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EDITORIAL

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Agriculture and Natural Resources

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Research and review articles

COVER: When *scutellata*-hybrid ("Africanized") honey bees arrived in California in 1994, experts were concerned about the potential impact they could have on agriculture. However, research suggests that pollination services provided by managed honey bees appear to have been relatively unaffected by the influx of *scutellata*-hybrid bees (Zarate et al., page 15). *Photo*: Krystle Hickman.

RESEARCH ARTICLE

Long-term reduced tillage and winter cover crops can improve soil quality without depleting moisture

Long-term reduced-disturbance tillage and winter cover cropping can improve San Joaquin Valley soil quality without depleting soil moisture.

by Anna Gomes, Alyssa J. DeVincentis, Samuel Sandoval Solis, Daniele Zaccaria, Daniel Munk, Khaled Bali, Anil Shrestha, Kennedy Gould and Jeffrey Mitchell

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Abstract

California farmers who use reduced-disturbance tillage and winter cover cropping can boost production and improve soil health. However, some farmers are hesitant to try these conservation practices due to uncertainty about whether planting winter cover crops will deplete soil moisture in already drought-stricken regions. Our study addresses these concerns by looking at how long-term reduced-disturbance tillage and winter cover cropping, compared to fallowed soils with standard tillage, affected soil moisture. Although we found a statistical difference in total soil water content, the difference was only about 0.3 inches of water per foot of soil. On average, the soil water content of the top 0–96 inches was highest for the reduced-disturbance fields with winter cover crops. This was especially evident during our driest field season, from November 1, 2017, to March 15, 2018, when cumulative rainfall was only 1.9 inches. Our findings show that winter cover cropping and reduced-disturbance tillage can improve soil without depleting soil water levels in row crops.

During the 2012–2016 drought, California farmers, particularly those in the San Joaquin Valley, were confronted with higher water prices and frequently turned to finite groundwater reserves to meet crop water demands (Hanak et al. 2017). The economic repercussions of prolonged water shortages in the region raise concerns about how to meet crop water requirements without degrading the environment. These concerns contribute to farmers' hesitation to adopt winter cover cropping and reduced-disturbance tillage (which relies on leaving crop residue on the field and can refer to either no tillage or reduced tillage). Although cover cropping (CC) and reduced-disturbance tillage (RD) improve soil quality and benefit ecosystems (Mitchell 2019; Yao et al. 2000), the hydrological impacts of these combined practices have not been well documented. At a time when groundwater sustainability agencies (GSAs) under California's Sustainable Groundwater Management Act (SGMA)

A tractor mows a cover crop of radish, *Phacelia*, vetch and triticale. Benefits of cover cropping include increased water infiltration and soil aggregate stability. *Photo:* Jeffrey Mitchell.

are meticulously tracking water use, including rainfed winter cover crops, there's a knowledge gap regarding the hydrologic impact of conservation agriculture practices. Simultaneously, irrigation districts are grappling with the fate of fallowing farmland and leaving some acreage unplanted (Hanak et al. 2021). Research addressing the combined impacts of winter cover cropping and reduced-disturbance tillage on soil moisture will play an important role in farmers' planting decisions.

Cover cropping has been widely studied for its agronomic and ecosystem benefits. These include improving soil porosity (Basche and DeLonge 2017), increasing water infiltration into the soil profile and reducing soil erosion (Dabney et al. 2001; Fageria et al. 2005), suppressing early-season weeds (Teasdale 1996), increasing microbial diversity (Schmidt et al. 2018), biomass and activity (Duchene et al. 2017; Fageria et al. 2005; Fernandez et al. 2016), mitigating net greenhouse gas emissions (Abdalla et al. 2019), reducing nitrogen leaching (Abdalla et al. 2019), and minimizing water quality degradation (Harter et al. 2012).

RD minimizes physical disturbance of the soil profile following the harvest of one crop and before the establishment of a subsequent crop, while leaving crop residues on the soil. Keeping the surface covered with residues is an important principle of soil health and is central to conservation agriculture (Mitchell et al. 2019). Reducing tillage and maintaining soil cover has been shown to increase soil water-holding capacity and to prevent top layer compaction and sealing, especially in dry climates (Basche and DeLonge 2017). These benefits have been observed under both irrigated (Klocke et al. 2009; van Donk et al. 2010) and rainfed or otherwise water-limited conditions (Unger and Baumhardt 1999; Unger and Parker 1976). Residues left on the soil surface reduce direct soil evaporation through the mulching and shading effect, which reduces surface soil temperature, ground heat storage, and direct wind effects on evaporation (Klocke et al. 2009; Ranaivoson et al. 2017).

Current adoption is low

Financial incentives from state and federal programs have promoted both cover cropping and reduced-disturbance tillage as multi-benefit conservation agriculture practices. However, their implementation into cropping systems can be complex. As a result, adoption rates vary widely across agroecological systems. In California, although rates have been increasing, reduced-disturbance tillage is only practiced on 7.1% of cropland acreage, compared to the U.S. average of 34.6%, and only 4.8% of California cropland acreage is cover cropped, compared to the U.S. average of 10.7% (LaRose and Myers 2019).

Understanding what drives farmers to change their agricultural practices depends on local conditions. Some consistent trends driving adoption of conservation practices include access to information, perceived costs and benefits (Bergtold et al. 2012; Knowler and Bradshaw 2007), understanding that short-term costs can lead to long-term benefits (DeVincentis et al. 2020), and social networks influencing norms of practice. Additionally, risk perceptions and acceptance, environmental attitudes, access to financial incentives for adaptation (including conservation programs such as USDA-NRCS EQIP and CDFA Healthy Soils Program), and a host of demographic variables specific to the operation and the farmer (e.g., farm size, crop type, soil type, farm income, years of farming experience, level of education, land tenure, etc.) (Knowler and Bradshaw 2007; Prokopy et al. 2008) play an important role.

Twenty-year (1999–2019) field study site at the UC West Side Research and Extension Center with surface residue preservation (center plots), cover cropping (green strips), and clean cultivation fallow plots (on the periphery of the photo). *Photo:* Jeffrey Mitchell.

While we can learn about adoption from similar research in other locations, these findings cannot provide a complete picture of farmer decision-making in California, where water limitations are unique. Due to the dynamic nature of soil and its slowly changing characteristics (Six et al. 2004), long-term research studies are critical to addressing questions of agricultural resource management, including the use of practices such as cover cropping and reduced-disturbance tillage. Long-term studies on soil water are particularly important in light of concerns that cover crops could exacerbate the depletion of soil moisture during the winter period due to evapotranspiration (Mitchell et al. 2015; Unger and Vigil 1998).

This study expands on earlier work that identified trade-offs between soil improvement and soil water depletion as a result of winter cover cropping (Mitchell et al. 2015) and is aligned with recent findings that cover crops do not cause significantly different soil moisture or evapotranspirative losses compared to control plots across 10 sites in California's Central Valley

(DeVincentis et al. 2022). Our 2016–2019 study builds on 17 years following the inception of the conservation agriculture treatments of reduced-disturbance tillage and winter cover cropping at a field site in the San Joaquin Valley. The focus of this research is to address a common scientific question from the local agricultural production and regulatory communities: "Do the combined soil conservation practices of winter cover cropping and reduced-disturbance tillage have an observable impact on soil moisture in San Joaquin Valley agricultural fields?"

This study addresses information gaps related to actual water use in cover cropping and how cover crops and reduced-disturbance tillage affect soil moisture. The setting is an annual crop sequence that has been underway since 1999. Our goal was to quantify and document changes in winter soil water storage due to cover crops and reduced-disturbance tillage.

Long-term field site

In 1999, the National Research Initiative (NRI) – Conservation Agriculture Systems Project (CASP) was created to evaluate reduced-disturbance tillage as a possible practice to reduce particulate matter emissions from the intensive soil disturbance tillage in a cotton-tomato rotation system. Located at the University of California's West Side Research and Extension Center (WSREC) in Five Points, California, the CASP study is the only study site in the state that has incorporated all critical soil health principles in its experimental design. For the reduced-disturbance tillage plots, the RD system fully transitioned to no tillage (NT) in 2012, with the only soil disturbance happening during seeding or transplanting. The site thus provides a unique resource that permits researchers to quantify the long-term impacts of consistently implemented alternative management practices on soil biodiversity and functions (Mitchell et al. 2017).

Since the initiation of the long-term research site, the objectives have been broadened to measure changes in soil chemical, physical, and biological properties under reduced-disturbance tillage and cover cropping management in the historically highly productive San Joaquin Valley. Previously published information from the site has documented improvements in several soil health indicators, including soil aggregate stability and water infiltration (Mitchell et al. 2017), abundance and diversity of soil macrofauna (Kelly et al. 2021), and soil porosity and water-holding characteristics (Araya et al. 2022).

Throughout the CASP's duration, the impacts of reduced-disturbannce tillage and cover cropping on crop yields have varied by crop. Half of the experimental field was in a tomato-cotton rotation and the other half was in a cotton-tomato rotation with both crops grown in each year from 1999 to 2014, followed by garbanzo (*Cicer arietinum*), sorghum (*Sorghum bicolor* L.) (2015 to 2018) and tomato and garbanzo in 2019. Tomato yields were 9.5% higher in RD versus standard tillage (ST) systems but were 5.7% higher in no-cover crop (NO) than in CC systems. The cotton yields were 10.0% higher in ST than RD and 4.8% higher in NO than CC systems in the early years of the study, largely due to problems encountered in establishing crop stands with no tillage. Sorghum yields in 2016 and 2017 were similar between RD and ST, while cover crops had no effect on sorghum yields in either year. Garbanzo yields were higher in RD than ST in 2016 and 2017, but similar in 2018. Tomato yields in 2018 were lower in the RD-CC system, due to problems that year with cover crop regrowth. In general, the yield results between treatments need to be viewed cautiously, as they reflect the inherent learning curve challenges and mistakes of experiment station work.

Experimental design

The 8.8-acre research site consists of 32 plots, each 33 feet wide by 328 feet long, with a 33-foot border plot (buffers) between treatments and six 5-foot buffers between rows (fig. 1). See the online technical appendix for cover crop mixes, planting and termination dates, and irrigation quantities with dates. The soil type is a Panoche clay loam with a fine-loamy texture, mixed, superactive, and thermic Typic Haplocambids. This soil is characterized as being well-drained with moderate permeability and formed by alluvial fans in flood plains (Mitchell 2015).

Our study consisted of four combinations of tillage and cover crop systems, arranged as a randomized

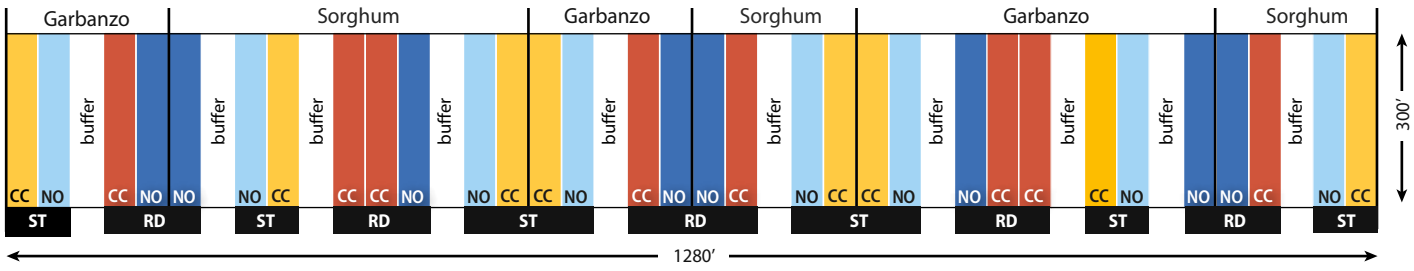

FIG. 1. Entire experimental field layout for season 1 of our study, consisting of four treatments, two cash crops, and several buffer/border rows. From 2015 to 2017, the cash crops were sorghum and garbanzos (rotated), in 2018 tomatoes and garbanzos, and in 2019 melons and tomatoes. CC = cover crop, NO = no cover crop, RD = reduced-disturbance tillage, ST = standard tillage.

complete block design in a typical row crop field in the San Joaquin Valley. The four combinations were (1) reduced-disturbance tillage with winter cover cropping (RD CC), (2) standard tillage with winter cover cropping (ST CC), (3) reduced-disturbance tillage without winter cover cropping (RD NO), and (4) standard tillage without winter cover cropping (ST NO) (fig. 1). The cash crops were rotated between seasons to maintain variability, while the soil management practices within each plot remained consistent. Standard tillage practices included surface residue shredding, multiple diskings to incorporate the residues from 8 inches to 10 inches, subsoil ripping to about 14 inches, and an additional disking, followed by bed shaping using a Wilcox Performer implement (Wilcox Agriproducts, Walnut Grove, Calif.).

Plot treatments remained consistent throughout the study, including management practices such as fertilizer and pest management interventions. Cover crops were planted by early November of each year and terminated in mid-March by mowing and spraying the standing residue with 2% glyphosate (N-(phosphonomethyl) glycine) for the RD treatments. Afterwards, the cover crop residues were disked into the soil for ST. Spraying the cover crop decreased the lag time between the termination of the cover crop and planting of the cash crops. Irrigation water was applied through a subsurface drip system, installed at the field site in 2013, with 1.5-inch diameter tape buried 12 inches in the center of each 60-inch-wide planting bed. Each year of the study the same amount of fall pre-plant irrigation water was applied to all of the treatment plots equally (3 inches in 2016, 3.5 inches in 2017, and 4 inches in 2018; see technical appendix).

Probe collects moisture data

Data for the study were collected between November and March for the years 2016 to 2019. Soil moisture was measured using a field-calibrated Campbell Nuclear Model 503 Hydroprobe (Campbell Pacific Nuclear, Martinez, Calif.) neutron probe depth gauge (503 DR Hydroprobe). Measurements were taken at 10 different depths (6, 12, 24, 36, 48, 60, 72, 84, 96, and 106 inches beneath the soil surface), with one access tube per plot. Previous research conducted at the same study site had shown that one access tube per plot is sufficient to capture the soil moisture of the entire treatment plot (Islam et al. 2006) given the homogeneity of soil hydraulic properties across the experimental plots.

On average, the neutron probe sampled a 26.4– to 26.8-inch radius of soil moisture at each depth. Neutron probe readings (counts of slow neutrons due to the interaction with soil water molecules) were recorded during the winter periods. The neutron probe data set included soil moisture data collected approximately weekly over three winter seasons from four treatments, from November 12, 2016 to April 20, 2017; November 7, 2017 to March 26, 2018; and October 17, 2018 to March 12, 2019.

NRCS soil health coordinator training at the NRI Project site in Five Points, Calif. *Photo*: Jeffrey Mitchell.

The percent canopy cover (the proportion of the soil surface area covered by cover crop foliage) was determined during the 2017–2018 cover crop growing season using Canopeo (https://canopeoapp.com), an app that measures fractional green canopy cover based on images captured by a smartphone camera (Patrignani and Ochsner 2015). Canopeo separates the green plant area from soil surface background and provides an estimated percentage of canopy coverage.

We used these data to assess the variations of water content in the soil profile between cash crop seasons, from November to March. This is a critical period to capture water from rainfall, because California's Mediterranean climate brings rain almost exclusively during the winter months. Neutron probe raw counts were manually recorded and then digitized, with the values checked for consistency by two research team members. The data set included 13,760 observations collected over 43 days, down 10 individual soil depths, and using 32 neutron probe access tubes. In order to compare the treatments over the same time period for the three winter seasons, the data set was truncated from November 1 to March 15 for each season, resulting in 10,880 observations after removing data from the 6-inch and 106-inch depths due to concerns about surface-atmospheric interactions and missing data, respectively.

The cumulative precipitation each season, from November 1 to March 15, was 6.3, 1.9, and 7.1 inches, respectively, and the average air temperature for November through March for each of the three seasons was 50.1°F, 50.1°F, and 49.8°F (CIMIS station no. 2, located on site in Five Points, Calif.; https://cimis.water.ca.gov/WSNReportCriteria.aspx). The average daily reference evapotranspiration (ET_o) value obtained with the Penman-Monteith method (ASCE-EWRI 2005)

Winter cover cropping and reduced-disturbance tillage can improve soil without depleting water levels in row crops.

from November 1 to March 15 for each season was 0.07, 0.08, and 0.07 inches, respectively. The average ET_o (PM) from January 1st, 2016 through December 31, 2019 is 0.18 inches (https://cimis.water.ca.gov/). For the purposes of this experiment, we treated the plots within the NRI field as comparable, because fall irrigation, soil type, and weather conditions remained constant among treatment plots, with cash crops being rotated each year. The plots that received tillage (ST) and winter cover crops (CC) have remained constant since the experimental field started in 1999, regardless of which rotational row crop was grown during the summer cash crop period.

Data analysis was conducted using R statistical software (R Core Team 2020, version 4.4.1). The raw neutron probe counts were transformed to volumetric water content (VWC) using a calibration equation that relates count ratios to percent soil moisture using linear regression. The raw neutron probe counts were transformed into a count ratio to minimize the impacts caused by changes in the probe functionality due to aging and decay. Count ratios were calculated by dividing each raw count by the average of the standard counts taken each day of neutron probe readings in the field (7127). The calibration equation ($VWC\% = 22.619x - 1.587$, $R^2 = 0.96$; technical appendix fig. A) was created by regressing neutron probe counts and gravimetric soil data that was simultaneously collected. In-situ field calibration of the 503 Hydroprobe was done by taking count readings using the standard calibration feature of the probe at a given soil depth, collecting three 2.25-inch diameter cores at the same depth adjacent to the access tube, weighing the soil, drying the sample for 24 hours at 105°C, weighing the sample again to determine the gravimetric water content, and then converting gravimetric water content to VWC using the soil bulk density values determined from samples that were collected in 2013.

After every soil neutron probe count was converted into VWC (%) using the calibration equation, then converted to inches of water per foot of soil (e.g., 30% × 12 inches = 3.6 inches of water per foot), these values were compared individually (ANOVA), and then averaged and compared (Tukey test of means). Prior to conducting an analysis of variance (ANOVA) test, the statistical assumptions were tested. A two-factor ANOVA test was performed, comparing the tillage and cover factors on each date-depth combination from the three field seasons. The date-depth analysis is based on the method proposed by DeVincentis et al. (2022). Of the 1,032 ANOVA tests, 16% (193) observations showed significantly different ($P < 0.05$) soil water content. We removed the data sets that were collected on three date-depth combinations that showed significant interaction (tillage: cover) between Feb. 28, 2017 and March 10, 2017. The remaining analysis was conducted with the final data set of 10,784 individual winter soil water content values from 43 days of observation (over three field seasons), four treatments, and eight depths.

