaptation measures may benefit from climate change decision support systems . . .

TABLE 1. Variables and temporal frames utilized in vineyard specific Cal-Adapt projections for two vineyards in the Paso Robles AVA

Climatic variable	Time frame	Westside vineyard	Eastside vineyard
Annual average days > 95°F	1961–1990*	7.0	38.0
	2020–2039†	20.0	64.0
	2050–2070†	35.0	85.0
Annual average days > 100°F	1961–1990*	0.0	16.0
	2020–2039†	5.0	38.0
	2050–2070†	12.0	54.0
Annual average days > 105°F	1961–1990*	0.0	3.0
	2020–2039†	1.0	13.0
	2050–2070†	3.0	25.0
Annual average 4-day heatwaves > 100°F	1961–1990*	0.0	1.0
	2020–2039†	0.2	3.6
	2050–2070†	1.0	7.6
Annual average longest stretch of days > 100°F	1961–1990*	0.4	4.1
	2020–2039†	2.0	8.4
	2050–2070†	4.1	12.3
Annual average nights minimum temp > 60°F	1961–1990*	4.0	4.0
	2020–2039†	17.0	12.0
	2050–2070†	41.0	36.0
Annual average maximum °F	1961–1990*	71.5	76.1
	2020–2039†	74.2	79.2
	2050–2070†	77.0	82.1
Annual average minimum °F	1961–1990*	40.3	42.1
	2020–2039†	42.9	45.1
	2050–2070†	45.4	47.6
Annual average inches of rain	1961–1990* (range)	26.1 (11–48.5)	11.9 (5.3–24.2)
	2020–2039† (range)	27.9 (9.4–58.7)	13.6 (4.7–26.2)
	2050–2070† (range)	27.2 (5.1–4.4)	13.1 (2.2–40.9)

RCP 8.5 emissions scenario and four-model average utilized for projections.

* Observed.

† Projected.

company employees. The advisors were boundary organization representatives comprised of NRCS and RCD staff, UC Cooperative Extension advisors, irrigation and pest control consultants, university researchers or grower organization representatives. We conducted interviews until saturation was achieved, meaning that data obtained from new interviews was redundant of data already collected (Prokopy 2011).

We conducted 20 interviews between June and November 2019, 11 with vineyard managers and nine with advisors. In each interview, we first assessed general perceptions of short (1 to 2 years) and long-term (3 to 20 years) risks facing their vineyard or the vineyards they advise. Then, an additional set of questions assessed the perceived level of risk from climate change for their vineyard operation or of those they advise. This interview strategy prevented introduced bias by first assessing perceived risks without mentioning climate change, thereby contextualizing the perceived risks from climate change with other risks (Church et al. 2018). Following these initial interview questions, we presented each interviewee with a paper copy containing, in both narrative and tabular form, a downscaled (6 km × 6 km resolution) vineyard-specific projection from Cal-Adapt. If the interviewee was a vineyard manager, the location we selected for the downscaled projection was the vineyard's primary grape-growing site. If the interviewee was an advisor, we chose a location that the advisor had experience advising. The interviewer read through the entire projection with the interviewee, stopping as needed for clarification. Finally, interviewers asked interviewees how, if at all, the downscaled, vineyard-specific projections from Cal-Adapt changed their perception of risks and whether it made them consider adaptation measures.

The full range of climatic variables and timeframes we generated and shared with interviewees can be found in the left-hand column of table 1. (Table 1 also presents results for two of the 20 vineyards we studied. These two vineyards, located only 12 miles apart, epitomize the increasing severity of projected climate change as one travels west to east across the microclimates of the Paso Robles AVA.) We obtained the projections before the interviews took place using the "Annual Averages," "Extreme Heat" and "Extended Drought" tools from the Cal-Adapt web portal (Cal-Adapt 2021). We used the four-model average and RCP 8.5 emissions scenarios. Figure 1 contains screen captures from the Cal-Adapt website and illustrates the overall process we used to obtain projections. In addition, we developed an instructional video and template that contains step-by-step instructions for generating an agriculturally relevant projection using Cal-Adapt. This video can be found at https://tinyurl.com/climateprojection.

In-person interviews lasted between one and two hours and were digitally recorded and professionally transcribed. The resulting transcripts were uploaded into the qualitative software package NVIVO (version 12; QSR International, Burlington, Mass.) for coding and analysis. We then reviewed the transcripts and suggested themes to use as a coding framework within NVIVO. Next, we selected four interview transcripts (two advisors and two managers) for each researcher to code within NVIVO, which resulted in a coding agreement of 80%. Following discussion, the coding framework was revised and a subsequent coding round resulted in 95% coding agreement (Mouter and Vonk Noordegraaf 2012). Table 2 shows the revised coding framework we used when analyzing the 20 interview transcripts. The 11 vineyard manager transcripts were then coded by one researcher while the nine advisor transcripts were coded by another researcher. The summary results and exemplar quotes presented below represent the dominant themes in the analysis.

FIG. 1A. Cal-Adapt homepage. Once at the homepage, click on the "TOOLS" tab in the top right.