A post-hoc Tukey test was then performed with all the data to determine whether there were differences between the average soil water content values of the respective treatments. Two main comparisons were conducted: (a) the average value (inches of water per foot of soil) for each of the four treatments across the three seasons (depth aggregated), and (b) the average value at each depth for each of the four treatments (depth resolved). Then, in order to estimate the differences in soil water storage between various treatments, the averages from part (b) above were summed across the measured soil depth along the depth of measurement (0–96 inches) for each treatment.

Depth aggregated: soil water content comparison between treatments

$$\overline{W}^T = \frac{\sum_{d=1}^{43}\sum_{z=1}^{8}\sum_{r=1}^{4} W^T_{d,z,r}}{N_d \times N_z \times N_r}$$

Depth resolved: soil water content comparison between treatments

$$\overline{W}^T_z = \frac{\sum_{d=1}^{43}\sum_{z=1}^{8}\sum_{r=1}^{4} W^T_{d,z,r}}{N_d \times N_r}$$

where $\overline{W}^T$ is the mean water content of treatment T; subscripts d, z, and r represent indices of the measurement day, depth, and replication number; $\overline{W}^T_z$ is the mean water content of treatment T at depth z; $W^T_{d,z,r}$ represents an individual water content measurement on day d, depth z and replication number r; and d, z, and r represent the total number of measurement days, depths and replicates, respectively (i.e., $d = 43$, $z = 8$, and $r = 4$). Following the calculation, we ended up with a total of 4 $\overline{W}^T$ means, one for each treatment, and 4 × 8 = 32 means, one for each treatment-depth pair.

Less tillage, more moisture

We found that the plots with combined reduced-disturbance tillage and winter cover crops had the highest average winter soil moisture from 2016 to 2019. After conducting a pair-wise test, all treatment averages are statistically different from each other ($P < 0.05$). However, the differences between the four combinations were minimal. Measured in inches of water per foot of soil, the differences were less than 0.5 inch (fig. 2), which is a small fraction of the average seasonal tomato water requirements (about 30 inches) in the southern San Joaquin Valley (Turini et al. 2018). For instance, when comparing ST NO to RD CC, there is on average 0.3 in/ft less water in the standard tillage, no cover crop treatment than in the treatment with both soil conservation practices. The main takeaway is that the ST NO to RD CC comparison of means is the farthest from the zero line in figure 2, and hence has the largest difference in soil water content.

Translating this further, the results show that, on average throughout the November 1–March 15 season, there is more water in the plots under RD with winter cover crops, compared to the plots under ST without

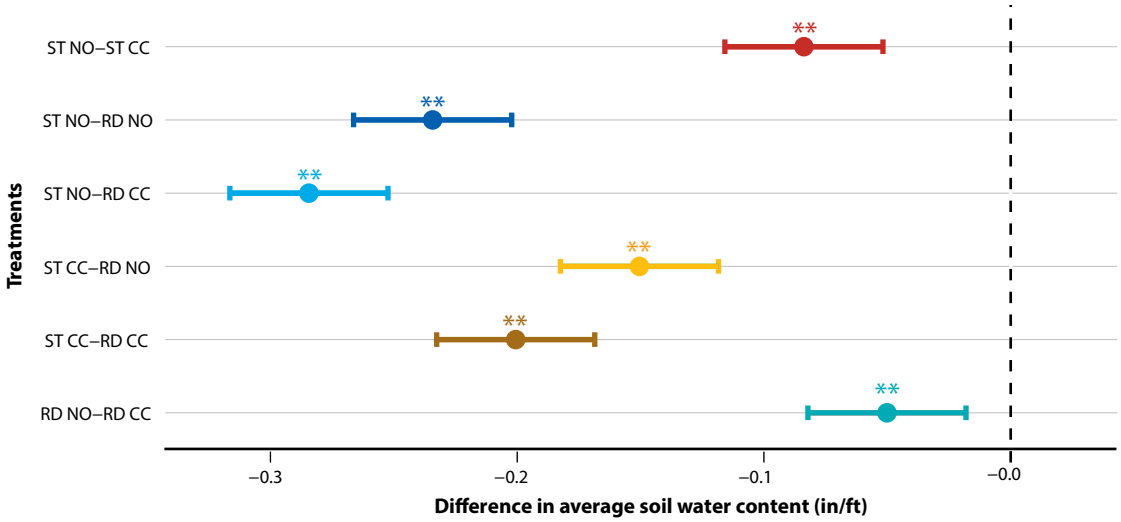

FIG. 2. Pairwise comparisons between soil water content (in/ft) between two different treatment means (95% family-wise confidence level). Soil water content differences between the treatment means (in/ft) as a result of the Tukey test of means. The results are averaged across the entire soil profile (0–96 inches) grouped by treatment. Error bars indicate standard errors. ** signifies that differences are statistically significant at $P < 0.05$. CC = cover crop, NO = no cover crop, RD = reduced-disturbance tillage, ST = standard tillage.

winter cover crops. When comparing the effect of tillage and cover crops on soil water content, CC has less of an impact on the soil moisture than the choice of tillage system (i.e., ST NO–ST CC and RD NO–RD CC have the least difference in mean levels). In short, compared to fallow or clean-cultivated soil, the cover crops are not depleting the soil moisture.

According to the Tukey test of means, there is a statistically significant difference between the aggregated four treatments (fig. 3). For the ST NO treatment, the distribution of observations peaks at the low end of the soil moisture spectrum, i.e., around 1–2 inches of water per foot of soil, indicating that this treatment generally had the least soil water (fig. 3). In contrast, both the reduced-disturbance treatments (RD CC and RD NO) have distributions that are concentrated farther to the right compared to standard tillage treatments (ST CC and ST NO), around the upper end of the soil moisture spectrum (2–3 inches) (fig. 3). This behavior indicates a tendency toward higher soil moisture in reduced-disturbance treatments.

The conservation agriculture practice of reduced-disturbance tillage coupled with winter cover cropping shows a combined positive impact on soil moisture,

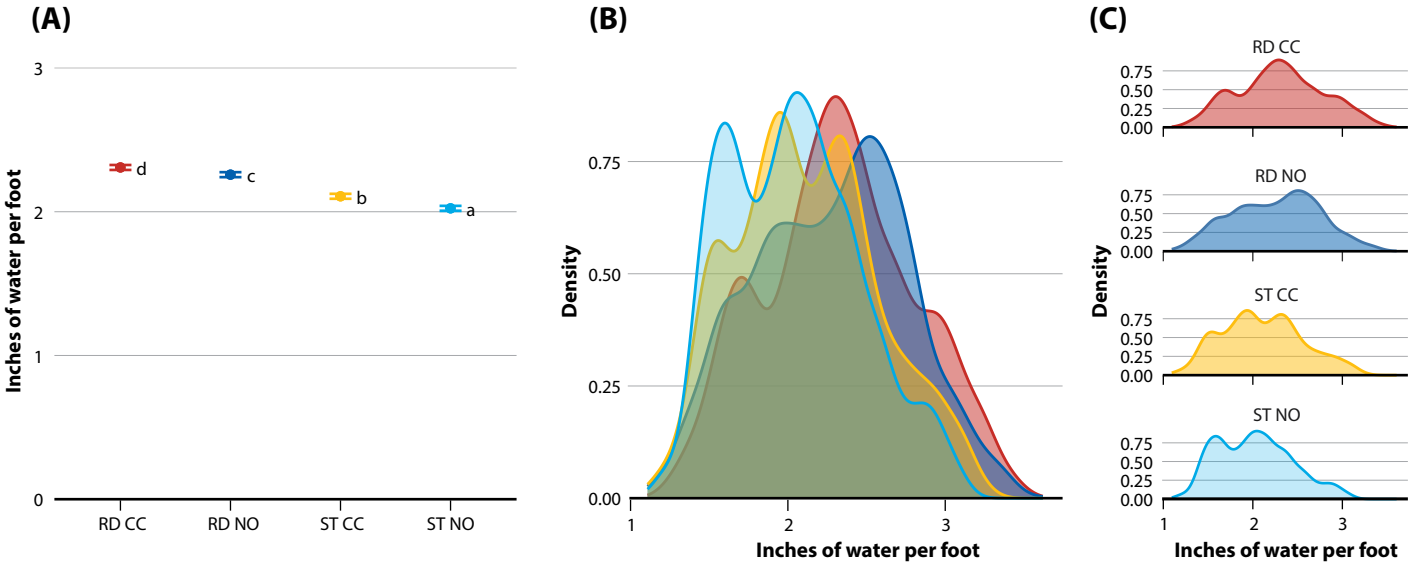

FIG. 3. Soil moisture (in/ft soil) density distribution. The overall trend in the dataset illustrates that there is a high degree of overlap between soil moisture comparing the four treatments. CC = cover crop, NO = no cover crop, RD = reduced-disturbance tillage, ST = standard tillage. (A) Average wintertime soil moisture from 2016 to 2019. Means followed by a common letter are not significantly different according to the Tukey test. (B) Density distribution of wintertime soil moisture from 2016 to 2019. (C) Density distribution per individual treatment.

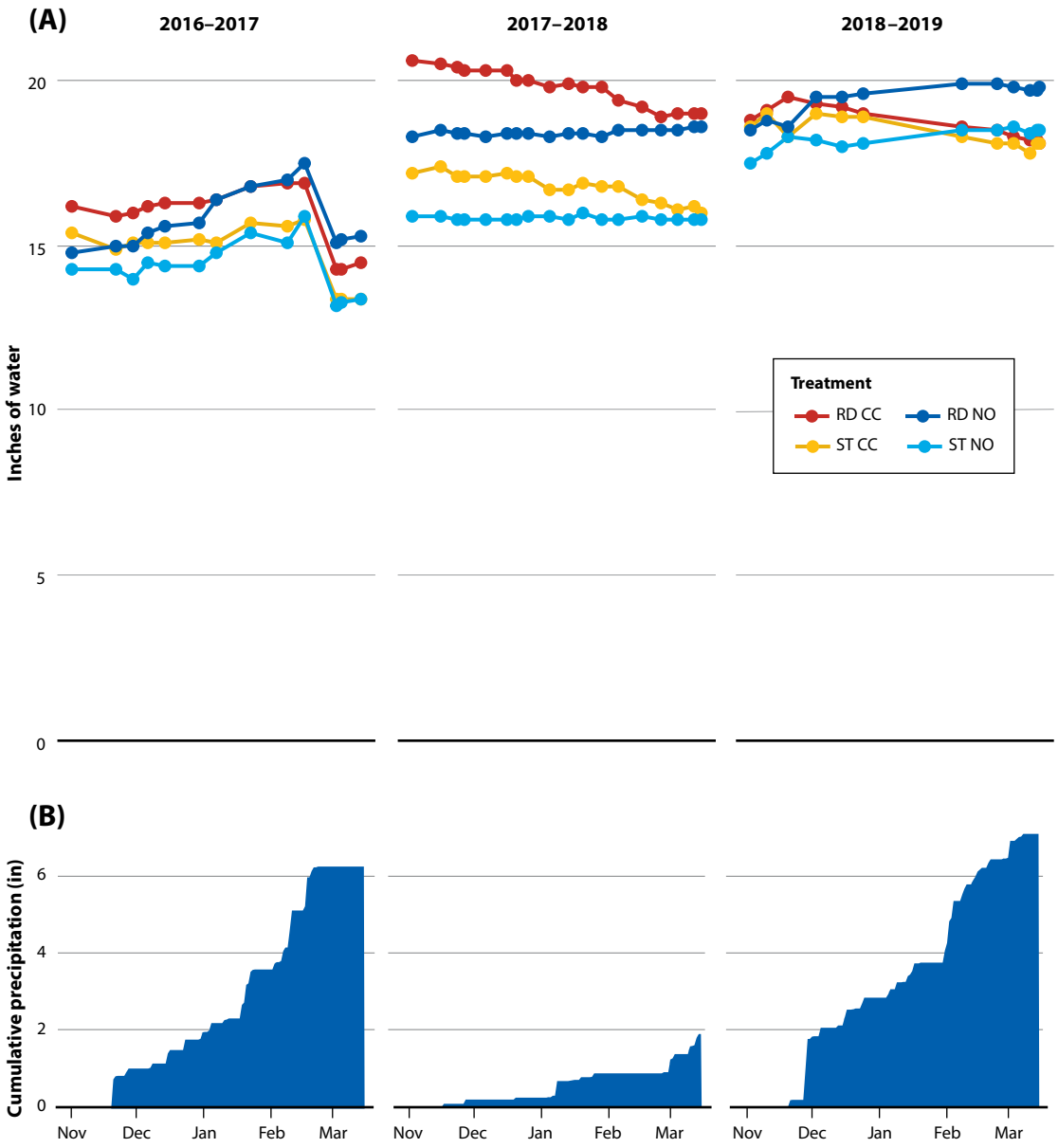

FIG. 4. Soil moisture response and precipitation patterns over the winter cover crop growing season. (A) Daily sum of average wintertime soil moisture in top 96 inches. (B) Cumulative precipitation between Nov. 1 and Mar. 15 in Five Points, Calif. CC = cover crop, NO = no cover crop, RD = reduced-disturbance tillage, ST = standard tillage.

most prominently during drought conditions. In relating our results to precipitation patterns, despite the low precipitation (1.9 inches) during the second season (November 1, 2017 to March 15, 2018), the RD CC treatment plots showed higher soil moisture content throughout the winter season compared to the other three treatments (fig. 4). For all three seasons, despite the water used to grow cover crops during the winter season, there was no noticeable difference in winter soil water content between the cover cropped plots and the fallow or clean-cultivated plots at the end of the cover crop season in March (fig. 4).

The four treatments differed slightly in behavior among the three seasons. The most distinctive differences in soil water content down the profile can be highlighted in the 2017 drought season, when the reduced-disturbance plots had a higher sum of average soil water content compared to the standard tillage plots (fig. 5). When examining the differences in soil moisture across depths along the soil profile, water down the soil profile follows a similar pattern across treatments, with a greater amount of soil water in the top and around 72 inches depth (fig. 6). Comparing soil water at the same depths in the profile among treatments, again we find that reduced-disturbance tillage plots had more soil water than standard tillage plots for most of the depths, regardless of the presence of cover crops (fig. 6). Additionally, the ST NO plots consistently show the lowest soil water (in water/ft soil) down the profile across the three seasons (fig. 6).

Extensive cover crop canopy

The cover crops were typically seeded by November 15 of each fall and terminated around March 15 of the following spring. This time accounts for a period of actively growing biomass, or "solar energy-capturing green ground cover," allowing for about 120 additional

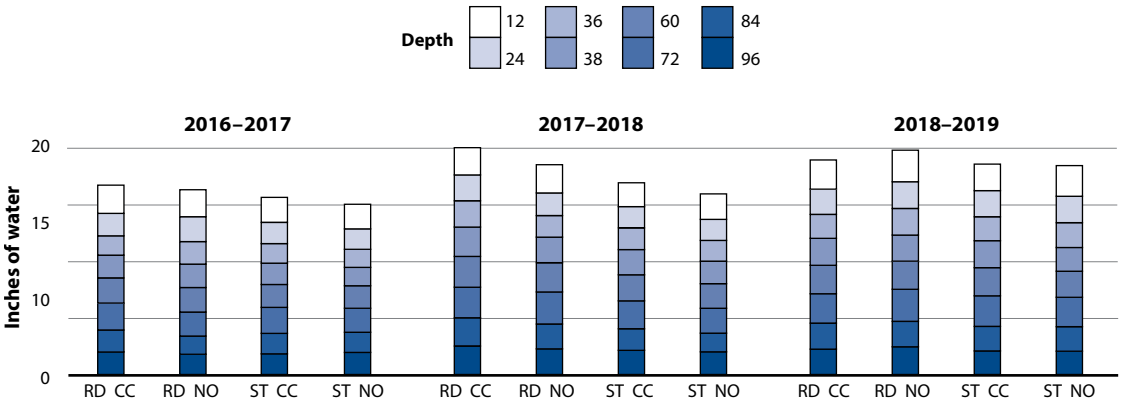

FIG. 5. Sum of average wintertime soil moisture in top 96 inches. This data represents the sum of the averages at each depth, allowing for understanding the distribution of water throughout the depth of the profile for each treatment, and any differences among seasons. CC = cover crop, NO = no cover crop, RD = reduced-disturbance tillage, ST = standard tillage.

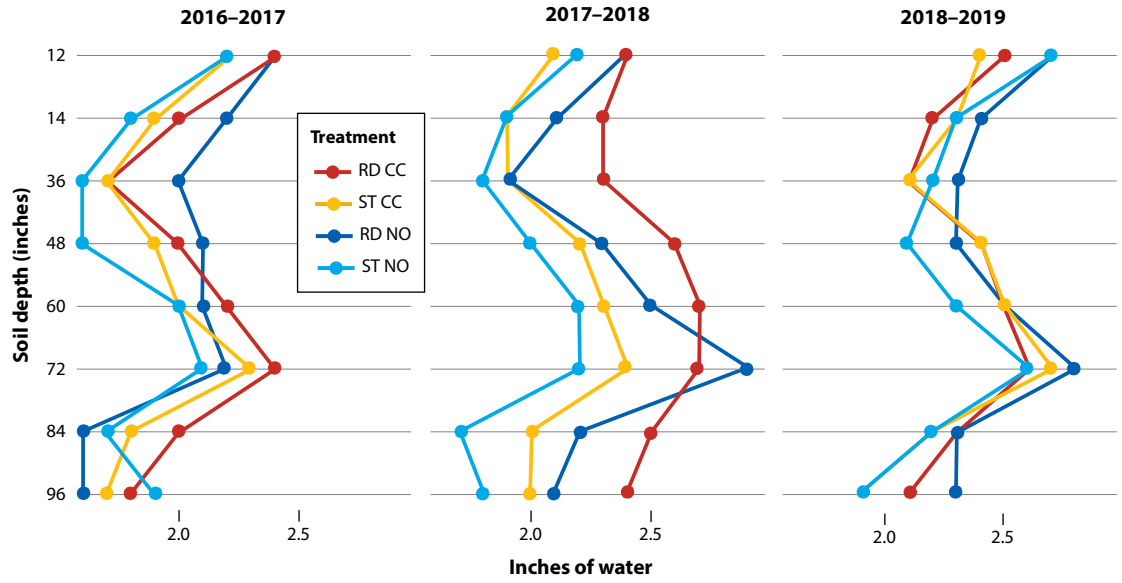

FIG. 6. Seasonal average wintertime soil moisture along the soil profile. CC = cover crop, NO = no cover crop, RD = reduced-disturbance tillage, ST = standard tillage.

days of living roots in the soil during the year relative to the NO systems, which were instead fallow during that time. The percent canopy cover, measured during the 2017–2018 winter, showed that the cover crop increased steadily to over 90% canopy cover during the 87-day period from November 12 through February 7.

Previous studies have shown that, depending on rainfall, climate, and the duration of the growing period, cover crops use water for growth and may create a water deficit for farmers (Mitchell et al. 2015; Unger and Vigil 1998). By contrast, our results suggest that, despite the water used by the cover crops, numerous benefits can be obtained from these conservation agricultural practices without depleting soil moisture from the active rootzone, provided the cover crop growth is terminated before periods of higher evapotranspiration demand, i.e., beyond March 15. Our results for the aggregated 2016–2019 winter seasons indicate that the reduced-disturbance tillage and cover crops (RD CC) plots had the most total soil water. This was especially evident during the drought of November 2017–March 2018, with the lowest cumulative rainfall of the three seasons of our study — only 1.89 inches, compared to 6.28 and 7.08 inches during the first and third season (fig. 4).

The tradeoff outlined in Mitchell et al. (2015) between winter cover crop growth and soil water depletion was based on the same field site as our study, in the 2013 and 2014 seasons. That study found that, compared to the fallow soils, cover crops depleted 2.1 inches of water in 2013 and 0.26 inches in 2014. We hypothesize that this tradeoff has now been overcome due to the extended period of reduced-disturbance tillage, and the accompanying benefits, including high surface residue and retainment of soil moisture. Furthermore, Mitchell et al. (2015) measured the soil water content only from 0–35 inches of the soil profile, and from early January to late March. By comparison, this study

measured 0–106 inches of the profile with soil water data from mid-November to mid-March. Estimating the water content at the end of the study period (mid-March) is critical to analyzing our data.

The power of living cover

Our study illustrates the effects of winter soil cover from living biomass (cover crops) and surface residues. In the 2017–2018 winter cover crop season, the RD plots started the winter cover crop growing season with noticeably more water (fig. 3). This is most likely due to post-summer 2017 retention of soil water from higher water infiltration combined with higher water retention. This aspect can be further explained by the comparable summer 2017 cash crop yields and the lack of precipitation in October 2017 (CIMIS station No. 2; https://cimis.water.ca.gov/WSNReportCriteria.aspx).

Reduced water application would also result in tangible energy savings.

As the cash crop yields have remained high (Mitchell et al. 2022), we hypothesize that the higher soil moisture results from the higher profile-level water storage and water availability following irrigation of these plots (Araya et al. 2022), developed over several years of consistent reduced tillage (Burgess et al. 2014; Busari et al. 2015). Combined, these practices lead to improved soil water infiltration with increased soil water holding capacity, due to the avoidance of soil compaction from machinery passes, the additional water held by surface residue, and the relatively higher levels of soil organic matter in the RD CC plots. Cover crops have a mulching effect, lowering soil temperatures and reducing soil water loss through evaporation. By combining reduced-disturbance tillage with winter cover cropping, the increased water held in the soil profile in the reduced-disturbance tillage plots can allow for growth of cover crops without depleting soil moisture for the subsequent cash crop.

Our results are in line with similar studies measuring the impact of these practices on soil water content. Villamil et al. (2006) found that the combined effect of no tillage and winter cover crops increased plant-available water in an Illinois corn and soybean rotation. Blanco-Canqui et al. (2011) found improved soil physical properties, including aggregate stability, and hence soil water infiltration, after 15 years of cover cropping with no-till. Basche and DeLonge (2017) found that total soil porosity and soil water held at field capacity increased after 10 years of continuous living soil cover, suggesting cover crops as a practice that can mitigate the effects of rainfall variability due to climate change. Rankoth et al. (2021) found that cover crop treatments had higher soil water in the top 12 inches of the soil profile, compared to plots without cover crops. DeVincentis et al. (2022) found that the differences in soil water content between the cover cropped and fallowed soil were minimal, aligning with our conclusion that conservation practices do not deplete the soil water.

Our study further supports the conclusions of Araya et al. (2022), whose research was conducted at the same site at WSREC in Five Points, that combining reduced-disturbance tillage with winter cover crops increases water capture and retention in the soil profile. The complexity of the wintertime soil water dynamics must include the shading and mulching effects of cover crops, which reduce the soil temperature; this reduces the heat transfer into the ground, thus decreasing soil evaporation losses (Mitchell et al. 2012).

Future research should include monitoring the response-to-rain of these treatments in order to understand the benefits to infiltration and overall increasing soil moisture, ensuring that the soil system can "catch and store every drop" of rain or irrigation where it falls (USDA 1938). The role of living cover crop biomass in capturing, condensing, and percolating moisture from fog and dew, in addition to monitoring soil moisture and actual ET in cover cropped and clean cultivated grounds through the end of April, should be included in future investigations of the on-farm water-related implications of conservation tillage with winter cover crops.

Cost savings vs. new costs

Translating our results for soil water into economic terms, we found that the RD CC had on average 0.3 in/ft more soil water than the ST NO treatments (fig. 3), which summed to 2.4 inches of water for the 8-foot (96 inches) soil profile. For garbanzo production in ET_o Zone 15, where seasonal net water requirements are 19.8 inches (Long et al. 2019), and considering an average root depth of 5 feet, our suggested practices could allow about 6.5% in water saving for farmers. This was calculated assuming an average irrigation application efficiency of 85%, which results in a seasonal gross water demand of 19.8/0.85 = 23.3 inches. The water saving using RD + CC equals 0.065 × 23.3 inches = 1.5 inches (0.12 acre-foot). Considering an average cost of water of $400 per acre-foot during normal years, and $2,000 per acre-foot during dry years, the resulting economic savings range from $50/acre (normal year) to $240/acre (dry years).

Reduced water application would also result in tangible energy savings. California agriculture relies on energy for lifting, filtering, and pressurizing water. From this perspective, the additional soil water storage capacity of conservation agriculture plots could result in measurable benefits to farm budgets and the environment (i.e., reductions in water diversions/extractions, energy usage, and greenhouse gas emissions).

However, our economic considerations do not include the cost to farming operations to establish and terminate the cover crops, compared to standard tillage and clean cultivated ground. New farm management practices will require new farm machinery, as well as possible changes in labor demands, irrigation practices, and land ownership. The timing of winter cover crop

termination or cash crop planting needs to be assessed to determine technical and economic viability. Our long-term perspective may help address farmers' uncertainty by illustrating the returns from the financial investments required.

Different farming systems

In organic farming systems, winter CC and RD may pose additional complications. The NRI field site is set up as a conventional farming system, using herbicide spray to terminate the winter cover cropping before planting the cash crops. Terminating the cover crops with herbicides greatly shortens the transition time between cover crops and cash crops due to the fast decomposition time of residues from the terminated cover crops. For organic farms, mowers, crimpers, or other farm machinery can be used to terminate the cover crops, and may have weed reduction benefits (Wortman et al. 2013), but these represent a significant capital expenditure.

Regarding specialty crops in California, DeVincentis et al. (2020) conducted an extensive cost-benefit analysis of winter cover cropping. That study found that the long-term benefits depend on several factors, including irrigation, water savings due to soil properties, financial subsidies, the cropping system, and finally the impacts of climate change. Future research should include a cost-benefit analysis of the transition from standard tillage and fallow field treatment to reduced-disturbance tillage and winter cover cropping for row crops. The implementation of such practices is currently supported in California through financial subsidies provided by state programs such as the Healthy Soil Initiative (CDFA-HSP).

Our research conclusions may hold in similar Mediterranean climate cropping systems, with cash crops other than grain sorghum, garbanzo, and tomatoes. With a focus on drought-tolerant cash crops in combination with winter cover cropping, we have shown that reduced-disturbance tillage and winter cover crops can be implemented together without compromising the available soil moisture.

Capturing every drop

Understanding how winter cover crops affect water balance and water management is critical, as climate change increases both the frequency and intensity of California droughts (Diffenbaugh et al. 2015) and their alternation with wet years and flooding. A report by the California Department of Water Resources (DWR 2015) found that California is expected to be 15% to 35% drier by 2100, with snowpack under a high warming scenario likely to be reduced by 65%, jeopardizing our surface water supply in a state where groundwater is also scarce.

Even if rain does fall during the winter season, the intensity or amount of rain over a given period of time is projected to increase (Pathak et al. 2018), which emphasizes the need to build soil that can capture every drop and hold this moisture in the profile. The combined use of winter cover crops with reduced-disturbance tillage can be a strategy for improved economic water productivity, with more marketable product per unit of consumptive water use within the San Joaquin Valley water portfolio options (Hanak et al. 2021), and should be politically and financially incentivized for farmer adoption.

Diverse, multi-species (triticale, *Phacelia*, mustard and vetch) cover crop planted in a reduced-disturbance plot to improve soil function at the long-term NRI Project study site in Five Points, Calif.

Twenty years of continuous reduced-disturbance tillage coupled with winter cover crops have provided evidence that these practices can be implemented in unison without depleting soil moisture levels in the drought-prone San Joaquin Valley. Going forward, these findings will hopefully encourage farmers to implement conservation practices that help foster viable production and healthy soils despite very challenging circumstances.

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References

Abdalla M, Hastings A, Cheng K, et al. 2019. A critical review of the impacts of cover crops on nitrogen leaching, net greenhouse gas balance and crop productivity. Glob Change Biol 25(8):2530–43. https://doi.org/10.1111/gcb.14644

Araya SN, Mitchell JP, Hopmans JW, Ghezzehei TA. 2022. Long-term impact of cover crop and reduced disturbance tillage on soil pore size distribution and soil water storage. SOIL 8(1):177–98. https://doi.org/10.5194/soil-8-177-2022

ASCE-EWRI. 2005. The ASCE standardized reference evapotranspiration equation. In: Allen RG, Walter IA, Elliot RL, et al. (eds.). Standardization of Reference Evapotranspiration Task Committee Final Report. Environmental and Water Resources Institute (EWRI) of the American Society of Civil Engineers. Reston: American Society of Civil Engineers (ASCE). 213 p.

Basche A, DeLonge M. 2017. The impact of continuous living cover on soil hydrologic properties: A meta-analysis. Soil Sci Soc Am J 81(5):1179–90. https://doi.org/10.2136/sssaj2017.03.0077

Bergtold J S, Duffy PA, Hite D, Raper RL. 2012. Demographic and management factors affecting the adoption and perceived yield benefit of winter cover crops in the Southeast. J Agr Appl Econ 44(1):99–116. https://doi.org/10.1017/S1074070800000195

Blanco-Canqui H, Mikha MM, Presley DR, Claassen MM. 2011. Addition of cover crops enhances no-till potential for improving soil physical properties. Soil Sci Soc Am J 75(4):1471–82. https://doi.org/10.2136/sssaj2010.0430

Burgess M, Miller P, Jones C, Bekkerman A. 2014. Tillage of cover crops affects soil water, nitrogen, and wheat yield components. Agro J 106(4):1497–1508. https://doi.org/10.2134/agronj14.0007

Busari MA, Kukal SS, Kaur A, et al. 2015. Conservation tillage impacts on soil, crop and the environment. Int Soil Water Conserv Res 3(2):119–29. https://doi.org/10.1016/j.iswcr.2015.05.002

Dabney SM, Delgado JA, Reeves DW. 2001. Using winter cover crops to improvesoil and water quality. Commun Soil Sci Plan 32(7–8):1221–50. https://doi.org/10.1081/CSS-100104110

DeVincentis AJ, Solis, SS, Bruno EM, et al. 2020. Using cost-benefit analysis to understand adoption of winter cover cropping in California's specialty crop systems. J Environ Manage 261:110205. https://doi.org/10.1016/j.jenvman.2020.110205

DeVincentis AJ, Solis SS, Rice S, et al. 2022. Impacts of winter cover cropping on soil moisture and evapotranspiration in California's specialty crop fields may be minimal during winter months. Calif Agr 76(1):37–45. https://doi.org/10.3733/ca.2022a0001

Diffenbaugh NS, Swain DL, Touma D. 2015. Anthropogenic warming has increased drought risk in California. P Natl Acad Sci 112(13):3931–6. https://doi.org/10.1073/pnas.1422385112

Duchene O, Vian J-F, Celette F. 2017. Intercropping with legume for agroecological cropping systems: Complementarity and facilitation processes and the importance of soil microorganisms. A review. Agr Ecosys Environ 240:148–61. https://doi.org/10.1016/j.agee.2017.02.019

[DWR] California Department of Water Resources. 2015. California Climate Science and Data for Water Resources Management. https://cawaterlibrary.net/wp-content/uploads/2017/06/CA_Climate_Science_and_Data_Final_Release_June_2015.pdf

Fageria NK, Baligar V, Bailey B. 2005. Role of cover crops in improving soil and row crop productivity. Commun Soil Sci Plan 36:2733–57. https://doi.org/10.1080/00103620500303939

Fernandez AL, Sheaffer CC, Wyse DL, et al. 2016. Structure of bacterial communities in soil following cover crop and organic fertilizer incorporation. Appl Microbiol Biot 100(21):9331–41. https://doi.org/10.1007/s00253-016-7736-9

Hanak E, Escriva-Bou A, Gray B, et al. 2021. Water and the Future of the San Joaquin Valley. Public Policy Institute of California. www.ppic.org/wp-content/uploads/water-and-the-future-of-the-san-joaquin-valley-february-2019.pdf

Hanak E, Lund J, Howitt R, et al. 2017. Water Stress and a Changing San Joaquin Valley. Public Policy Institute of California. https://doi:10.13140/RG.2.2.31739.31522

Harter T, Lund JR, Darby J, et al. 2012. Addressing Nitrate in California's drinking water with a Focus on Tulare Lake Basin and Salinas Valley Groundwater. Report for the State Water Resources Control Board Report to the Legislature. Davis, CA: UC Davis Center for Watershed Sciences.

Islam N, Wallender WW, Mitchell JP, et al. 2006. Performance evaluation of methods for the estimation of soil hydraulic parameters and their suitability in a hydrologic model. Geoderma 134(1-2):135–51. https://doi.org/10.1016/j.geoderma.2005.09.004

Kelly C, Fonte SJ, Shrestha A, et al. 2021. Winter cover crops and no-till promote soil macrofauna communities in irrigated, Mediterranean cropland in California, USA. Appl Soil Eco https://doi.org/10.1016/j.apsoil.2021.104068

Klocke NL, Currie RS, Aiken RM. 2009. Soil water evaporation and crop residues. Transactions of the ASABE 52(1):103–10. https://doi.org/10.13031/2013.25951

Knowler D, Bradshaw B. 2007. Farmers' adoption of conservation agriculture: A review and synthesis of recent research. Food Policy 32(1): 25–48. https://doi.org/10.1016/j.foodpol.2006.01.003

LaRose J, Myers R. 2019. Soil Health Institute Progress Report on Cover Crops and No-Till Adoption. https://soilhealthinstitute.org/app/uploads/2021/11/Soil-Health-Census-Report.pdf

Long R, Leinfelder-Miles M, Mathesius K, et al. 2019. Garbanzo Bean (Chickpea) Production in California. https://anrcatalog.ucanr.edu/pdf/8634.pdf

Mitchell J, Shrestha A, Epstein L, et al. 2022. No-tillage sorghum and garbanzo yields match or exceed standard tillage yields. Calif Agr 75(3):112–20. https://doi.org/10.3733/ca.2021a0017

Mitchell JP. 2019. Conservation agriculture systems. CABI Reviews: Perspectives in Agriculture, Veterinary Science, Nutrition and Natural Resources 14(001). https://doi.org/10.1079/PAVSNNR201914001

Mitchell JP, Shrestha A, Irmak S. 2015. Trade-offs between winter cover crop production and soil water depletion in the San Joaquin Valley, California. J Soil Water Conserv 70(6):430–40. Https://doi.org/10.2489/jswc.70.6.430

Mitchell JP, Shrestha A, Mathesius K, et al. 2017. Cover cropping and no-tillage improve soil health in an arid irrigated cropping system in California's San Joaquin Valley, USA. Soil Tillage Res 165:325–35. https://doi.org/10.1016/j.still.2016.09.001

Mitchell JP, Singh PN, Wallender WW, et al. 2012. No-tillage and high-residue practices reduce soil water evaporation. Calif Agr 66(2):55–61. https://doi.org/10.3733/ca.v066n02p55

Pathak TB, Maskey ML, Dahlberg JA, et al. 2018. Climate change trends and impacts on California agriculture: A detailed review. Agronomy 8(3):25. https://doi.org/10.3390/agronomy8030025

Patrignani A, Ochsner TE. 2015. Canopeo: A powerful new tool for measuring fractional green canopy cover. Agronomy J 107: 2312–20. https://doi.org/10.2134/agronj15.0150

Prokopy LS, Floress K, Klotthor-Weinkauf D, Baumgart-Getz A. 2008. Determinants of agricultural best management practice adoption: Evidence from the literature. J Soil Water Conserv 63(5):300–11. https://doi.org/10.2489/jswc.63.5.300

R Core Team. 2021. R: A language and environment for statistical computing. Vienna, Austria: R Foundation for Statistical Computing. https://www.R-project.org/

Ranaivoson L, Naudin K, Ripoche A, et al. 2017. Agro-ecological functions of crop residues under conservation agriculture. A review. Agron Sust Dev 37(4):26. https://doi.org/10.1007/s13593-017-0432-z

Rankoth LM, Udawatta RP, Anderson SH, et al. 2021. Cover crop influence on soil water dynamics for a corn–soybean rotation. Agrosyst Geosci Environ 4(3):e20175. https://doi.org/10.1002/agg2.20175

Schmidt R, Gravuer K, Bossange AV, et al. 2018. Long-term use of cover crops and no-till shift soil microbial community life strategies in agricultural soil. PLOS ONE 13(2):e0192953. https://doi.org/10.1371/journal.pone.0192953

Six J, Ogle SM, Breidt FJ, et al. 2004. The potential to mitigate global warming with no-tillage management is only realized when practiced in the long term. Glob Change Biol 10(2):155–60. https://doi.org/10.1111/j.1529-8817.2003.00730.x

Teasdale JR.1996. Contribution of cover crops to weed management in sustainable agricultural systems. J Prod Agric 9(4):475–9. https://doi.org/10.2134/jpa1996.0475

Turini T, Stewart D, Murdock J, Sumner D. 2018. Sample costs to produce processing tomatoes, San Joaquin Valley South, Fresno County. https://coststudyfiles.ucdavis.edu/uploads/cs_public/2e/7a/2e7a8cf0-b7fd-4207-b945-7b4b8a82625c/17processtomatofresnosdi-final_draft.pdf

Unger PW, Baumhardt RL. 1999. Factors related to dryland grain sorghum yield increases: 1939 through 1997. Agron J 91(5):870–5. https://doi.org/10.2134/agronj1999.915870x

Unger PW, Parker JJ. 1976. Evaporation reduction from soil with wheat, sorghum, and cotton residues. Soil Sci Soc Am J 40(6):938–42. https://doi.org/10.2136/sssaj1976.03615995004000060035x

Unger PW, Vigil MF. 1998. Cover crop effects on soil water relationships. J Soil Water Conserv 53(3): 200–7.