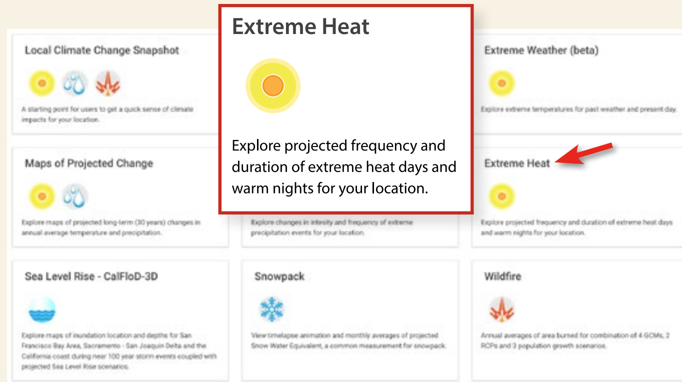


FIG. 1B. Tools on the Cal-Adapt tools page can be activated by clicking.

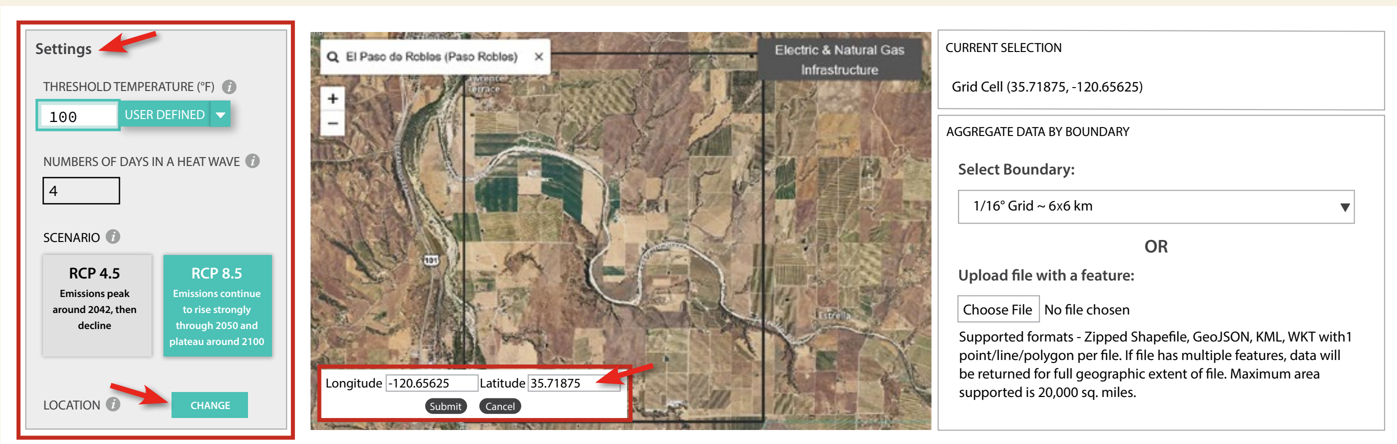


FIG. 1C. Once a specific tool is chosen, the scale of projection can then be selected. Scale options include counties, watersheds and 6 km × 6 km plots. A sample 6 km × 6 km grid projection is shown here.

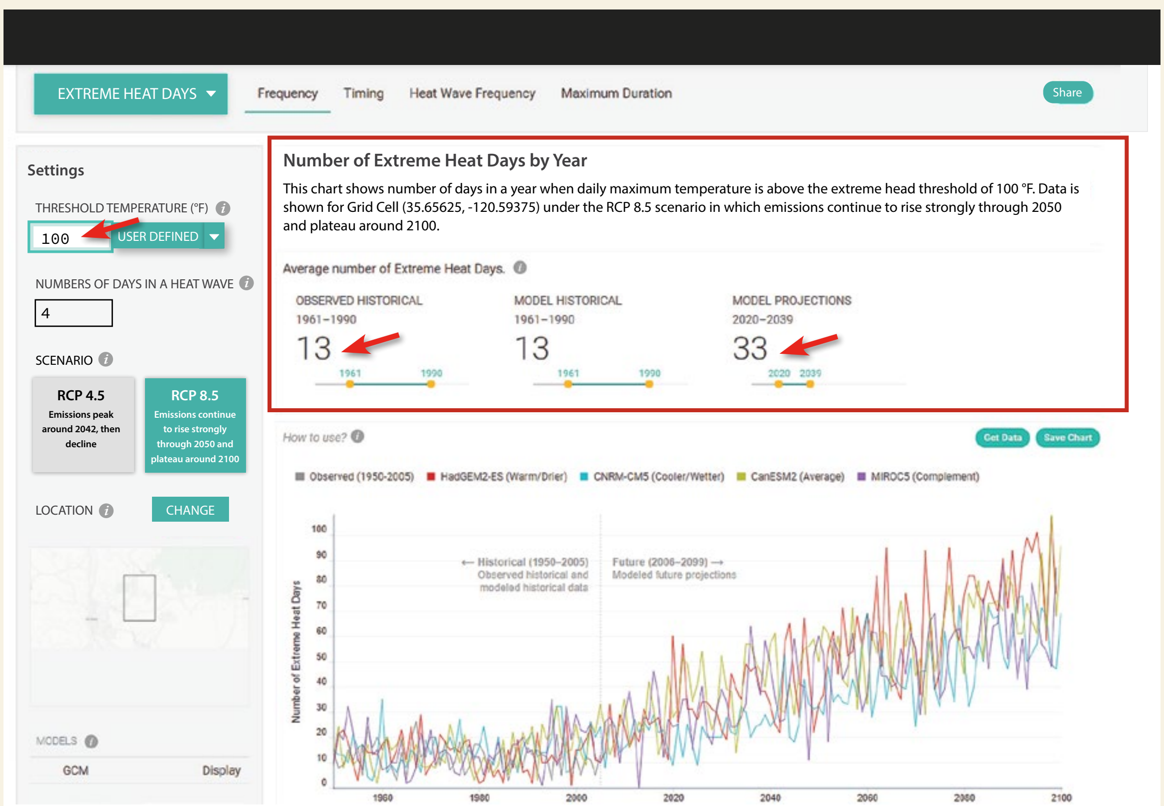


FIG. 1D. Extreme heat results for a Paso Robles vineyard indicate that this particular vineyard experienced an average of 13 days per year of temperatures over 100°F between 1961 and 1990 and that it is projected to experience temperatures over 100°F for an average of 33 days per year from 2020 to 2039.

TABLE 2. Coding framework

Risks (short- and long-term)	Climate change risks	Downscaled projections	Climate change risk management
• Labor • Water • Market • Regulations • Disease or pests • Input costs • Climate or weather	• Water availability • Extreme heat • Growing degree change • Erosion • Grape quality • Pests • Phenology • Yields • Frosts	• Overall response • Risks • Adaptations • Improvements	• Current practices to reduce risk • Potential practices to reduce risk - Short-term farming and winemaking adaptations - Long-term diversification and vineyard design adaptations

TABLE 3. Unprompted short-term risk perceptions over the next 2 years

Risk	Manager ($n = 11$)	Advisor ($n = 9$)
Labor	7 (64%)	4 (44%)
Market oversupply	6 (55%)	6 (67%)
Diseases/pests	6 (55%)	3 (33%)
Water supply	5 (45%)	7 (78%)
Regulations	4 (36%)	4 (44%)
Climate/weather volatility	3 (27%)	4 (44%)

Number of interviewees who mentioned risk is followed by percentage of all interviewees from each group.

TABLE 4. Unprompted long-term risk perceptions over the next 3 to 20 years

Risk	Manager ($n = 11$)	Advisor ($n = 9$)
Water supply	6 (55%)	4 (44%)
Regulations	5 (45%)	3 (33%)
Diseases/pests	4 (36%)	1 (11%)
Labor	3 (27%)	3 (33%)
Climate weather volatility	3 (27%)	5 (56%)
Market oversupply	1 (9%)	3 (33%)

Number of interviewees who mentioned risk is followed by percentage of all interviewees from each group.

TABLE 5. Prompted climate change risks

Risk	Manager ($n = 11$)	Advisor ($n = 9$)
Extreme heat events	9 (82%)	8 (89%)
Water availability	8 (73%)	8 (89%)
Seasonal shifts	4 (36%)	5 (56%)
Frosts	4 (36%)	2 (22%)
Pests	0 (0%)	7 (78%)

Number of interviewees who mentioned risk is followed by percentage of all interviewees from each group.

Unprompted risk perception

Only one-quarter of vineyard managers identified climate or weather volatility as risks in the short- and long-term, compared to about half of advisors (tables 3 and 4). Labor, market oversupply and diseases and pests were the most frequently identified unprompted short-term risks by vineyard managers, while market oversupply and water supply were the most frequently cited short-term risks by advisors. In the long-term, market oversupply and regulations were the most mentioned risks by vineyard managers, while climate and weather volatility was the most common risk mentioned by advisors.

When asked to identify the climate change risks most concerning to viticulture in the Paso Robles AVA, vineyard managers identified extreme heat events and water availability as being the most significant (table 5). Advisors identified extreme heat events, water availability and pests as being the most concerning.

Projections and risk perception

The Cal-Adapt projections we shared with interviewees contained narrative expositions of the climate variables found in table 1. The most frequently identified risks prompted by this information were those associated with the effect of increased average temperatures and heat waves on wine quality. The following quotes exemplify reactions among vineyard managers (VMs) and vineyard advisors (VAs).

> *We already are on the edge of quality grapes due to our high-heat wave, low-humidity events . . . and so this projected change absolutely is going to harm our great quality and our yield which then harms our profitability. — VM 6*

> *We're already a hot area . . . So if it gets any warmer than that, we're kind of getting out of the realm of quality wine production. — VM 5*

> *If this occurs we would probably end up with not quite as flavorful wines as we're growing now. — VM 7*

> *This is going to affect my ability to ripen the grapes. It's going to be crazy to have a hotter summer. And the fruits not ripening because they've been too hot and they haven't been able to process properly. — VM 4*

The negative feedback of higher temperatures on water usage was noted and was compounded by uncertainty surrounding future water availability due to potential SGMA-related pumping restrictions.

> *I get nervous about the heat spikes and water as a resource. — VM 8*

> *You start getting into long days of 105, 108, and stuff like that . . . If you see those coming, you're going to want to water it. So it's going to up your water usage. — VM 10*

> *Back to water. Absolutely, that's the biggest risk. — VM 2*

Vineyard managers and their advisors from the east side of the AVA displayed more severe risk perception than those from the west side.

> *So east Paso is the one that has the highest temperatures. Right? Like more extreme weather. West Paso is very different. They get a lot of rain. So I think east Paso will be more susceptible. — VA 2*

The linkage between climate change and increased pest pressure was widely acknowledged by advisors but not managers, indicating an area of future research, outreach and education.

Projection-prompted adaptations

Adaptation responses prompted by Cal-Adapt projections overwhelmingly focused on long-term as opposed to short-term measures. However, some short-term measures were discussed; these included increased use of shade cloths, spray-shield products, misting, improving irrigation efficiency and targeted pruning.