[USDA] United States Department of Agriculture. 1938. Keep the rain drop where it falls. Soil Conservation Service flier.

van Donk SJ, Martin DL, Irmak S, et al. 2010. Crop residue cover effects on evaporation, soil water content, and yield of deficit-irrigated corn in West-Central Nebraska. T ASABE 53(6):1787–97. https://doi.org/10.13031/2013.35805

Villamil MB, Bollero GA, Darmody RG, et al. 2006. No-till corn/soybean systems including winter cover crops: Effects on soil properties. Soil Sci Soc Am J 70(6):1936–44. https://doi.org/10.2136/sssaj2005.0350

Wortman SE, Francis CA, Bernards MA, et al. 2013. Mechanical termination of diverse cover crop mixtures for improved weed suppression in organic cropping systems. Weed Sci 61(1):162–70. https://doi.org/10.1614/WS-D-12-00066.1

Yao H, He Z, Wilson MJ, Campbell CD. 2000. Microbial biomass and community structure in a sequence of soils with increasing fertility and changing land use. Microb Ecol 40(3):223–37. https://doi.org/10.1007/s002480000053

REVIEW ARTICLE

Three decades of "Africanized" honey bees in California

Hybrid bees appear to pose little threat to California agriculture but may compete with native pollinators for resources.

by Daniela Zarate, Dillon Travis, Amy Geffre, James Nieh and Joshua R. Kohn

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Abstract

"Africanized" honey bees (AHB) have been part of California's agricultural and natural landscapes for nearly three decades. Prior to their arrival in 1994, leading honey bee experts expressed concern over the potentially disastrous impact of AHB on California agriculture and public safety. Despite these concerns, the state's agricultural production has not been significantly impacted by AHB. However, some evidence suggests that the abundance of AHB in natural habitats can have negative consequences for native pollinators. At the same time, AHB may provide a genetic resource for improving managed honey bee health. We recommend updating the term "Africanized" honey bees to more accurately reflect their biology and to avoid unfortunate connotations.

Now a common feature of California ecosystems and commercial agriculture, honey bees are not native to the American continents, having been first introduced in the early 1500s. German, Italian, Iberian and Carniolan honey bee subspecies were the most commonly introduced. We broadly refer to these subspecies and the mixtures of these lineages as European honey bees (EHBs). These subspecies were adapted to temperate climates and did well in the northern latitudes, but in some cases, fared poorly in the tropical regions of the Americas. To fortify managed honey bee populations, Brazilian geneticists interbred African and European lineages. They hoped to create an improved hybrid that combined the tropical hardiness of African honey bees with the honey production capabilities and less defensive nature of European subspecies (Schneider et al. 2004). To this end, in 1956 scientists imported 47 queens of *Apis mellifera scutellata* from South Africa and Tanzania to São Paulo, Brazil, for experimental breeding.

In California, pollination services provided by managed honey bees appear to have been relatively unaffected by the influx of *scutellata*-hybrid honey bees. *Photo:* Three Spots, iStock.com.

These African honey bee queens and their mixed offspring were inadvertently released from research apiaries and quickly established themselves in the surrounding regions, where they interbred with pre-existing European lineages. "Africanized" honey bees rapidly replaced pre-existing European honey bees with hybrid bees, in which most genes came from *A. m. scutellata*. From their Brazilian origin, "Africanized" honey bees expanded their range at a rapid rate (160–500 kilometers/year), extending south into parts of Argentina and north throughout the rest of South and Central America and Mexico (Schneider et al. 2004).

Time for a name change

While the term "Africanized" honey bee has become commonplace, it is due for revision. "Africanized" as a descriptor is frustratingly broad and fails to accurately reflect the diversity of geographic lineages that a hybrid honey bee of the American continents can encompass. In addition, there exist more than a dozen African honey bee subspecies exhibiting a diverse range of behavioral and life history traits distinct from those of the subspecies *A. m. scutellata* from which the "Africanized" honey bee originated. Perhaps more alarming is the association of aggressive behavior with the term "Africanized." This is confounding and inaccurate because certain African subspecies (e.g., *Apis mellifera monticola*, the Ethiopian highlands honey bee), and some populations of "Africanized" honey bees are well known for their docile natures (Acevedo-Gonzalez et al. 2019; Ruttner 1988). Thus, the term "Africanized" can lead to problematic and misleading generalizations regarding the larger African honey bee taxonomic group (Ruttner 1988). In fact, it can be argued that the term reflects a larger Western cultural consciousness that perceives the African continent as a monolithic entity and associates negative characteristics (e.g., aggression, violence, otherness) with African identity (Welch 2007). Thus, the term "Africanized" is offensive to many people, and we should move away from its use because it resonates with racist human tropes. Considering this, researchers have begun to use a label of greater phylogenetic specificity: "*scutellata*-hybrid" (Calfee et al. 2020). We use this term hereafter.

Initial alarms

As *scutellata*-hybrid honey bees spread north, their impending arrival into California caused great concern. Page (1992), writing in this journal two years before the arrival of these bees, declared that the "imminent arrival of Africanized honey bees in California . . . threatens the foundation of the honey bee pollination service industry and those agricultural commodities that depend on bees. Once feral Africanized honey bees arrive in California, it will be extremely difficult to maintain hives with . . . European honey bees — and Africanized bees are not amenable to commercial methods of transportation." *Scutellata*-hybrid honey bees appeared to pose a looming threat for California agriculture and public safety. Scientists and beekeepers feared that genes from *A. m. scutellata* would spread into domesticated, largely European, commercial stock and cause substantial economic impacts. This concern was based in part on the assumption that the heightened defensive behaviors of *scutellata*-hybrid honey bees would make it difficult to use them in large-scale husbandry or to transport them in trucks for agricultural pollination. Page (1992) warned that, with *scutellata*-hybrid bees present in California, apiarists from states outside the range of the *scutellata*-hybrids would be reluctant to send their hives to California for fear of genetic mixing. Page (1992) also expressed some concern for public safety, given that *scutellata*-hybrid bees exhibit high levels of nest defense and had caused multiple human fatalities in Central and South America. (See table 1 for an overview of trait differences between *scutellata*-hybrid and EHB.)

Range of hybrid bees

The first *scutellata*-hybrids in the United States were identified in Texas in 1990 and reached California in

TABLE 1. A comparison of *scutellata*-hybrid and European honey bees

Trait	*Scutellata*-hybrids	European honey bees	References
Genetic ancestry	Admixed genetic ancestry from *Apis mellifera scutellata* and other (mostly) European honey bees	*Apis mellifera ligustica, Apis mellifera carnica, Apis mellifera mellifera*	Calfee et al. 2020; Ruttner 1988; Schiff and Sheppard 1996; Zarate et al. 2022
Defensiveness	Higher	Lower	Schneider et al. 2004 and references within
Genetic diversity	Higher	Lower	Harpur et al. 2012; Themudo et al. 2020; Zarate et al. 2022
Hygienic behavior	Greater rates of removing *Varroa*-infected brood	Lower rates of removing *Varroa*-infected brood	Aumeier et al. 2000; Invernizzi et al. 2015
Swarming and absconding	Higher rates of swarming and absconding	Lower rates of swarming and absconding	Schneider et al. 2004 and references within
Usurpation	Higher rates of usurping a colony and lower rates of accepting a usurping queen.	Lower rates of usurping a colony and higher rates of accepting a usurping queen	Schneider et al. 2004 and references within

Note that we do not compare morphological traits. While un-admixed *A. m. scutellata* and European honey bees can be distinguished morphologically using wing and body size measurements (Ruttner 1988), these measurements fail to reliably distinguish between *scutellata*-hybrid and European honey bees in California (Calfee et al. 2020; Kono and Kohn 2015).

1994. *Scutellata*-hybrids are thought to require warmer winter temperatures than European honey bee races (Schneider et al. 2004), and their northern range limit is of considerable interest. All feral honey bees sampled in Southern California now have approximately 40% *A. m. scutellata* genomic content, with their remaining ancestry coming from several different European and Middle Eastern lineages (Calfee et al. 2020; Zarate et al. 2022). The frequency of feral bees with African ancestry, as well as their amount of African genomic content, declines with increasing latitude and reaches its California limit in Napa and Sacramento counties (Calfee et al. 2020; Kono and Kohn 2015; Lin et al. 2017). Rapid range expansion has ceased, although further, slow northern expansion may be expected under warming climate conditions (Calfee et al. 2020; Harrison et al. 2006; Kono and Kohn 2015; Lin et al. 2017; Schneider et al. 2004). Interestingly, *scutellata*-hybrids in Southern California have only about half as much *A. m. scutellata* genomic content as those from Mexico and Central America or *scutellata*-hybrids from U.S. states such as Texas and Arizona (Calfee et al. 2020; Pinto et al. 2005; Zarate et al. 2022).

Modest effects so far

California beekeepers anticipated that the arrival of *scutellata*-hybrids would impair honey production, as occurred in several South and Central American countries when *scutellata*-hybrids became the dominant managed honey bee (Guzman-Novoa et al. 2020). While California honey production decreased slightly the first year *scutellata*-hybrids were discovered in the state, a subsequent quick rebound of production suggests that other factors such as disease, weather and reduced honey demand caused the downturn (Livanis and Moss 2010). Additionally, in the years following the arrival of *scutellata*-hybrids, California beekeepers did not purchase more European colonies, suggesting that *scutellata*-hybrids had a negligible effect on the maintenance of managed colonies (Livanis and Moss 2010). Further, the presence of *scutellata*-hybrids may not increase requeening costs. Beekeepers in areas with *scutellata*-hybrids regularly requeen their colonies (Schneider et al. 2004) to maintain their European ancestry, but this occurs even in areas without *scutellata*-hybrids because of declining honey bee queen longevity.

Pollination services provided by managed honey bees also appear to have been relatively unaffected by the influx of *scutellata*-hybrid honey bees. Annual yields of nuts, fruits, vegetables and seeds that require commercial bee pollination have steadily increased from 1994 to the present, despite the presence of feral *scutellata*-hybrids in the southern Central Valley, where many of these crops are grown (California Department of Food and Agriculture 2020). Almonds, one of California's most profitable crops, use more than 60% of all U.S. commercial honey bee colonies to produce expected yields (Sáez et al. 2020). In the last 25 years, the state's almond production has increased more than eightfold, with perturbations in annual production primarily attributed to poor weather during the plant's short flowering period (USDA 2021). The success of almond production in California suggests that importation of commercial hives from states outside the current range of *scutellata*-hybrids has not been seriously affected.

The main impact of California *scutellata*-hybrids on apiculture (beekeeping) has been on hive management in Southern California, where *scutellata*-hybrids dominate the feral bee population. Jurisdictions in Southern California enacted policies regulating both hobbyist and commercial beekeepers, with the aim of preventing the spread of genes from feral *scutellata*-hybrids into managed bee populations. In general, colonies are expected to be requeened frequently with queens that are produced and mated in regions outside the range of *scutellata*-hybrids (Schiff and Sheppard 1996). There has been little study of how effective these measures have been in keeping the gene pools of managed and feral bees separated, though Kono and Kohn (2015) reported that mitochondrial DNA from the *scutellata* lineage, found in most feral bees in San Diego County, was rare in hobbyists' hives. However, beekeepers in Southern California often report their hives becoming increasingly defensive as time passes from the last requeening. Presumably this is due to the death of the original queen and the mating of the next queen to drones from feral *scutellata*-hybrid colonies or, less commonly, due to nest usurpation by feral *scutellata*-hybrid swarms (Schneider et al. 2004).

With respect to public safety, following the arrival of *scutellata*-hybrids in the American continents, there have been more than 1,000 human fatalities associated with honey bee attacks and thousands more on pets and livestock (Schneider et al. 2004). While the great majority of these have occurred in Central and South America, there have been fatalities in Southern California (California Department of Public Health 2018). The general concern that such incidents cause, and the use of the term "killer bees" in accompanying press reports, have served to keep public fear of these bees high — even if attacks by bees are relatively rare.

Pollinator competition

While agricultural production and commercial apiculture have been largely unaffected by the arrival of *scutellata*-hybrids, both European and *scutellata*-hybrid honey bees are non-native. Therefore, their prevalence in California's habitats may have negative consequences for native species. Much of the state is in the California Floristic Province, a biodiversity hotspot that extends from central Oregon to northern Baja California, Mexico. California is home to about 6,500 species of vascular (water-transporting) plants and over 1,600 species of bees, many of which are endemic. Multiple

The main impact of California's *scutellata*-hybrids on beekeeping has been on hive management in Southern California, where the hybrids dominate the feral bee population. *Photo*: Anita Galeana.

A swarm of *scutellata*-hybrids. Traits such as higher swarming rates and smaller colony sizes may reduce the impact of diseases and parasitism. *Photo*: Ashley Kim.

pollinators are in decline due to a variety of threats, including pollution, habitat destruction, climate change, and, potentially, resource competition from exotic species, particularly from introduced honey bees, whether European or *scutellata*-hybrid (Thomson 2006).

Today, *scutellata*-hybrid honey bees dominate the feral bee population in Southern California (Kono and Kohn 2015; Lin et al. 2017; Zarate et al. 2022). Unlike their primarily arboreal nesting European relatives, *scutellata*-hybrid colonies often nest in cavities found in rocks or in the ground, as well as in anthropogenic structures (e.g., irrigation boxes, attics, cinder block walls, etc.). Their nesting habits may be among the traits facilitating their abundance. In San Diego County, feral *scutellata*-hybrids are the dominant floral visitor to native vegetation, accounting for 75% of all flower visitors, even though there are more than 600 species of native bees in the county (Hung et al. 2018). This degree of honey bee dominance of the pollinator community in natural vegetation is among the highest reported anywhere in the world (Hung et al. 2018). Feral *scutellata*-hybrids are even more dominant, accounting for over 90% of all visitors on the most abundantly blooming plant species in wildlands (Hung et al. 2019). Thus, the great majority of pollen and nectar resources gathered by insect pollinators in San Diego's wildlands likely go to feral *scutellata*-hybrid honey bees. It is not clear whether the population densities of feral honey bees in Southern California have increased since the arrival of *scutellata*-hybrids, because baseline data are scarce. However, Cumberland (2019) surveyed pollinators visiting wild sunflower (*Helianthus annuus*) populations that were originally surveyed in the 1970s. This study found that honey bees, nearly entirely absent in earlier population surveys, are now the dominant pollinator in California, Arizona and New Mexico sites, while the numbers of native pollinators visiting this plant have decreased over the same period.

It is difficult to directly assess the effect that resource competition with honey bees may have on native bee populations. During one summer season, a strong managed EHB hive in wildlands can collect 10 kilograms (kg) of pollen, enough to feed 110,000 progeny of an average native solitary bee species (Cane and Tepedino 2017). Impressively, *scutellata*-hybrid honey bees remove even more pollen from the environment than their EHB counterparts, because they allocate more foragers to collect pollen rather than nectar (Schneider et al. 2004).

While there is debate as to the extent to which native pollinator populations are limited by floral resources, evidence suggests that, when honey bees are present at high densities, they compete with other insects for pollen and nectar. Research conducted across a variety of environments has shown that wild bee diversity and abundance decreases where honey bees are present in wildlands (Mallinger et al. 2017; Torné-Noguera et al. 2016; Valido et al. 2019). Wild bees and other pollinators are often displaced from their preferred floral resources when honey bees are present, reshuffling their diets to presumably lower-quality resources and potentially decreasing the number or fitness of their offspring (Magrach et al. 2017; Portman et al. 2018; Roubik and Villanueva-Gutierrez 2009). Large, social pollinators such as bumble bees may be particularly susceptible to competition with honey bees because of significant niche overlap and their higher energy requirements compared to smaller, solitary bees (Thomson 2006). This is of concern in California, where native bumble bees are important pollinators of both agricultural and native plants. In a California study, placing honey bee colonies near bumble bee nests resulted in bumble bees collecting less pollen and producing smaller and fewer offspring, indicating significant resource competition (Thomson 2004).

Bee-to-bee diseases

In addition to resource competition with native bees, honey bees serve as disease reservoirs, spreading pathogens among managed and feral populations, as well as among native bees, mediated by the flowers they all visit (Alger et al. 2019; Burnham et al. 2021; Graystock et al. 2015). While generally of good health, feral honey bees harbor several viral diseases, such as deformed wing virus, which can infect multiple pollinator species

(Alger et al. 2019; Geffre et al. 2021; Graystock et al. 2015; López-Uribe et al. 2017). The degree to which native bees and both feral and managed honey bees transmit pathogens among each other, and the effects of these pathogens on native bee species, deserves further study.

Currently, managing the health of European honey bee colonies is a major challenge for beekeepers and adds to the time and expense of maintaining colonies. Because mite-borne pathogens are a serious threat to honey bees, beekeepers often use a variety of anti-mite treatments. However, feral honey bees, such as the *scutellata*-hybrid honey bees of Southern California, achieve high densities without such human intervention, even though they carry several viral diseases at levels similar to those found among managed honey bees (Geffre et al. 2021). Several traits of *scutellata*-hybrids may account for their ability to thrive in the face of exposure to diseases that currently plague the honey bee industry.

Useful genetic diversity?

Due to their hybrid origin, *scutellata*-hybrid honey bees harbor higher levels of genetic diversity than the European honey bee strains currently used by beekeepers (Harpur et al. 2012; Themudo et al. 2020; Zarate et al. 2022). Genetic diversity in any population allows more evolutionary flexibility in response to environmental challenges but has been decreasing in managed honey bees. Thus, the input of genetic variation from feral populations could be beneficial, particularly for combating diseases.