Long-term adaptations, especially those associated with potential vineyard redevelopment, dominated interview conversations and included measures such as changing grape variety, rootstock, vine spacing, row orientation, trellising systems, dry farming, relocation and diversification out of grapes.

> *Any sort of vineyard design, row orientation, solar interception . . . So maybe you're redeveloping a vineyard and you change the row orientation. — VM 6*

> *Row orientation, and maybe trellis system and maybe pruning system. So long-term decisions, not short-term decisions. — VA 6*

> *It'll definitely change the way we have to grow grapes here. I mean, look for a northern slope versus a southern slope. — VM 7*

Advisors were adamant that, to grow quality grapes in the climate projected, varieties other than cabernet sauvignon, merlot and zinfandel would need to be explored.

> *Variety selection, trying to find varieties that certainly do well, or at least avoiding the ones that we know are going to be disasters with the high temperatures. — VA 7*

> *By far I'm going to tell you that the best possibility, particularly thinking long-term, it has to do with the choice of the variety. — VA 6*

> *We've been kind of boxed in to mostly French varieties . . . it wouldn't surprise me at all if heat-tolerant varieties became more of a thing. — VA 3*

Despite the fact that new varieties might perform better in the projected future climate, both advisors and managers recognized that the marketing of unknown varieties from a region steeped in name recognition and tradition would be a challenge, especially in the current situation of oversupply and low prices.

> *Over time as a vineyard comes out, let's say in five years, that person now has a choice. What do I put in? What looks to be most acceptable? And for them, their biggest deterrent is going to be, what does the winery want to buy? What will somebody give me a contract for? . . . The new varieties have unusual names and the growers are not going to produce them until there's a shift in taste in the consumer. So that's where we have kind of painted ourselves into a corner if the consumer only says I want to buy cabernet. — VA 7*

> *I love different varieties. I did my whole masters on that. But no, you're locked in. You're already in an oversupply market. I don't need to create 30 new varieties that no one has ever heard of. They can't even sell the line they have. — VM 6*

Vineyard redevelopment in the Paso Robles AVA. As vineyards are planted new or redeveloped, long-term adaptations can be introduced, such as changing grape variety, rootstock, vine spacing, row orientation and trellising systems. *Photo*: Nicholas Babin.

The dry farming of grapes is one potential strategy for conserving water in the critically overdrafted Paso Robles Watershed Subbasin. *Photo*: Nicholas Babin.

Advisors observed that production of the varieties that currently dominate the Paso Robles AVA would probably shift to other regions, underscoring the need to develop consumer acceptance for new varieties.

If the climate is like this, then there's going to be a new Paso somewhere else . . . So Paso could shift up, north, or further south, depending on what makes sense . . . there's going to be a new area that that takes over because Paso is done. — VA 4

Several advisors noted that larger, corporate estate vineyards are already planning for this shift. This illustrates that while climate change will be a challenge for some grape-growing locales, it will present opportunities for others.

Those larger corporate investor types who are planning long-term, managing finances are saying, "Okay, long term, some of this is looking a little sketchy." They'll run the same scenario up in Idaho or Washington and say that looks pretty good. — VA 6

The very large companies are skeptical of the Central Coast. Based on long-term projections of heat and water scarcity . . . They're not bullish on the Central Coast, that was in the '90s. Now they're shying away from it. — VA 7

The Cal-Adapt projections, when combined with the current oversupply market, prompted some managers to consider diversification out of viticulture on either part or all of their vineyards.

We may be growing something completely different in this area. Thirty years ago, there weren't all these vineyards around. They were growing alfalfa. And they were growing almonds. And they were growing other things. And so why grapes here? Because they worked so well. But it was an adaption to the area. And that could change. — VM 9

I think you'd have to adapt to other crops . . . I just don't know what that is. I don't have answers right now. — VM 8

One of our growers was talking about the glut of cab sauvignon. And someone was asking him, "So if I was replanting, what should I plant then? What variety should I plant?" He said, "Almonds." So it just could be that that we've reached a saturation point. — VA 4

Finally, several managers who were also owner-operators discussed the possibility of selling their vineyards so that they could either retire or relocate.

Hopefully, I would have sold my vineyard by then. Yeah, maybe that's what I need to do, is get out of this business. I don't need to go to Vegas anymore. All my gambling urges and risk-taking are completely locked down by farming. — VM 4

The best-case scenario is still a scary scenario. I don't know if people understand that . . . If it was an owner-operator guy, he might say, "I can't do anything with this. I'm going to sell my property and get out of here." — VA 4

Reactions to the Cal-Adapt tool

While none of the advisors expressed skepticism toward the validity of the projections, three out of the 11 managers did. The dramatic increase in extreme heat days in the projections may have shocked some into disbelief.

I think I'm not buying in to this assumption. I think I would buy more of this assumption if the impacts were less severe. This becoming Death Valley is hard for my brain. — VM 8

However, when we included downscaled past annual average temperatures, extreme heat frequencies and precipitation totals that managers perceived as being historically accurate, they expressed greater confidence in the validity of the projections. Future sharing of projections could more extensively involve the validation of historic vineyard level data generated by Cal-Adapt as a strategy for building vineyard manager trust in the projections. This, in turn, could lead to an increased willingness to include climate projections in vineyard risk management and adaptation planning.