In comparison with European honey bees, *scutellata*-hybrids can exhibit higher levels of hygienic behavior (Aumeier et al. 2000), including successful grooming to remove *Varroa* mites (Invernizzi et al. 2015), which are a vector for multiple viruses. *Scutellata*-hybrids also exhibit other behaviors that, while perhaps not beneficial to commercial beekeeping, may reduce the impact of diseases and parasitism (table 1). Such traits include higher swarming rates, smaller colony sizes, and enhanced defensive behaviors (Schneider et al. 2004). The higher swarming rates are particularly intriguing because swarming induces a broodless period that decreases the population of brood parasites such as *Varroa* mites. In fact, broodlessness induced by colony cold storage is being studied as a way to control *Varroa* (Kulhanek 2017).

Feral honey bees may generally harbor useful genetic variation because they have been subject to natural selection. Like *scutellata*-hybrids, feral honey bees elsewhere in the United States outside the range of *scutellata*-hybrids are more robust to environmental and disease stressors than their managed counterparts (Locke 2016; Seeley et al. 2015). For example, feral bees of European descent have adapted to resist the negative effects of *Varroa* mites and now thrive unaided in areas where commercial beekeepers use a variety of preventative measures but still suffer considerable hive mortality from *Varroa* (Seeley et al. 2015). Further research on the traits associated with robust health in feral honey bee populations, including *scutellata*-hybrids, may shed light on how these insects mitigate the impact of pests and pathogens. Such knowledge can inform honey bee breeding programs, possibly allowing for the development of new varieties that combine the genetic diversity and health associated with *scutellata*-hybrids with desirable behavioral qualities associated with European varieties (e.g., low defensiveness and absconding rates, and higher honey production).

However, *scutellata*-hybrids' presumed heightened defensiveness raises concerns about breeding them with European varieties. So far there have been no quantitative studies comparing the defensive behaviors of California *scutellata*-hybrids and European honey bees. The relatively low *A. m. scutellata* genomic content of Southern California feral bees in comparison with other *scutellata*-hybrid populations could correspond to reduced defensive behavior. As an example, non-defensive *scutellata*-hybrid bees, which have similarly low levels of *A. m. scutellata* ancestry, are known to occur in Puerto Rico (Acevedo-Gonzalez et al. 2019). The discovery of *scutellata*-hybrids with desirable traits and low defensiveness in Southern California could strengthen the argument for breeding with European varieties. CA

Because both European and *scutellata*-hybrid honey bees are non-native, their prevalence in California's habitats may have negative consequences for native pollinators. *Photo*: Panom, iStock.com.

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References

Acevedo-Gonzalez JP, Galindo-Cardona A, Avalos A, et al. 2019. Colonization history and population differentiation of the honey bees (Apis mellifera L.) in Puerto Rico. Ecol Evol 9(19):10895–902. https://doi.org/10.1002/ece3.5330

Alger SA, Burnham PA, Brody AK. 2019. Flowers as viral hot spots: Honey bees (Apis mellifera) unevenly deposit viruses across plant species. PLoS One 14(9):e0221800. https://doi.org/10.1371/journal.pone.0221800

Aumeier P, Rosenkranz P, Gonçalves LS. 2000. A comparison of the hygienic response of Africanized and European (Apis mellifera carnica) honey bees to Varroa-infested brood in tropical Brazil. Genet Mol Biol 23(4):787–91. https://doi.org/10.1590/S1415-47572000000400013

Avalos A, Pan H, Li C, et al. 2017. A soft selective sweep during rapid evolution of gentle behavior in an Africanized honeybee. Nat Commun 8(1550):1–9. https://doi.org/10.1038/s41467-017-01800-0

Burnham PA, Alger SA, Case B, et al. 2021. Flowers as dirty doorknobs: Deformed wing virus transmitted between Apis mellifera and Bombus impatiens through shared flowers. J Appl Ecol 58(10): 2065–74. https://doi.org/10.1111/1365-2664.13962

Calfee E, Agra MN, Palacio MA, et al. 2020. Selection and hybridization shaped the rapid spread of African honey bee ancestry in the Americas. PLoS Genet 16(10):e1009038. https://doi.org/10.1371/journal.pgen.1009038

California Department of Food and Agriculture. 2020. California Agricultural Statistics Review 2019–2020. State of California. www.cdfa.ca.gov/Statistics/PDFs/2020_Ag_Stats_Review.pdf

California Department of Public Health. 2018. A California date palm worker dies after being stung by bees. Case Report 17CA003. Fatality Assessment and Control Evaluation Program. www.cdph.ca.gov/Programs/CCDPHP/DEODC/OHB/FACE/CDPH%20Document%20Library/17CA003.pdf

Cane JH, Tepedino VJ. 2017. Gauging the effect of honey bee pollen collection on native bee communities. Conserv Lett 10(2):205–10. https://doi.org/10.1111/conl.12263

Cumberland C. 2019. Forty years of change in southwestern bee assemblages. Doctoral dissertation. University of New Mexico.

Geffre AC, Travis D, Kohn J, et al. 2021. Preliminary analysis shows that feral and managed honey bees in southern California have similar levels of viral pathogens. J Apicult Res. https://doi.org/10.1080/00218839.2021.2001209

Graystock P, Goulson D, Hughes WO. 2015. Parasites in bloom: Flowers aid dispersal and transmission of pollinator parasites within and between bee species. Proc R Soc B 282:20151371. https://doi.org/10.1098/rspb.2015.1371

Guzmán-Novoa E, Morfin N, De la Mora A, et al. 2020. The process and outcome of the Africanization of honey bees in Mexico: Lessons and future directions. Front Ecol Evol 8:1–17. https://doi.org/10.3389/fevo.2020.608091

Harpur B, Minaei S, Kent CF, et al. 2012. Management increases genetic diversity of honey bees via admixture. Mol Ecol 21(18):4414–21. https://doi.org/10.1111/j.1365-294X.2012.05614.x

Harrison JF, Fewell JH, Anderson KE et al. 2006. Environmental physiology of the invasion of the Americas by Africanized honeybees. Integr Comp Biol 46(6):1110–22. https://doi.org/10.1093/icb/icl046

Hung KLJ, Kingston JM, Albrecht M, et al. 2018. The worldwide importance of honey bees as pollinators in natural habitats. Proc R Soc B 285:20172140. https://doi.org/10.1098/rspb.2017.2140

Hung KLJ, Kingston JM, Lee A, et al. 2019. Non-native honey bees disproportionately dominate the most abundant floral resources in a biodiversity hotspot. Proc Royal Soc B 286:20182901. https://doi.org/10.1098/rspb.2018.2901

Invernizzi C, Zefferino I, Santos E, et al. 2015. Multilevel assessment of grooming behavior against Varroa destructor in Italian and Africanized honey bees. J Apicult Res 54(4):321–7. https://doi.org/10.1080/00218839.2016.1159055

Kono Y, Kohn JR. 2015. Range and frequency of Africanized honey bees in California (USA). PLoS ONE 10(9):e0137407. https://doi.org/10.1371/journal.pone.0137407

Kulhanek K. 2017. Potential for Varroa control in cold storage: A review. www.projectapism.org/varroa-control-in-cold-storage.html

Lin W, McBroome J, Rehman M, et al. 2017. Africanized bees extend their distribution in California. PLoS ONE 13(1):e0190604. https://doi.org/10.1371/journal.pone.0190604

Livanis G, Moss CB. 2010. The effect of Africanized honey bees on honey production in the United States: An informational approach. Ecol Econ 69(4):895–904. https://doi.org/10.1016/j.ecolecon.2009.11.013

Locke B. 2016. Inheritance of reduced Varroa mite reproductive success in reciprocal crosses of mite-resistant and mite-susceptible honey bees (Apis mellifera). Apidologie 47:583–8. https://doi.org/10.1007/s13592-015-0403-9

López-Uribe MM, Appler RH, Youngsteadt E, et al. 2017. Higher immunocompetence is associated with higher genetic diversity in feral honey bee colonies (Apis mellifera). Conserv Genet 18:659–66. https://doi.org/10.1007/s10592-017-0942-x

Magrach A, González-Varo JP, Boiffier M, et al. 2017. Honeybee spillover reshuffles pollinator diets and affects plant reproductive success. Nat Ecol Evol 1(9):1299–1307. https://doi.org/10.1038/s41559-017-0249-9

Mallinger RE, Gaines-Day HR, Gratton C. 2017. Do managed bees have negative effects on wild bees?: A systematic review of the literature. PLoS ONE 12(12):e0189268. https://doi.org/10.1371/journal.pone.0189268

Page Jr RE. 1992. How Africanized honey bees will affect California agriculture. Calif Agr 46(1):18–19. https://calag.ucanr.edu/archive/?article=ca.v046n01p18

Pinto MA, Rubink WL, Patton JC, et al. 2005. Africanization in the United States: Replacement of feral European honeybees (Apis mellifera L.) by an African hybrid swarm. Genetics 170(4):1653–65. https://doi.org/10.1534/genetics.104.035030

Portman ZM, Tepedino VJ, Tripodi AD, et al. 2018. Local extinction of a rare plant pollinator in Southern Utah (USA) associated with invasion by Africanized honey bees. Biol Invasions 20:593–606. https://doi.org/10.1007/s10530-017-1559-1

Roubik DW, Villanueva-Gutierrez R. 2009. Invasive Africanized honey bee impact on native solitary bees: A pollen resource and trap nest analysis. Biol J Linn Soc 98(1):152–60. https://doi.org/10.1111/j.1095-8312.2009.01275.x

Ruttner F. 1988. Biogeography and Taxonomy of Honeybees. New York City, NY: Springer.

Sáez A, Aizen MA, Medici S, et al. 2020. Bees increase crop yield in an alleged pollinator-independent almond variety. Sci Rep 10(3177):1–7. https://doi.org/10.1038/s41598-020-59995-0

Schiff NM, Sheppard WS. 1996. Genetic differentiation in the queen breeding population of the western United States. Apidologie 27(2):77–86. https://doi.org/10.1051/apido:19960202

Schneider SS, DeGrandi-Hoffman G, Smith DR. 2004. The African honey bee: Factors contributing to a successful biological invasion. Annu Rev Entomol 49(1):351–76. https://doi.org/10.1146/annurev.ento.49.061802.123359

Seeley TD, Tarpy DR, Griffin SR, et al. 2015. A survivor population of wild colonies of European honeybees in the northeastern United States: Investigating its genetic structure. Apidologie 46:654–66. https://doi.org/10.1007/s13592-015-0355-0

Themudo EG, Rey-Iglesia A, Tascón LR, et al. 2020. Declining genetic diversity of European honeybees along the twentieth century. Sci Rep 10(10520):1–12. https://doi.org/10.1038/s41598-020-67370-2

Thomson DM. 2004. Competitive interactions between the invasive European honey bee and native bumble bees. Ecology 85(2):458–70. https://doi.org/10.1890/02-0626

Thomson DM. 2006. Detecting the effects of introduced species: A case study of competition between Apis and Bombus. Oikos 114(3):407–18. https://doi.org/10.1111/j.2006.0030-1299.14604.x

Torné-Noguera A, Rodrigo A, Osorio S, et al. 2016. Collateral effects of beekeeping: Impacts on pollen-nectar resources and wild bee communities. Basic Appl Ecol 17(3):199–209. https://doi.org/10.1016/j.baae.2015.11.004

[USDA] United States Department of Agriculture. 2021. 2020 California Almond Acreage Report. National Agricultural Statistics Service. www.nass.usda.gov/ca

Valido A, Rodríguez-Rodríguez MC, Jordano P. 2019. Honeybees disrupt the structure and functionality of plant-pollinator networks. Sci Rep 9(4711):1–11. https://doi.org/10.1038/s41598-019-41271-5

Welch K. 2007. Black criminal stereotypes and racial profiling. J Contemp Crim Just 23(3):276–88. https://doi.org/10.1177/1043986207306870

Zarate D, Lima T, Poole J, et al. 2022. Admixture in Africanized honey bees (Apis mellifera) from Panamá to San Diego, California (U.S.A.). Ecol Evol 12(2):e8580. https://doi.org/10.1002/ece3.8580

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UNIVERSITY OF CALIFORNIA
Agriculture and Natural Resources

RESEARCH ARTICLE

Economic damages of food-safety incidents in complex markets: 2018 *E. coli* outbreak and romaine lettuce

Processors lose the most from leafy greens food-safety incidents because they incur the most financial burden for product that cannot be harvested or sold.

by Ashley Spalding, Rachael E. Goodhue, Kristin Kiesel and Richard J. Sexton

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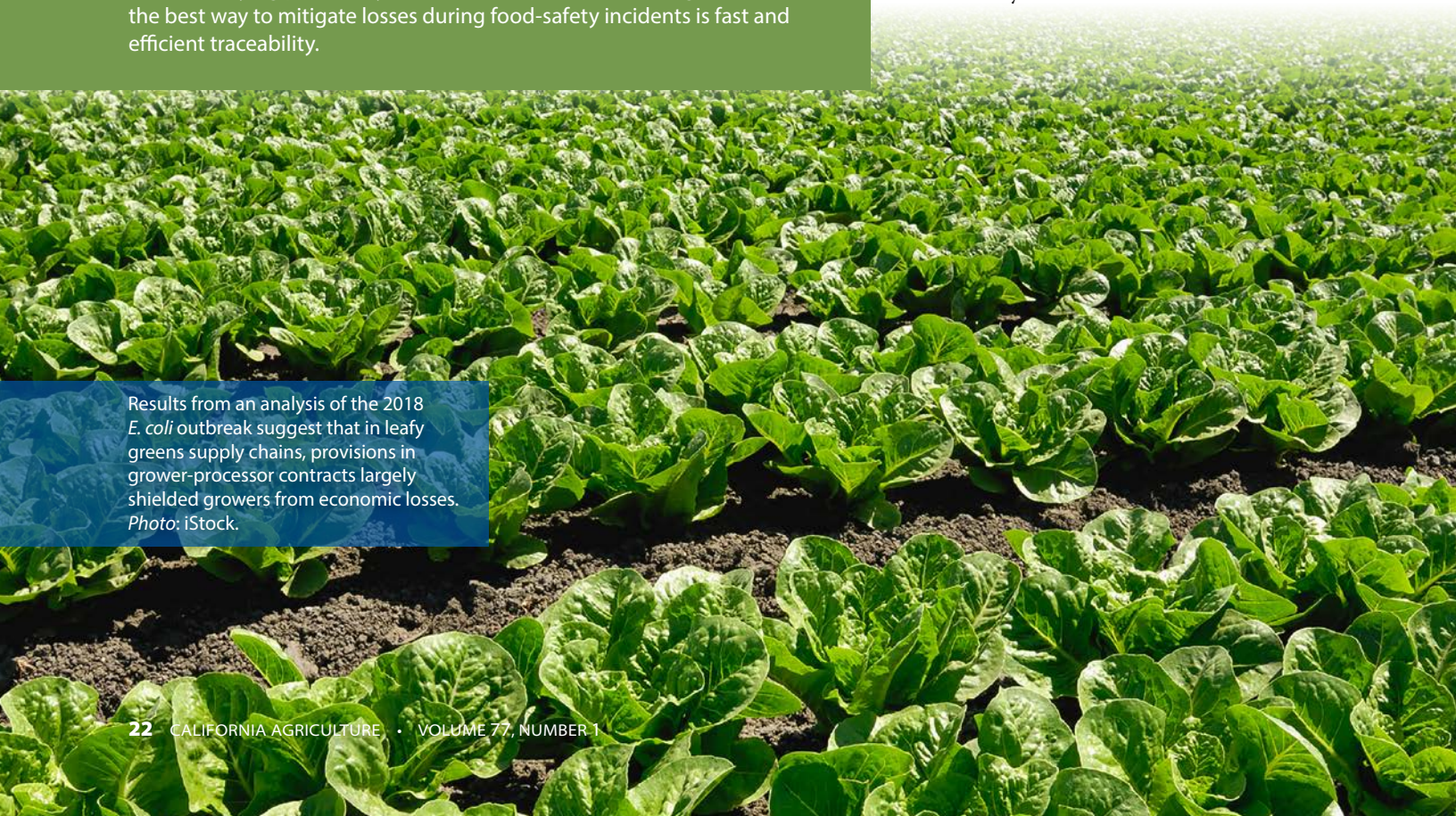
Abstract

Food-safety incidents are costly for everyone in the leafy greens industry. However, it is challenging to estimate the size and distribution of these costs in today's complex supply chains. Extensive use of formal contracts in markets such as leafy greens obscures prices and other terms of trade from the public view. Using proprietary data on prices and sales from a major leafy greens processor operating in the retail and food-service sectors, we are able to separately estimate short-run damages associated with the November 2018 romaine *Escherichia coli* advisory for grower-shippers, processors, retailers, and food-service operators. Due to fixed prices in grower-processor contracts, growers were only minimally impacted by the advisory. Processors, meanwhile, lost approximately $55.3 million from price and quantity impacts. Retailers incurred $14.1 million in losses after pulling product from distribution channels and shelves. Food-service operators were less impacted because lower prices offset losses from destroying potentially contaminated products. Moving forward, the best way to mitigate losses during food-safety incidents is fast and efficient traceability.

Food-safety incidents are pervasive and have widespread effects on supply chain participants. After identifying an outbreak (two or more epidemiologically related incidents), the U.S. Food and Drug Administration (FDA) and Centers for Disease Control and Prevention (CDC), in coordination with state and local health agencies, investigate foodborne illness outbreaks to determine the source of the outbreak and prevent additional illnesses linked to that outbreak. Public health agencies issue advisories to identify actions to protect consumers, such as avoiding selling or consuming foods linked to the outbreak. In instances where a product from a specific firm is identified, a recall may be initiated, either voluntarily by the firm, or as requested by the FDA. This causes supply chain participants to lose revenue from product that cannot be sold, and also from reduced consumer demand due to food-safety concerns.



Results from an analysis of the 2018 *E. coli* outbreak suggest that in leafy greens supply chains, provisions in grower-processor contracts largely shielded growers from economic losses. *Photo*: iStock.