Looking out at 2100, it's hard to fathom just from a glance at the map. This [vineyard-specific projection] actually helped, putting it localized to a ranch that we're familiar with. I could see where it makes sense as far as the amount of past days over 100 and rainfall. Those numbers actually seem to track. And they resonate with me here. So I think that if that's what these are based on, then the projection's probably got some validity to it. I'm very curious to go and plug in some other addresses and see what pops up. — VM 9

Overall, interviewees' impressions of the projection tool were positive. Several vineyard managers commented that the personalized narrative projections were more helpful than coarse-resolution, map-based projections.

I think putting a number to the heat waves and the narrative is very helpful. The physical maps I think people see quite a bit but having someone be able to read it is a fairly powerful way to present it. — VM 6

Bridging psychological distance

By making risks seem less distant and diffuse over space and time, CCDSSs like Cal-Adapt promise to help bridge the psychological distance associated with climate change (Spence et al. 2012). This could prove especially valuable for outreach among workers in the agricultural sector, who tend to view the potential impacts of climate change skeptically.

> *If this was to be true I'd definitely be more proactive about mitigating risk. — VM 8*

> *Climate change is a real thing. It's a big deal. It's really a big deal. — VM 1*

> *I'm finding that more and more people are willing to admit that it's a problem, and they're trying to find mitigation measures for that. — VA 4*

Several interviewees mentioned that the utilization of climate projections and adaptation forecasting was more likely to be employed by large corporate estate vineyards with the time and resources to invest in comprehensive planning and asset evaluation, rather than by small owner-operator contract growers.

> *We need more of a commitment to helping the smaller-scale growers, because they're less likely to have the resources to be able to deal with this. — VA 7*

> *What happens if you grow just one variety, and you're small, and you're dependent on selling to a winery, and all of a sudden your variety goes downhill from climate change? — VA 3*

There is a prospective role here for boundary organizations such as RCDs, UC Cooperative Extension, wine sustainability organizations (e.g., The Vineyard Team and the California Sustainable Winegrowing Alliance) and small-producer organizations (e.g., Independent Grape Growers of the Paso Robles Area, Paso Robles Wine Country Alliance) for further training in and utilization of the Cal-Adapt tool. These boundary organizations are natural constituencies for transforming the publicly available data into useable information, for example, during resource-planning exercises and outreach activities.

Barriers to adaptation

Suggested adaptations inspired by the projections focused both on long-term practices implemented during redevelopment and on relocation. As mentioned above, however, prior to the sharing of the projections the majority of vineyard managers did not include climate change as a significant long-term risk. Indeed, climate change was mentioned as only one among many risks they are managing, demonstrating the multiple dimensions of risk exposure inherent in commercial agriculture (Belliveau et al. 2006). Advisors and managers shared that their general approach to managing risk in viticulture is to tackle issues as they arise.

> *I know and care about climate change, but I listed a number of factors before I got to that . . . I mean, it would be nice if you could be truly strategic and be thinking forward, but in a lot of cases, it's kind of a hand-to-hand combat figuring out what you're going to sell this year, trying to make as good a decision as you can about the next year. — VM 11*

> *I'm just trying to navigate day by day, year by year. — VM 8*

> *It's just this mentality of only being able to deal with one to two years or one to a couple of things at a time. — VA 4*

This just-in-time approach may prove to be a fundamental barrier in adopting needed viticultural adaptation practices during redevelopment.

Improving Cal-Adapt projections

Interviewees requested that future iterations of the tool include extreme cold events during the growing season, growing season average temperatures and growing degree-days as projection outputs. This information, they maintained, could assist them in selecting new grape varieties or other crops that may be more appropriate to grow in the future. Interviewees also indicated that projected budbreak and harvest dates would be useful additions. Due to widespread concerns over the impacts of extreme heat and drought on vine stress, interviewees also recommended including the variables of soil moisture and evapotranspiration. These two variables could be included in future Cal-Adapt iterations as a composite indicator, such as climatic water deficit, which quantifies the amount of evaporative demand exceeding available soil moisture.

From a current-user standpoint, we found the projection generation process cumbersome. The tool was not designed for agricultural use, so it took quite a while to become acquainted with the many options for projection generation and to learn how to narrow in on those most relevant for viticultural decision-making. Then we had to convert the numeric indicators generated by Cal-Adapt into narrative form so that the projection was clearer and more easily conveyed to interviewees. This also meant that the process was somewhat lengthy (about 30 minutes per projection). However, the breadth of highly detailed and free data available from Cal-Adapt is a potential boon for the agricultural sector, and many of these issues could be addressed by the creation of a plug-in tool that automatically generates in a narrative form variables and indicators relevant to agriculture.

Conclusions

Cal-Adapt has significant potential for improving risk communication and promoting climate change adaptation strategies among viticulturalists in the Paso Robles AVA. The unprompted solicitation of risks during this research revealed that, at the present time, most managers don't consider climate change an important risk and, for those who do consider it a risk, it often isn't a priority. Risk management includes identifying, evaluating and prioritizing risks. Actions can then be taken to minimize risk probability and impact or to maximize opportunities. However, managers can't manage for risks that they haven't identified as existing. The Cal-Adapt projections showed promise in reducing the psychological distance of climate change perceived by vineyard managers and advisors. This has the potential to increase growers' willingness to utilize climate projection data for long-term risk management and adaptation planning purposes (Jones et al. 2017). In order to be truly useful and useable, key climatic variables need to be included and the tool's web-based navigation should be improved. There is a role for boundary organizations in improving, employing and promoting this CCDSS in their work with managers so they can better evaluate and address risks from climate change (Lemos et al. 2012). Long-term planning processes are already a part of managing a perennial crop such as wine grapes, and Cal-Adapt projections should be included in these processes to facilitate long-term redevelopment decisions.