California produces approximately 75% of the nation's lettuce and leafy greens, the produce category most frequently linked to food-safety outbreaks (CDFA 2021). As a result, California growers are often implicated in and/or affected by outbreaks of foodborne illnesses. From 1996 through 2016, the California Department of Public Health, Food and Drug Branch (CDPH-FDB) identified 46 outbreaks related to California leafy greens (Turner et al. 2019). From 2016 through September 2021, FDA and CDC investigated 36 *Escherichia coli* (*E. coli*) and salmonella outbreaks associated with fruits, vegetables, or nuts. Nine were traced back to California entities, resulting in two advisories and seven recalls of varying size (FDA 2021). Table 1 summarizes these nine outbreaks.

While some recalls have been narrow in scope, other outbreaks have been characterized by uncertainty and lack of information for regulators and market participants as to the extent of implicated products and regions. A study of the economic implications of these outbreaks will aid in understanding how the scope of an advisory impacts the distribution of resulting losses. The November 2018 and November 2019 *E. coli* outbreaks, ultimately traced to romaine lettuce, resulted in broad advisories impacting production that was later determined not to have been implicated in the incident. The result was widespread industry damages.

Researchers have sought to quantify the economic damages to industry members from food-safety incidents. The challenge has been in obtaining the information necessary to determine the full scale of damages. For a public company, changes in stock prices may be used (McKenzie and Thomsen 2001; Pozo and Schroeder 2015). However, many companies in the agro-food chain are privately held, limiting the scope of this approach. Spot-market prices are publicly reported by the U.S. Department of Agriculture (USDA), but for many commodities these represent only a small portion of the market.

In this paper, we address how the expansion of contract production in industries such as leafy greens over the past half century complicates the measurement of damages and their diffusion across supply-chain participants. Using a combination of proprietary price and sales data from an industry partner, retail scanner sales data from Nielsen, and publicly available spot prices, we estimate damages to grower-shippers and processors, retailers, and food-service operators resulting from the November 2018 romaine *E. coli* advisory and its aftermath. We then discuss how government regulation and industry collective action can limit damages from food-safety incidents.

Contracts assign risks

The structure of produce supply chains has changed dramatically in past decades in ways that may affect how damages from food-safety incidents are transmitted to industry participants, how participants respond, and their incentives to avoid such incidents going forward. Increasingly, exchange in the produce industry is governed by formal contracts. Nearly one-third of the value of agricultural production was governed by contracts in 2019 compared to just 11% in 1969 (MacDonald 2015; USDA ERS 2020). The share under contract varies significantly across commodities and commodity groups (fig. 1).

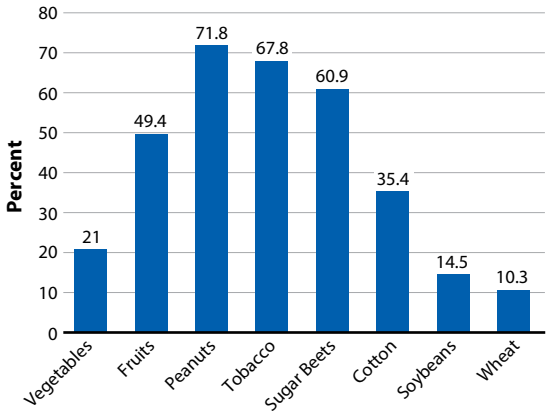


FIG. 1. Percent of U.S. agricultural production under contract by commodity or commodity group in 2019. *Source*: USDA ERS 2020.

TABLE 1. Public health advisories from investigations of *E. coli* and salmonella foodborne illness outbreaks traced to California produce, 2016–2021

Date	Product	Pathogen	Total illnesses	Recall	Advisory
Apr 2021	Cashew brie	Salmonella	20	Yes	No
Dec 2020	Leafy greens	*E. coli*	40	No	No
Fall 2020	Leafy greens	*E. coli*	18	Yes	No
Aug 2020	Peaches	Salmonella	101	Yes	No
July 2020	Onions	Salmonella	1,127	Yes	No
Dec 2019	Salad mix	*E. coli*	10	No	No
Nov 2019	Romaine	*E. coli*	27	Yes	Yes
Nov 2018	Romaine	*E. coli*	62	Yes	Yes
Mar 2016	Pistachio	Salmonella	11	Yes	No

Source: FDA, CDC.

Uncontracted produce not produced under vertical integration or sold directly to consumers is sold through shipping point (spot) markets. Shipping points are the first stage in the post-farm supply chain for spot sales; the concept refers to the district from which produce is originally shipped to processors, retailers, or distributors. The USDA's Agricultural Marketing Service (AMS) reports crop prices at shipping point and terminal markets across the United States and in parts of Mexico, making spot prices readily available.

In a supply chain that relies exclusively on spot sales, the incidence of damages is relatively easy to assign. Growers bear the costs of plowing under crops that cannot be sold and of harvested product for which the processor has not taken delivery. The processor bears the cost of product that cannot be marketed from the time it takes delivery to the time the retail or food-service buyer receives the product. The retail or food-service buyer bears the cost of unmarketable product in its possession. The loss due to reduced consumer demand due to avoidance of the impacted product is distributed across supply chain members according to the relative price responsiveness of the buyers' demand functions and sellers' supply functions.

Contracted product is more easily traceable than spot-sale product in the event of a food-safety incident; however, the private nature of contracts makes it difficult to compute the full scope of damages or determine who incurs them. From the point of view of researchers and public agencies, contracts obscure prices paid and received and may stipulate cost-sharing practices and product liabilities that are not obvious to outside observers. In many instances, contracting processors assume partial or full responsibility for the variable costs of growing and harvesting the product. Contracts may also specify who is liable for product that cannot be delivered due to recalls and/or safety advisories. These terms vary across commodities and contract partners. For many commodities, the structure of specific contract terms may be similar across contracts accounting for a significant share of production. Figure 2 summarizes common contract terms for the leafy greens industry.

FIG. 2. Common contract terms in the leafy greens industry.

Nearly all leafy greens are procured from growers or grower-shippers through contracts with processors; industry sources estimate that spot markets account for only about 10% of sales. Most often, contracts are for a season/year. Contract terms vary, but it is common in the leafy-greens industry for grower-processor contracts to have fixed prices, as shown in figure 2. Grower-processor contracts for romaine often stipulate that growers will be paid a fixed price per acre planted rather than by weight or other product characteristics. Once the crop is planted, the processor has the right to determine whether it is harvested or plowed under. This arrangement enables the processor to adjust harvest schedules as needed based on projected demand and respond to unanticipated changes in demand post-planting.

Another type of contract less commonly used involves both the grower and the processor bearing some of the risks associated with a recall. Contracts also define which party is responsible for harvest costs. Typically, the buyer pays rather than the grower. A single processor may use different contracts with different growers, and the processor's ability to set contract terms rather than negotiate can vary, depending on such factors as the acreage/volume the grower can supply and the harvest season for the grower's output.

Contracts between processors and retailers are generally negotiated between the two parties and signed for one or two years. Most often, prices are fixed, while the retailer has some flexibility to determine its purchase quantity. In contrast, contracts negotiated between processors and food-service buyers include a minimum quantity purchased and a two-part pricing mechanism: a base price and a "trigger" price linked to the spot price. If the trigger price is reached or exceeded, then the price for contract deliveries increases above the base price.

The impact of food-safety incidents on participants in the leafy greens supply chain is very strongly influenced by the nature of contracting at every level of the supply chain, i.e., between grower-shippers and processors and between processors and their downstream buyers in retail and food service. At the farmgate level, only spot-market sellers are fully exposed to the forces of supply and demand in effect during a food-safety incident. Processors bear losses for contracted product that cannot be harvested or is not profitable to harvest due to a food-safety incident. They also incur losses based on the volume of harvested product in their possession at the time of the incident that cannot be sold, due either to a recall or to reduced consumer demand in response to the incident. Losses to retailers and

food-service buyers depend on the amount of unsalable product in their possession at the time of the incident.

November 2018 outbreak

On November 1, 2018, U.S. and Canadian health and regulatory agencies, including the CDC, the FDA, and various state partners, launched an investigation into an outbreak of *E. coli* O157:H7 infections spanning multiple states and provinces, reported from October 8 through October 31. On November 20, 2018, health agencies in both countries issued a food-safety advisory, calling on consumers not to eat and restaurants and retailers not to serve or sell any romaine lettuce or salads containing it. At the time of the advisory, 50 people from 11 states and two provinces had reported illnesses, only one of whom had been hospitalized.

Figure 3 illustrates how the geographic scope of the advisory for romaine production in California evolved over time. The advisory initially covered all romaine production in California and elsewhere. CDC updates issued on November 26 and December 6 reduced the geographic scope of the advisory until, on December 13, only romaine from Santa Barbara, San Benito, and Monterey counties remained subject to the advisory.

That day, investigators located the outbreak strain in a reservoir on a farm owned by Adam Bros. Farming, Inc. (a grower-shipper of leafy greens in Santa Barbara County), but did not rule out other sources of contamination (FDA 2019). The company had not shipped romaine since November 20 but voluntarily recalled all red leaf lettuce, green leaf lettuce, and cauliflower harvested between November 27 through November 30 out of an abundance of caution (FDA 2018). While the investigation continued for several weeks, no additional sources were identified.

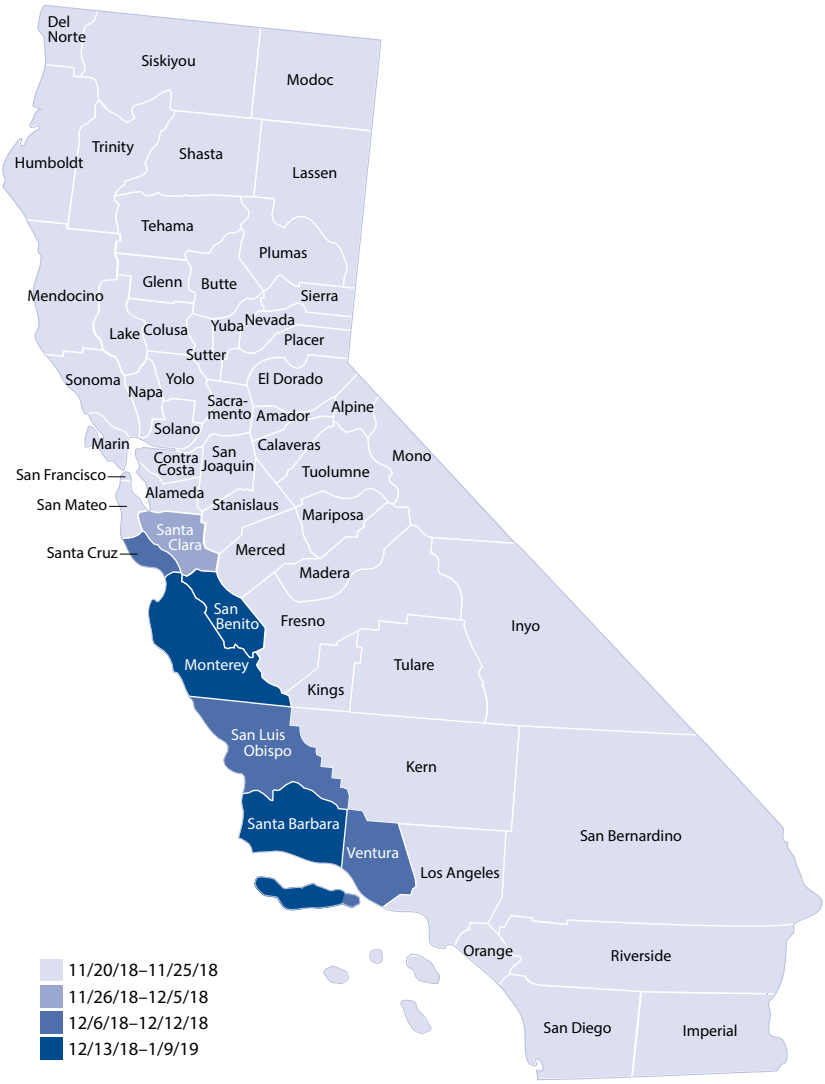


FIG. 3. Geographic scope of advisory associated with the November 2018 outbreak over time. The 11/20/18–11/25/18 advisory also included all growing regions outside of California.

Estimating economic damages

We estimated economic damages associated with the advisory and its aftermath using the methodology described in Spalding et al. (2022). Note that the aftermath is the short-run period following lifting of the advisory. In the longer run, growers may need to rotate land out of lettuce due to reduced demand, and buyers in both channels may move away from using romaine, either of which could result in additional economic damages. Specific firms could also incur reputational damage.

We separately estimated losses to growers, processors, retailers, and food-service operators, as well as losses to consumers and providers of inputs to the industry. The broad scope of this analysis is facilitated by access to proprietary data on prices and sales within the leafy greens supply chain from a cooperating processor who serves both food service and retail.

Similar to Spalding et al. (2022), the proprietary data used to study the food service includes the processor's cost of acquiring romaine from growers, pounds shipped, wholesale price obtained, and the processor's cost of labor per pound. Data regarding the retail channel included weekly pounds sold and revenues obtained from romaine and iceberg products identified by stock-keeping unit (SKU), as well as monthly procurement costs for romaine and iceberg lettuce.

Processing costs are likely quite similar across major firms because contracting practices are quite uniform across the industry for each marketing channel, and the technology of the processing plants producing bagged-salad products is rather basic and common among them. In addition, the processing facilities are all located in relatively close proximity within the localized producing regions. Accordingly, using these proprietary firm-specific data should allow a reasonable estimation of industry-level damages. We combined these data with public data on spot-market prices provided by the USDA-AMS and scanner data on national-level retail prices and sales for prepackaged salads by universal product code (UPC) from Nielsen.

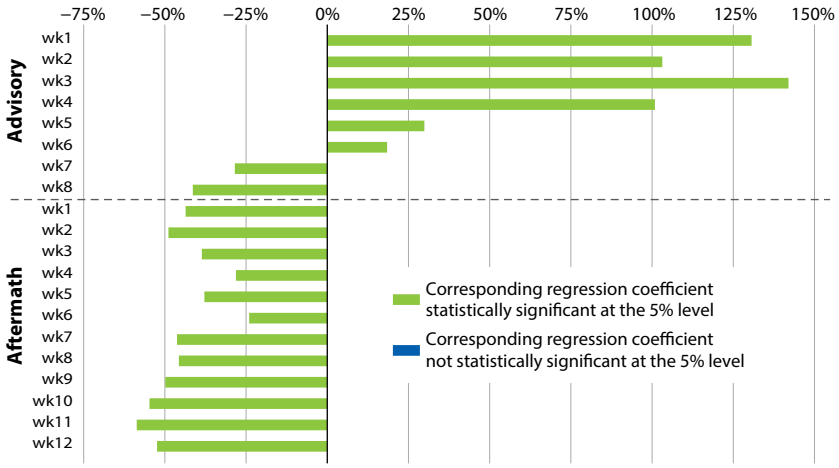


FIG. 4. Percentage change in average North American farmgate spot-market price for romaine hearts associated with each week of the advisory and aftermath relative to the counterfactual.

FIG. 5. Percentage change in average North American farmgate spot-market price for romaine heads/leaf associated with each week of the advisory and aftermath relative to the counterfactual.

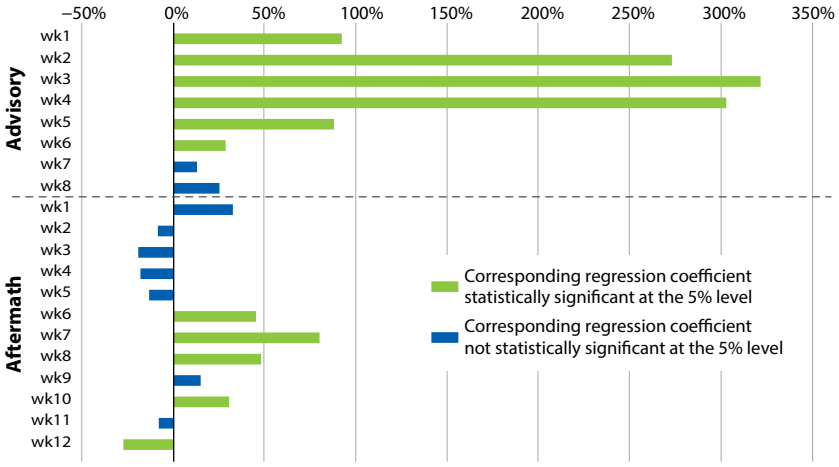


FIG. 6. Percentage change in average North American farmgate spot-market price for iceberg lettuce associated with each week of the advisory and aftermath relative to the counterfactual.

Losses in each stage

Damages to supply-chain actors from the incident and its aftermath include both price and quantity effects. The price effects result from disruptions to supply and demand. The quantity effects are caused not only by removal of the romaine product under advisory from the supply chain, but also from reduced demand for romaine product not covered under the advisory. Quantity-based damages from removing product from the supply chain depend on the product's stage in the supply chain at the onset of the advisory. Each unit of harvested romaine removed from the supply chain already had incurred most or all production and handling costs, creating losses for processors, retailers, and food-service operators who were responsible for the product under their control but could not recoup costs through product sales. Losses per pound were lower for romaine that was planted but removed from the supply chain prior to harvest due to reduced demand, because harvest and post-harvest costs were not incurred.

We used multivariate regression analysis to predict what prices and sales would have been absent the *E. coli* advisory. This analysis detected the incident's impacts on the market for up to 12 weeks after the advisory was lifted. Comparisons of these counterfactual prices and quantities to the actual prices and quantities during the advisory period and the 12 weeks immediately following it, henceforth known as the aftermath period, yield estimates of impacts from price changes and lost sales.

Safe product earned premium

Results indicate that farmgate spot-market prices for romaine hearts and romaine heads and leaf increased for the first several weeks of the advisory period, relative to their counterfactual values. Grower-shippers and processors who had safe romaine to sell earned a premium in these early weeks due to the significant reduction in supply, but eventually faced reduced demand due to the incident, which caused prices to fall. Prices decreased beginning in week 7 of the 8-week advisory and remained lower for as long as an additional 12 weeks in the aftermath of the advisory. Conversely, spot prices for iceberg lettuce increased throughout the advisory relative to counterfactual values, consistent with statements by multiple industry stakeholders that buyers sought to replace romaine with iceberg.

Figures 4 through 6 illustrate the estimated spot-market price changes for each week of the outbreak and its aftermath. Green bars indicate that the point estimates underlying the estimated percentage price changes were statistically significant at the 5% level. Conversely, blue bars represent weeks in which the estimated price effect was not statistically significant at the 5% level. For a given variable, we concluded that the effect of the advisory had dissipated if the estimated effects of the weekly indicator variables were not statistically significant for three consecutive weeks. In such

Overall, the romaine lettuce industry incurred damages of roughly $70 million due to the advisory and its aftermath. *Photo*: Elena Zhukova.

instances, we set the estimated effects for those weeks and all later weeks to zero. We included all estimated effects prior to the three-week period, or throughout the entire aftermath period if no three-week period existed, regardless of their significance level.

The effect of the advisory on the processor's acquisition costs varied by supply channel and week. We estimate that the processor that provided our data incurred higher weekly acquisition costs that ranged from 21% to 29% in the retail channel throughout the study period. In the food-service channel, the processor's weekly acquisition costs increased by between 83% and 124% across weeks 2–4 of the advisory before returning to around the same levels as in the counterfactual. Because prices received by contract growers are typically fixed in the retail channel, increases in acquisition costs reflect loss of harvested product due to the advisory and costs associated with plowing under unsalable product or harvesting product at suboptimal times due to the advisory. Contracts in the food-service channel may have built-in price triggers, so cost increases in this channel reflect a combination of these costs as well as price increases.

Price paid to processors

Compared to the no-outbreak counterfactual, the price paid to processors by food-service operators increased in the early weeks of the outbreak before modestly decreasing in the remaining weeks of the advisory and aftermath, likely because of reduced demand. In the retail channel, prices received by processors for bagged products containing romaine (e.g., kits and blends) decreased by 25% to 37% in the first full week of the advisory (week 2) followed by modest decreases (< 8%) for blends through week 6, 11% increases for premium classics through week 6, and small increases (< 10%) for kits throughout the study period, reflecting the fixed-price aspect of most retail contracts. Similarly, prices charged at retail for bagged products containing romaine were consistent across the study period. Consequently, retailers' margins on bagged products remained relatively stable.

Romaine sales fell

We estimated changes in sales volume associated with the advisory using an econometric model and Nielsen retail sales data and data on sales to food-service operators from our cooperating processor from January 2017 through December 2019. Processor sales of romaine leaf to food-service operators decreased 73% in the initial week of the advisory and sustained more modest decreases through week 10 of the aftermath. Retail sales for all romaine products decreased dramatically in the initial weeks of the outbreak due to product being removed from shelves. The largest decreases, 97%, occurred in week 2, the first full sales week after the advisory. Sales for romaine hearts remained lower through the remaining weeks of the advisory and 11 weeks of aftermath (fig. 7). Sales for other romaine products followed a similar pattern, indicating consumers avoided romaine even after it was deemed safe to consume. Across the entire study period, according to our estimate, retail sales decreased by about 25% for romaine hearts and 26% for premium classic salads. We estimated a somewhat smaller sales decrease in the range of 16% to 18% for salad blends and kits containing romaine.

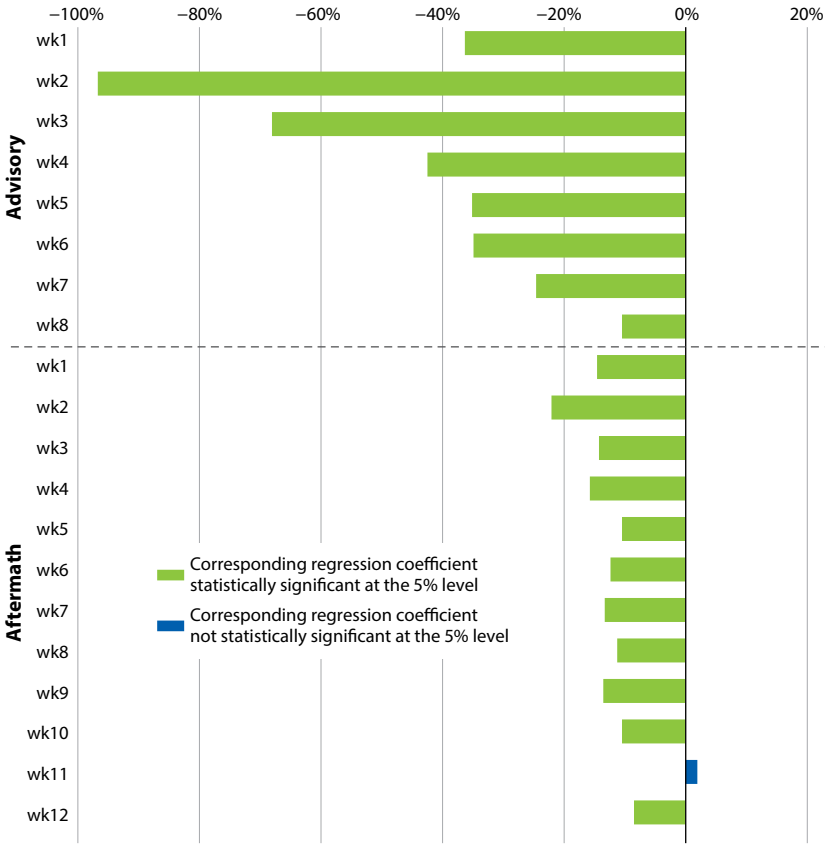


FIG. 7. Percentage change in average North American retail sales for romaine hearts associated with each week of the advisory and aftermath relative to the counterfactual.

Processors hit hardest

Overall, the romaine lettuce industry incurred damages of roughly $70 million due to the advisory and its aftermath. About 85% of losses occurred in the retail channel; however, the distribution of damages within the two channels differed at times, as shown in figures 8 and 9. Growers were minimally impacted by the advisory due to contract terms that largely insulate them from loss in a food-safety event, including in many instances payment by the acre rather than by the volume of lettuce delivered, with processors bearing the cost of product that is plowed under. This finding of minimal grower losses is particularly notable because the food-safety incident originated at this level. Only grower-shippers selling on the spot market were exposed to the full impact of the incident. Significantly, spot sellers gained in the early weeks of the advisory due to rising spot prices. Some of those gains were transferred to processors operating in the food-service channel due to contract trigger prices tied to spot prices.

Processors were hit hardest by the incident, losing approximately $55.3 million, with profits down 28.1% and 13% in the food-service and retail channels, respectively, compared to the same period a year prior. This amount was due entirely to lost sales on harvested product during the initial weeks of the outbreak, and to planted romaine under processors' control that was not harvested or sold due to reduced demand later in the advisory period and its aftermath. Processors also gained a few million dollars on net from price movements caused by the incident.

Retailers also incurred a significant share of the total losses, $14.1 million, mostly due to pulling product in the early weeks of the advisory. However, this amount is small compared to the estimated $1 billion in romaine retail sales in the 20 weeks prior to the advisory. Food-service operators were impacted to a lesser degree because the loss associated with destroying implicated product at the outset of the advisory was offset by lower net costs to acquire romaine during the advisory and aftermath periods.

Including losses to consumers and providers of inputs such as labor in the supply chain, we estimate that societal losses from the November 2018 incident were in the range of $275 to $343 million, depending on how responsive the quantity of romaine demanded is to changes in price. The more responsive the quantity demanded is to price, the smaller are societal losses. As with industry damages, the bulk of societal losses occurred in the initial weeks of the advisory.

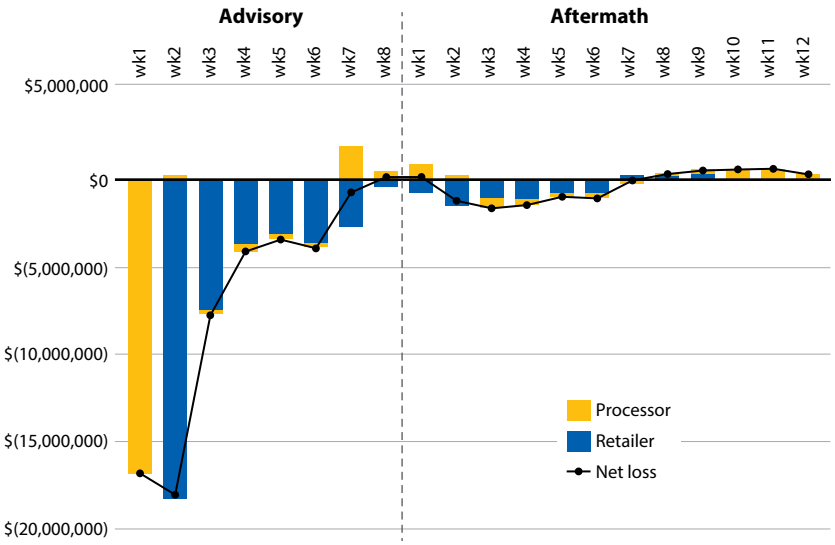


FIG. 8. Weekly damages by supply-chain participant and net losses in the retail channel.

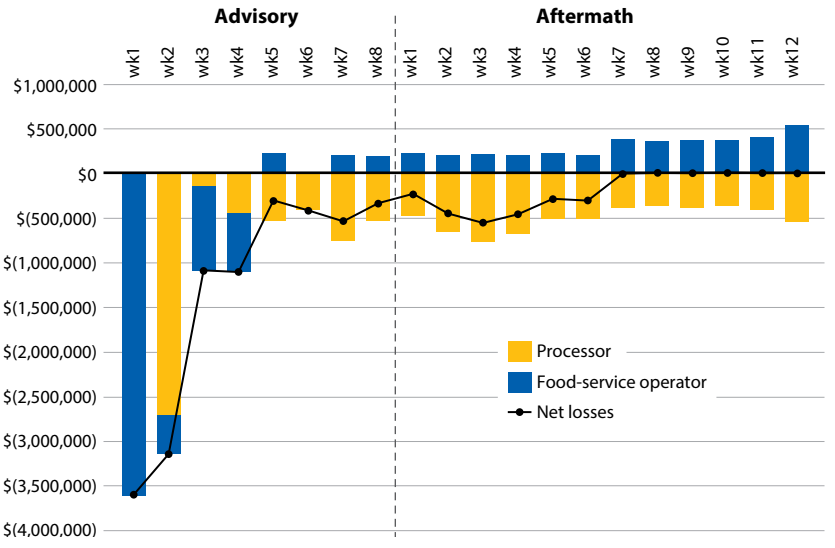


FIG. 9. Weekly damages by supply-chain participant and net losses in the food-service channel.

Mitigating economic damages

The first and most obvious way to reduce damages associated with food-safety outbreaks is to reduce their occurrence. Since the turn of the century, industry members and government agencies have implemented policies to reduce the likelihood of microbial contamination. The California leafy greens industry established the first commodity-specific food safety program in 2007, the Leafy Greens Marketing Agreement (LGMA), in response to the 2006 *E. coli* outbreak linked to fresh spinach produced in San Benito County, which resulted in three deaths. Arizona produce operators followed suit, creating their own LGMA. These voluntary programs establish minimum safety standards for on-farm practices that are verified by third-party auditors. Members of the agreements produce roughly 90% of the leafy greens grown in the U.S (Latack and Ozeran 2021).

The 2006 outbreak also prompted the federal government to pass the Food Safety Modernization Act (FSMA) in 2011. The FSMA authorizes the FDA to order recalls of contaminated food products and set minimum safety standards for growing, harvesting, packing, and holding fruits and vegetables; the

standards are based on scientific research and good agricultural practices (GAPs). The standards, as established by the Produce Safety Rule (PSR) in 2016, were phased in from 2017 through January 2020. A 2017 change in LGMA rules aligned the California and Arizona standards with the PSR's on-farm standards, such that LGMA certification is equivalent to PSR compliance.

After a series of *E. coli* outbreaks in the preceding years, including three originating in California between November 2018 and December 2019, and in tandem with its FSMA implementation efforts, the FDA released the 2020 Leafy Greens STEC Action Plan, where STEC stands for Shiga-toxin producing *E. coli*. The FDA rolled this plan into the broader New Era of Smarter Food Safety Plan, the blueprint for which was released in July 2020.

Informed by the FDA's implementation of FSMA, the New ERA plan establishes an overarching goal to create a safer food system with improved traceability. Relying on smarter technologies and new management approaches, the FDA, in partnership with industry, has announced its intention to standardize tracking data and develop a system to trace contaminated food to the source in minutes (FDA 2020). While such a goal is ambitious, and its success remains to be seen, our analysis indicates that improvements in traceability have the potential to drastically reduce industry and societal damages associated with future outbreaks by narrowing the initial scope of public health advisories and helping restore consumer confidence in the safety of the impacted products.

Improved traceability is key

Our analysis of the November 2018 *E. coli* outbreak associated with romaine lettuce highlights the importance of considering contracted output and specific contract terms when estimating damages resulting from food-safety incidents and apportioning those damages to supply-chain participants. To do this, it is necessary to understand the implications of contract terms for risk distribution. Our findings show that, in leafy greens supply chains, provisions in grower-processor contracts largely shielded growers from economic losses during and after the advisory. Additionally, leafy greens processors instead incurred the largest share of damage for products that could not be harvested or sold during and after the incident.

Further, the distribution of damages over time indicates the potential for curtailing losses by more quickly identifying the source of outbreaks and limiting the geographic scope of associated advisories. Most economic damages associated with the 2018 romaine advisory were concentrated in the initial weeks of the advisory, when romaine from all growing regions was pulled from retail shelves and menus. This is likely the case in other incidents in which there is prolonged uncertainty surrounding the outbreak's source, resulting in broad advisories. Santa Barbara County, the source of the 2018 outbreak, is home to less than 8% of California's lettuce acreage. Limiting the initial advisory to romaine grown in Santa Barbara County, instead of to the entire country, would have kept a substantial portion of romaine on retail shelves and in restaurants, thereby reducing damages to processors, retailers, and food-service operators, as well as consumers and suppliers of inputs to the industry. Even if quick pinpointing was not initially feasible, any narrowing of the advisory would have reduced losses to some extent. This means that the FDA's recent efforts to require firms to improve traceability may yield substantial benefits in reducing both illnesses and economic damages associated with future outbreaks. CA

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References

[CDFA] California Department of Food and Agriculture. 2021. ***California Agricultural Statistics Review: 2019-2020***. www.cdfa.ca.gov/Statistics/PDFs/2020_Ag_Stats_Review.pdf

[FDA] U.S. Food and Drug Administration. 2018. Adam Bros. Farming, Inc. recalls red and green leaf lettuce and cauliflower because of possible health risk. www.fda.gov/safety/recalls-market-withdrawals-safety-alerts/adam-bros-farming-inc-recalls-red-and-green-leaf-lettuce-and-cauliflower-because-possible-health

FDA. 2019. Outbreak Investigation of E. coli: Romaine (November 2018). www.fda.gov/food/outbreaks-foodborne-illness/outbreak-investigation-e-coli-romaine-november-2018

FDA. 2020. ***New Era of Smarter Food Safety — FDA's Blueprint for the Future***. www.fda.gov/food/new-era-smarter-food-safety/new-era-smarter-food-safety-blueprint

FDA. 2021. Public Health Advisories from Investigations of Foodborne Illness Outbreaks. www.fda.gov/food/outbreaks-foodborne-illness/public-health-advisories-investigations-foodborne-illness-outbreaks

Latack B, Ozeran R. 2021. Hasty responses to foodborne illness outbreaks impact California growers. Calif Agr 74(1):4–10. https://doi.org/10.3733/ca.2020a0007

MacDonald JM. 2015. Trends in agricultural contracts. Choices 3(30):1–6. www.choicesmagazine.org/choices-magazine/theme-articles/current-issues-in-agricultural-contracts/trends-in-agricultural-contracts

McKenzie A, Thomsen M. 2001. The effect of E. coli O157:H7 on beef prices. J Agr Resour Econ 26(2):431–44. www.jstor.org/stable/40987119

Pozo V, Schroeder T. 2015. Costs of meat and poultry recalls to food firms. Appl Econ 1–6. Utah State University Extension. https://digitalcommons.usu.edu/cgi/viewcontent.cgi?article=1690&context=extension_curall

Spalding A, Goodhue RE, Kiesel K, Sexton RJ. 2022. Economic impacts of food safety incidents in a modern supply chain: E. coli in the romaine lettuce industry. Am J Agr Econ 105(2):597–623. https://doi.org/10.1111/ajae.12341

Turner K, Moua CN, Hajmeer M, et al. 2019. Overview of leafy greens-related food safety incidents with a California link: 1996 to 2016. J Food Protect 82(3):405–14. https://doi.org/10.4315/0362-028X.JFP-18-316

[USDA ERS] U.S. Department of Agriculture, Economic Research Service. 2020. Contracting. www.ers.usda.gov/topics/farm-economy/farm-structure-and-organization/contracting/

RESEARCH ARTICLE

UC 4-H programs bolster youths' public speaking confidence

4-H helps young people practice public speaking. Leaders can help by offering feedback, speaking venues, and "how to present" materials.

by Steven M. Worker, Roshan Nayak, Yu Meng and Nicole Marshall-Wheeler

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Abstract

Public speaking is an essential skill for the workforce, yet many professionals lack confidence when speaking in front of an audience. While the 4-H Youth Development Program helps young people learn and practice public speaking, little is known about which specific 4-H activities foster these skills. We conducted a study to explore 4-H members' public speaking confidence and to identify specific 4-H activities that bolster young people's public speaking confidence. Quantitative and qualitative survey analyses revealed that, regardless of age, the longer 4-H members spend in the program, the more their self-confidence in public speaking improves. The 4-H program offers unique opportunities for public speaking at club meetings and formal presentations. There is room to expand these opportunities by offering youth more instructional "how to present" materials and increasing low-stakes speaking venues.

The ability to communicate information in front of an audience is an essential skill in the workforce (Zekeri 2004). Professionals are expected to demonstrate strong communication skills and confidence when speaking in front of groups. However, most people dread public speaking. "Nearly 90% of people reported feeling shy or uncomfortable speaking in front of others at some time in their lives" (McCain 2012). Lack of confidence and fear of speaking to large audiences are some of the most common reasons for public speaking anxiety (Raja 2017). While practice can help alleviate anxiety, to become more confident over time, young people should begin developing their public speaking skills at an early age.

Young people may practice public speaking in their school classrooms, but these opportunities are usually few and far between. Also, these opportunities are often in groups, and can be full of tension due to high-stakes environments (Anderson 1997; Kellam 2018). There is a lack of published K-12 communication research and

Youth speak at a 4-H club meeting. The low-stakes environment is an essential component in helping boost young people's public speaking confidence. *Photo*: National 4-H Council.

curriculum, and few educators are trained in communication. Those who teach communication education courses have few opportunities to learn best practices in their teaching credential program (Hunt et al. 2014).