The interaction between stable or declining average annual rainfall and increased heat will stress water resources in this already critically overdrafted basin. Past research has estimated vineyard irrigation water usage in the Paso Robles AVA (Battany and Tindula 2018); future research should determine the current extent of water efficiency best-management practice adoption on vineyards in the region. Future research should also identify the barriers and opportunities for more widespread adoption of soil and water conservation practices that will make vineyards more resilient to the projected impacts of climate change. In addition, because small, owner-operated growers may be more vulnerable to the impacts of climate change than larger corporate entities, future outreach and support should focus on improving the adaptive capacity of the small-scale producers. This will be crucial in ensuring the long-term sustainability of grape production in the region. CA

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RESEARCH ARTICLE

Low prevalence of handwashing and importance of signage at California county fair animal exhibits

Signage showing a link between animal contact and pathogen transmission may lead to increased frequency of handwashing at California county fairs.

by Melissa T. Ibarra, Cheryl L. Meehan, Miles Daniels, Woutrina A. Smith and Martin H. Smith

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Abstract

Disease outbreaks among visitors at venues where animals are exhibited, such as animal shows at county fairs or petting zoos, are national public health concerns. Zoonotic disease transmission at fairs can occur through a variety of pathways, including direct contact with livestock and indirect exposure through contact with animals' immediate surroundings. Handwashing can reduce pathogen transmission. The goal of this observational study was to determine rates of handwashing among county fair visitors and to learn whether signage and/or contact with animals were correlated with handwashing practice. The investigation was conducted at four county fairs located across two geographic regions of California. Observations occurred over the course of one summer. Results from our observations of fair visitors revealed a low overall prevalence (5%) of handwashing behavior. However, fair visitors who made contact with animals were more likely to wash their hands. Additionally, those individuals who walked through barns where handwashing signage was present were significantly more likely to wash their hands than those who visited barns without signage.

Animal exhibitions at county and state fairs bring the public into close proximity with many species of livestock. These interactions create recreational and educational opportunities. However, interfaces between visitors and exhibition animals may also pose public health risks. Livestock may carry zoonotic enteric pathogens, such as *Salmonella*, *Campylobacter*, *Escherichia coli* and *Cryptosporidium* (Conrad et al. 2017; Hoelzer et al. 2011; Roug et al. 2012). These pathogens can cause serious illnesses in humans, often manifesting as gastrointestinal symptoms, including diarrhea (with or without blood), vomiting, nausea, fever and abdominal cramps (Steinmuller et al. 2006). One study estimated that during a single year in the United States roughly 445,213 illnesses, 4,933 hospitalizations and 76 deaths were caused by the transmission of pathogens (mostly *Salmonella, Campylobacter* and *Cryptosporidium*) from animals (Hale et al. 2012).

While exact numbers of illnesses and deaths from enteric diseases originating at county fairs is unknown,

A handwashing station and signage at a California county fair. Results from a recent study of fair visitors indicate a significant positive association between the presence of signage and handwashing practice. *Photo*: Melissa T. Ibarra.

multiple reports of outbreaks resulting from disease transmission through animal contact at livestock exhibitions have been reported (Bender and Shulman 2004; CDC 2011; LeJeune and Davis 2004). In California, multiple cases of Shiga toxin–producing *E. coli*, a contagious bacterial infection with potential severe illness consequences, were associated with animal contact at the San Diego County fair in the summer of 2019 (Robbins and Riggins 2019; Sisson 2019). Although any person exposed to zoonotic fecal pathogens is potentially at risk for contracting a disease, some populations are at greater risk for developing a serious or life-threatening illness, including children (less than five years of age), the elderly (over 65 years of age), pregnant women and individuals with weakened immune systems (LeJeune and Davis 2004).

[M]ultiple reports of outbreaks resulting from disease transmission through animal contact at fairs have been reported . . ..

While disease transmission can occur through a variety of pathways, fecal-oral transmission is the most common route for enteric diseases (CDC 2011). At livestock exhibitions, transmission can occur when visitors make direct physical contact with animals that have pathogen-containing fecal material on their skin/coat, or when visitors come into contact with contaminated feed, bedding, water or pen furnishings. The risk of transmission is increased by several factors associated with exhibitions, including animal transport, increased contact rates among livestock species, frequent livestock handling and the number of animals sharing pen space (Daniels et al. 2021; NASPHV 2013; Thunes and Carpenter 2007).

FIG. 1. Example of handwashing signage at the California county fairs included in this study. *Photo:* Melissa T. Ibarra.

Some livestock exhibitions offer areas dedicated to animal contact (i.e., petting zoos) while others display animals in barns where visitors are able to make physical contact with livestock and their environments even if not expressly permitted. Exhibit livestock are typically separated from the public by a barrier (e.g., waist-high walls or railings). However, these barriers do not often prevent fair visitors from interacting with the animals. Visitors' hands can become soiled by pathogen-containing feces through direct contact with animals or by touching contaminated pen furnishings, including bedding, equipment and clothing (Steinmuller et al. 2006). These individuals can inadvertently ingest pathogen-containing feces if they bring their hands to their faces, increasing their risk of developing enteric disease (Erdozain et al. 2013).

Fecal-oral disease transmission is preventable, and appropriate protective measures can be taken to mitigate this risk. Handwashing is a cost-effective option that helps prevent pathogen transmission (CDC 2011; NASPHV 2013), and many fairs provide handwashing stations in livestock areas. Fair visitors, however, do not always make use of handwashing stations, particularly if they are not informed about the role of handwashing in reducing pathogen transmission risks.

While signage has been shown to promote handwashing behavior in health-care settings (Filion et al. 2011), the effectiveness of handwashing signage at California county fairs has not been investigated to date. The goal of this study was to determine if handwashing by California fair visitors after visiting an animal barn was associated with animal contact and/or the presence of handwashing signage.

Study methods

We conducted this observational study at four county fairs across the state of California during the summer months (July, August, September) of 2015. The fairs were located within two geographic regions of California, the Central Valley (two fairs) and the Central Coast (two fairs). We observed fair visitors specifically for handwashing practice at barns containing livestock. Barn setups varied; some barns contained exhibition animals, others contained animals in petting zoos. However, all observation sites consisted of pens that kept livestock separated from visitors, walkways for visitor traffic and an entrance and exit. Handwashing (sink or alcohol-based hand sanitizer) stations were present at the exits of all barns where observations were made, and handwashing signage was present in some, but not all, barns.

Handwashing signage

Signage type varied across barns and fairs (one example is shown in fig. 1). Messaging included both simple content such as “wash your hands” or “wash your hands after petting livestock,” as well as more educational descriptions about the importance of handwashing. An example of educational signage included “Help stop the spread of *E. coli* bacterial infection by washing your hands and helping your children wash theirs after any contact with animals.” Some signs consisted of a laminated piece of paper created by youth exhibitors; others were permanent and/or prominent fixtures provided by county fair administrators.

Selection of fair visitors

To select a fair visitor to observe, a researcher in a livestock barn randomly drew a number from 1 to 10, represented as x. This xth adult visitor entering the barn was the designated observee. Once an observational period ended, a new number was drawn, and the process was repeated.

Data collection

An observational period began when the observed fair visitor reached the barn entrance and ended when the individual exited the barn. We noted whether or not visitors made contact with livestock (i.e., petting or feeding), walked past signage about handwashing, and washed their hands (either with soap and water or with an alcohol-based hand rub) at the barn exit. Data were collected by indicating yes/no for each observed variable. All observations were conducted by a single researcher during regular fair operating hours open to the public. The researcher was dressed in casual attire, was situated outside the direct pathway of visitor foot traffic, maintained distance from visitors during an observational period and carried a clipboard. Research protocols were approved by UC Davis’s Institutional Review Board (protocol #717432-3).

Statistical analysis: Handwashing practices

We calculated fair visitor prevalence of animal contact (count yes/total), passing signage (count yes/total) and handwashing practice (count yes/total) from raw data. To investigate the relationship between handwashing practice and predictor variables, we ran a logistic regression model with handwashing practice as the response variable. As predictors we used whether or not visitors passed handwashing signage and whether or not they had physical contact with an animal while in the barn. A bivariate model was fit and assessed for multi-collinearity as defined by a variance inflation factor of greater than 10 and a condition index of greater than 30. Regression coefficients were exponentiated such that results are presented as odds ratios (ORs) for ease of interpretation. The OR represents the ratio of the odds of an outcome (handwashing) occurring given a particular exposure (animal contact, signage presence) compared to the odds of the outcome occurring given nonexposure. We conducted our analyses using Jamovi software (version 1.0; The jamovi software project 2019), and we set the significance threshold at an α-level of $P < 0.05$.

Associations between signage, animal contact and handwashing

We observed a total of 337 fair visitors. Of these, 17 (5%) washed their hands upon exiting a barn; 320 (95%) did not wash their hands. The rates of handwashing at the four individual fairs were: 7%, 2.5%, 0% and 18% (table 1).

A total of 93 visitors (28%) were observed to make contact with one or more animals. Of these 93 visitors, 14 (15%) washed their hands upon exiting the barn. Of the 241 visitors that did not make physical contact with an animal, three (1.2%) washed their hands upon exiting the barn (table 2).

TABLE 1. Frequency of visitor handwashing by fair

	Fair number			
Washed hands	1	2	3	4
No	73	79	112	56
Yes	5	2	0	10

TABLE 2. Frequency of visitor handwashing by animal contact

	Animal contact	
Washed hands	No	Yes
No	241	79
Yes	3	14

Example of handwashing signage, near a handwashing station. *Photo:* Melissa T. Ibarra.

Twenty-nine (9%) of all visitors walked past handwashing signage. Of these, 10 (34%) washed their hands upon exit. Of the 308 visitors who did not pass handwashing signage, seven (2%) washed their hands upon exit (table 3).

Results from the logistic regression analysis (table 4) indicated a significant positive association between the presence of signage and handwashing practice. Results also indicated a significant positive association between animal contact and handwashing practice. The OR for signage was 14.5, which indicates that visitors who walked past signage were 14 to 15 times more likely to wash their hands than those who did not. The OR for animal contact was 9.5, which means that people who had contact with animals were nine to 10 times more likely to wash their hands than those who did not.

Understanding the low frequency of handwashing

Overall, the frequency of handwashing among the fair visitors we observed in this study was very low (5%). The number of visitors who were exposed to handwashing signage was also low (9%). Despite these frequencies, our results showed that walking past handwashing signage was associated with a significantly greater likelihood of handwashing, indicating that the presence of signage may be an important strategy in encouraging handwashing practice.

Some of the signage observed in this study incorporated an educational message regarding the health risks associated with animal contact; however, we did not differentiate between signage that was educational in nature and signage that was directional, i.e., "wash your hands," in our analyses. However, this type of analysis would be a beneficial avenue for further study. Although some previous research found no difference in the effectiveness of the type of handwashing signage on handwashing practice (e.g., Erdozain et al. 2013), Xu et al. (2018) reported recently that awareness of the risk of infectious disease from animals was a reliable predictor of handwashing behavior among adults who made contact with animals in public settings. Signage that promotes such awareness, therefore, might have a positive effect on handwashing behavior.

In interpreting our handwashing results, we could not account for other factors that could affect handwashing behavior, such as visitors' potential knowledge of being observed, prior knowledge of disease transmission risks, fair location, age of visitors or type of handwashing facilities. As such, the efficacy of signage on influencing handwashing behavior should be interpreted cautiously, and further research is warranted. However, based on our findings, our recommendation is that fairs and public exhibitions where animals and people come in close proximity provide an abundance of signage that is visible, offered in multiple languages and provides clear explanations about the risks associated with animal contact and the benefits of handwashing.

Given the general low frequency of handwashing observed in this study, we strongly recommend additional measures be taken to limit health risks to fair visitors. Specifically, limiting visitor access to animal areas and/or having fewer points of entry and exit could direct the flow of visitors past handwashing signage and to handwashing stations. Additionally, fair administrators could consider establishing rules restricting the presence of food or drink inside barns, which could reduce the likelihood of fecal-oral pathogen transmission. Lastly, partnerships among fair administrations, academic institutions, youth agricultural organizations like 4-H and FFA, and local health departments might be advantageous in developing educational announcements, printed materials or video demonstrations — all of which could help reduce disease transmission risks at fairs.

Following completion of this study, our research team partnered with the California Department of Food and Agriculture to produce a series of informational videos highlighting the importance of handwashing as well as other biosecurity best practices for

TABLE 3. Frequency of visitor handwashing by presence of signage

	Signage	
Washed hands	No	Yes
No	301	19
Yes	7	10

TABLE 4. Multivariable assessment of handwashing behavior at the barn exit using logistic regression

Predictor	Estimate	SE	Z	*P*	Odds ratio	95% Confidence interval	
						Lower	Upper
Intercept	−4.86	0.631	−7.70	< .001	0.00776	0.00225	0.0267
Signage	2.68	0.583	4.59	< .001	14.51844	4.62961	45.5298
Animal contact	2.25	0.679	3.31	< .001	9.49808	2.50805	35.9696

Estimates represent the log odds of "Washed hands exit = YES" vs. "Washed hands exit = No."

visitors and exhibitors during public livestock displays. The videos were created for three discrete audiences: fair administrators (as planning and policy resources), exhibitors (as best practices resources for 4-H and FFA) and fair visitors (as public service announcements). These videos are available for free download at https://ucanr.edu/sites/bio-securityeducation/Educational_Videos/. We recommend the use of these or similar resources whenever possible to help increase knowledge and improve biosecurity practices regarding human/livestock interactions at fairs and exhibitions.

Opportunities for reducing health risks

The results from this study highlight the fact that the vast majority of fair visitors are not utilizing a simple and effective tool — handwashing — for reducing the potential for zoonotic disease transmission at county fairs. Therefore, continued efforts to develop and disseminate guidelines for best practices and educational materials for animal exhibitors and the public will be important to assist in the mitigation of disease transmission risks at California county fairs. A combined approach to accomplish this is recommended, including biosecurity education for animal exhibitors (e.g., Smith et al. 2011; Smith et al. 2021; Smith and Meehan, unpublished manuscript), enhanced fair policies designed to limit pathogen transmission, and strategically placed handwashing signage or other forms of fair visitor education like looped videos such as those described previously to increase handwashing practice. Together, these strategies will likely help reduce the public health risks associated with the presence and persistence of fecal-borne pathogens among livestock exhibited at fairs in California (Daniels et al. 2021; Keen et al. 2006; Roug et al. 2012). CA

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2022 San Joaquin Valley Grape Symposium

https://ucanr.edu/sites/viticulture-fresno/

Date: January 12, 2022
Time: 7:00 a.m. to 12:00 p.m.
Location: CPDES Hall, Easton, Calif.
Contact: George Zhuang, UCCE Fresno County, gzhuang@ucanr.edu

Statewide Pistachio Day (Virtual)

https://ucanr.edu/sites/pistachioday/

Date: January 19–20, 2022
Time: 8:00 a.m. to 12:00 p.m.
Location: Online
Contact: Registration: UC ANR Program Support, 530-750-1361; course: Louise Ferguson, UC ANR CE Specialist, lferguson@ucdavis.edu

California Naturalist Tuleyome Course

http://www.tuleyome.org/projects/calnat/

Date: January 14–March 18, 2022
Time: 8:00 a.m. to 5:00 p.m.
Location: Online with in-person option at Woodland, Calif.
Contact: Nate Lillge, nlillge@tuleyome.org