Building confidence

While developing communication skills involves learning content, practicing skills, and improving attitudes, one of the most essential goals of any public speaking education program is to strengthen *confidence* itself. Building confidence is key, as a lack of confidence is the one of the most common reasons for anxiety in public speaking (McCain 2012). Confidence may be investigated using the concept of "self-efficacy," defined by Bandura (1997) as the individual's belief in their skills and ability to perform, "the conviction that one can successfully execute the behavior required to produce outcomes" (Bandura 1997). We use the terms confidence and self-efficacy interchangeably, while acknowledging theoretical distinctions: "Confidence is a catchword rather than a construct embedded in a theoretical system" (Bandura 1997).

Public speaking self-efficacy can be described as the belief in an individual's own skill to successfully present a speech with effective content, structure and delivery (Tucker and McCarthy 2001). There are four primary sources hypothesized to influence self-efficacy (Bandura 1997; Bandura 2010): (a) mastery experiences (i.e., positive or negative public speaking experiences), (b) vicarious experiences (i.e., observing others give successful or inferior presentations), (c) social persuasion (i.e., positive or negative encouragement and feedback from peers and adults), and (d) affective state (i.e., psychological factors such as one's anxiety about public speaking). These sources of self-efficacy have remained prevalent in the scholarly literature since the inception of self-efficacy theory (Phan and Ngu 2016). Previous research has suggested that mastery experiences are the most impactful in influencing self-efficacy (Bandura 1997). Mastery experiences have the highest correlation with public speaking confidence, while the other three sources tend to have little to no influence (Warren 2011).

Mastery leads to confidence

Public speaking programs have been a cornerstone of the 4-H Youth Development Program since its inception (Wessel and Wessel 1982). Participation in 4-H public speaking events has immediate and long-term impacts, such as improved self-confidence, knowledge of subject matter, and life skills (Silliman 2009). Alumni of the 4-H program report that participation in 4-H was more helpful in developing their communication skills than participation in other youth organizations (Maas et.al. 2006; Radhakrishna and Doamekpor 2009).

The University of California 4-H Youth Development Program encourages 4-H members to give presentations in multiple venues: project meetings, club meetings, community projects, formal presentation days, and many others (Borba et al. 2019). Every 4-H member is encouraged to give a presentation in front of a live audience each year. There are multiple opportunities for youth to experience positive mastery experiences and build their public speaking self-efficacy. Annually, thousands of 4-H youth members participate in an organized event at the county, region (multi-county), and state level to present and receive feedback from a panel of three external raters (University of California 4-H Youth Development Program 2021; Worker et al. 2020; Worker et al. 2021).

While the outcomes of 4-H public speaking programs are acknowledged, there is a lack of empirical data exploring sources of self-efficacy and specific 4-H program activities that support youth in improving their public speaking. Our previous work (Marshall-Wheeler et al. 2022) showed that positive mastery experiences have the greatest correlation with high levels of public speaking self-efficacy. That is, successful presentation experiences were related to more positive self-efficacy beliefs, while negative experiences were related to lower self-efficacy beliefs (Tucker and McCarthy 2001; Warren 2011). Marshall-Wheeler et al. (2022) demonstrated that 4-H members report high levels of confidence in their public speaking abilities (mean = 4.6 on a 5-point scale), while successful presentation (mastery) experiences have the greatest relationship with public speaking confidence ($\beta = 0.435$; $P < 0.001$; $n = 125$); we also found a positive (albeit small) positive correlation between public speaking self-efficacy and ratings given by external evaluators on the youth's 4-H presentations ($\rho = 0.191$; $n = 126$; $P = 0.034$). We advocated for more research to determine which mastery experiences influence public speaking self-efficacy. Identifying specific factors has the potential to inform program practice so that the most promising opportunities are leveraged to support youth in building their public speaking self-efficacy.

Professionals are expected to demonstrate strong communication skills and confidence when speaking in front of groups. However, most people dread public speaking.

Surveying youth

The present study sought to explore relationships between 4-H membership and public speaking confidence, and to identify 4-H program activities members report as helping them improve their confidence.

Both 2020 and 2021 surveys included demographic information (age, years in 4-H, gender, race/ethnicity). The surveys also included a public speaking self-efficacy scale consisting of 10 items assessing speech content, structure, and delivery, with five items adapted from Warren (2011) and five items adapted from Karnes and Chauvin (2000). The 2021 survey included three open-ended questions asking youth where they practiced

public speaking (in 4-H and other settings) and asked about specific 4-H public speaking experiences.

We conducted this study with youth who participated in the virtual 2020 and 2021 State 4-H Presentation Days and a 2021 County 4-H Presentation Day. We administered Qualtrics surveys sent via email to all participants. Out of 299 participants in the 2020 State 4-H Presentation Day, 176 responded to the public speaking self-efficacy questions in the post-event surveys, a response rate of 59%. For the 2021 State 4-H Presentation Day, 117 responded to public speaking self-efficacy questions, a response rate of 32%. For 2021, 47 youth responded to the survey at a 2021 County 4-H Presentation Day. The completed surveys were combined and checked for duplicate responses and missing data. If a youth had participated in multiple events, only their response to the 2021 State 4-H Presentation Day was considered for analysis. The combined dataset was composed of responses from 310 youth participants. Participants were 9 to 18 years of age, with an average age of 12.8 ± 2.5, and had been a 4-H member for a median of 5 years (mean = 4.8 with a standard deviation of 2.5). With regard to event participation, 61% of youth reported that this was their first time at either the 2020 or 2021 State 4-H Presentation Day. Nearly 67% identified as female, 32% as male, and 2% as preferring not to respond; 78% identified as White, 32% as Hispanic, 14% as Asian, 4% as American Indian or Alaskan Native, 2% as Black, and 2% as Native Hawaiian.

For the quantitative data, we computed Cronbach's alpha to calculate reliability (internal consistency) of the 10-item public speaking self-efficacy scale (α = 0.89). We created a composite variable using the mean of all items (missing data from items were dropped and the remainder of the items averaged). Using statistical software packages SPSS and R, we calculated correlations (Pearson's *r*), analysis of variance (ANOVA), and linear regression models (findings shared later in the manuscript), including scale reliability scores. We also standardized the public speaking self-efficacy composite variable as well as the five individual items from Warren (2011) using percent of maximum possible (POMP) (Fischer and Milfont 2010). POMP expresses scores in terms of the maximum possible score (e.g., 6 on Warren's 2011 survey and 5 on the present study's survey). Formula = ((Variable-Minimum Score)/(Maximum Score-Minimum Score)) * 100.

The qualitative data was analyzed using an inductive thematic analysis (Braun and Clark 2006). First, two coders independently coded 40 longest-word county responses to the three questions, came to consensus on code application, and developed a code list. A decision was made to combine questions 1 and 2 because of similarity in code sheets. Coder 1 (first author) coded responses to the first two questions; Coder 2 (fourth author) coded responses to the third question. On the first two questions, there were 304 code applications on 124 responses (22 responses with one code application, 52 responses with two codes, and 50 responses with three or more codes). On the third question, there were 166 code applications on 122 responses (88 responses with one code application, 29 responses with two codes, and five responses with three or more codes applied).

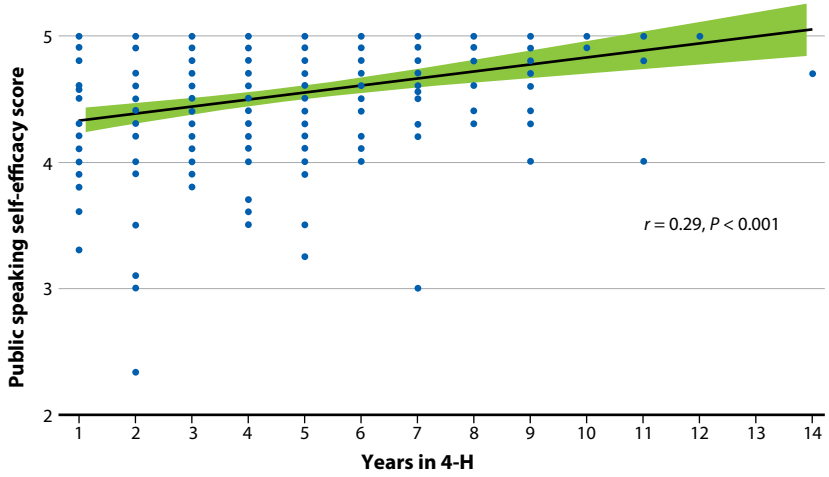

FIG. 1. Correlation scatter plot for years in 4-H versus public speaking self-efficacy (*n* = 270)

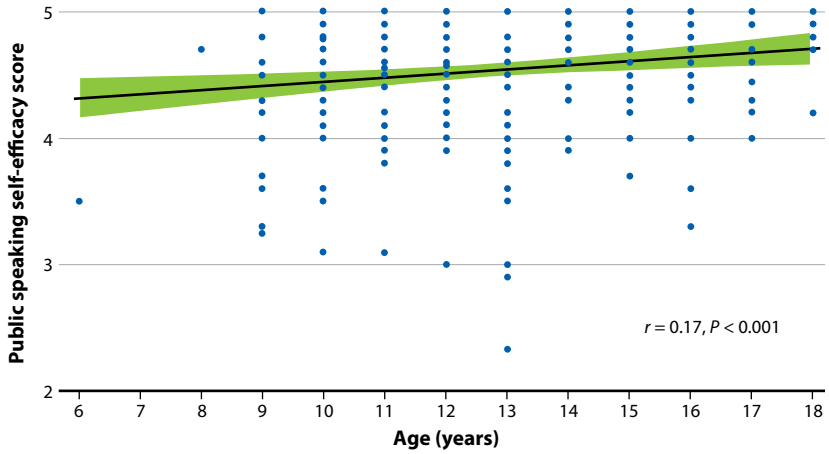

FIG. 2. Correlation scatter plot for age versus public speaking self-efficacy (*n* = 297)

Confidence grows over time

The number of years in 4-H was positively correlated with public speaking self-efficacy (Pearson's $r = 0.29$, $n = 270$, $P < 0.001$), indicating that the more years a young person participated in 4-H, the higher was public speaking self-efficacy on average (fig. 1). Additionally, age was positively correlated with public speaking self-efficacy (Pearson $r = 0.17$, $n = 297$, $P = 0.003$), indicating that older youth, on average, reported higher levels of public speaking self-efficacy (fig. 2).

A plausible hypothesis was that older youth were more confident due to their development and maturity rather than being influenced by participation in 4-H. To examine this, we computed three linear regression models with public speaking self-efficacy (dependent variable). Model 1: only years in 4-H (independent

variable); Model 2: only age (independent variable); and Model 3: combined years in 4-H and age (using both as independent variables).

As separate models, age and years in 4-H were statistically significant (see table 1, Models 1 and 2). However, when combined into the same model, years in 4-H had the greatest effect (Standardized B) and was statistically significant, while age was not statistically significant (see table 1, Model 3). These results provided evidence for our claim that 4-H youth members report higher levels of public speaking self-efficacy the more years they have participated in 4-H, even when controlling for age.

Note that we also tested for, and did not find, a statistically significant difference in public speaking self-efficacy on gender or race/ethnicity.

Comparing to college students

We compared our findings to a study conducted by Warren (2011), who surveyed college students. The 4-H members in our sample reported higher scores when we compared findings for the entire scale and on the five individual items that were consistent between both studies. On average, 4-H members reported 89% public speaking self-efficacy compared to college students from Warren's (2011) sample reporting 75% public speaking self-efficacy. On individual item comparisons, 4-H members reported higher on all items than the college comparison sample. See table 2.

Formal presentations

We asked youth where in 4-H they practiced public speaking and which 4-H experiences had helped them grow their public speaking skills. Through a qualitative analysis of their open-ended responses, we found that 67% reported public speaking at 4-H club meetings (e.g., project reports, committee reports, practice presentations), and 64% at formal 4-H presentation days (fig. 3). Only 35% reported practicing at 4-H project meetings or other events (e.g., countywide events, fairs, being a workshop facilitator). A lesser number, 22%, reported practicing at club meetings due to their officer role, and 15% in other leadership roles, such as being a county 4-H ambassador.

TABLE 1. Linear regression models for public speaking self-efficacy versus years in 4-H and age

Model 1: Years in 4-H versus public speaking self-efficacy						
Variable	**Unstandardized B**	**Std. error**	**95% CI of B**	**Standardized β**	***t*-value**	***P*-value**
Constant	4.27	0.06			71.4	< 0.001
Years in 4-H	0.06	0.01	[0.03, 0.08]	0.29	5.0	< 0.001
Adjusted R^2 = 0.082; F = 25 on Df (1, 268), P = 0.0001						
Model 2: Age versus public speaking self-efficacy						
Variable	**Unstandardized B**	**Std. error**	**95% CI of B**	**Standardized β**	***t*-value**	***P*-value**
Constant	4.12	0.14			28.86	< 0.001
Age	0.03	0.01	[0.01, 0.05]	0 .17	2.96	0.003
Adjusted R^2 = 0.026; F = 8.75 on Df (1, 268), P = 0.003						
Model 3: Years in 4-H and Age versus public speaking self-efficacy						
Variable	**Unstandardized B**	**Std. error**	**95% CI of B**	**Standardized β**	***t*-value**	***P*-value**
Constant	4.14	0.15			27.42	< 0.001
Age	0.01	0.01	[–0.01, 0.04]	0.07	0.96	0.340
Years in 4-H	0.05	0.01	[0.02, 0.08]	0.26	3.64	< 0.001
Adjusted R^2 = 0.082; F = 13 on Df (2, 267), P = 0.0001						

TABLE 2. Comparisons of public speaking self-efficacy between Warren (2011) college student sample and California 4-H member sample

	Warren (2011) (*n* = 510)	**Present study (*n* = 293)**	**Difference**
	Mean†	**Mean†**	
Entire scale*	75.0%	88.8%	+13.8
I can deliver an organized speech	82.0%	89.8%	+7.8
I can speak so that others can understand me	82.0%	90.0%	+8.0
I can use emotion to make my speech better	77.6%	87.0%	+9.4
I can fully support my main ideas with evidence	81.4%	90.0%	+8.6
I can use creative ways to express my emotions	77.6%	87.0%	+9.4

* Comparisons must be made cautiously; Warren's (2011) scale consisted of 19 items and Marshall-Wheeler et al. (2022) consisted of 10 items, only five from Warren (2011) (shown in table 2).
† Standardized mean using percent of maximum possible (Fischer and Milfont 2010).

Besides school, young people do not have many opportunities to practice or grow their public speaking skills. Thus, 4-H is providing a valuable service focusing on public speaking.

When we asked youth where else they practiced public speaking besides 4-H, the overwhelming response — 80% of respondents — was at school (fig. 4). None of the other categories, as developed through qualitative analysis of the open-ended responses, came close. Only 21% of respondents reported the next highest category, which was other youth development or nonprofit organization.

Low-stakes opportunities needed

Our research suggests that the longer youth participate in 4-H and have opportunities to practice public speaking, the more confident they become. Presenting in front of real-life audiences increases confidence and public speaking skills (Marshall-Wheeler et al. 2022). While 4-H alumni consistently report 4-H helped them develop their public speaking skills (Radhakrishna and Doamekpor 2009), there has not been any published empirical literature exploring the contributing factors.

Our study revealed two primary program activities where youth say they are offered mastery experiences: 4-H club meetings and presentation days. This is not surprising considering these are the two recommended venues for public speaking in 4-H. What is interesting is that these two venues offer divergent mastery experiences. Club meetings are comprised of adults and young people who know each other, which lends a sense of familiarity and belonging. There are typically no awards or scored rubrics on performance. Club meetings are low-stakes environments where youth practice presenting in front of friendly audiences.

In contrast, presentation days are formalized events with several clubs and county programs where youth may not know each other. These events have panels of adult evaluators who use standardized rubrics to score and provide written feedback. Presentation days are higher-stakes venues, and youth — typically younger youth — may have some anxiety before presenting.

We argue that both low-stakes, friendly venues (such as club meetings) and formal higher-stakes settings (presentation days) are needed to provide youth with a comprehensive set of mastery experiences. If young people present at only one or the other type of venue, it may not be enough to bolster their public speaking self-efficacy to the same degree. We acknowledge our explanation needs further testing, with data collected from youth who participate only in one venue or the other.

Given our findings, we offer several practical recommendations. First, 4-H professionals, in partnership with 4-H volunteer educators, should continue to host 4-H presentation days (at the county, regional, and state levels), while also providing low-stakes speaking opportunities at club meetings and other 4-H meetings. Professionals need to encourage 4-H club leaders to provide more speaking opportunities for members, especially for newer and/or younger youth. Second, there is a need for additional public speaking support materials (extension publications) to support youth and 4-H volunteers. Specifically, 4-H professionals need to design fact sheets and templates for 4-H youth on "how to present" that focus on content, structure and mechanics. Project and 4-H club leaders also need to offer more encouragement, support, and constructive feedback. We also need to investigate public speaking self-efficacy of all 4-H members, not only those who choose to participate in formal presentation days. It would also be helpful to conduct additional research to explore the differences in public speaking self-efficacy by race/ethnicity and gender.

One limitation to this study was that the regression models did not include several variables that could potentially help predict public speaking self-efficacy — for example, mastery skills and

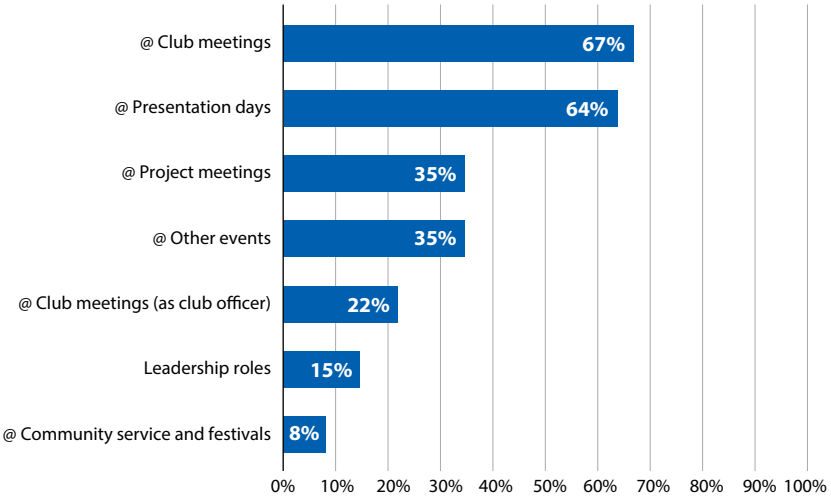

FIG. 3. 4-H experiences members report as helping them practice their public speaking.

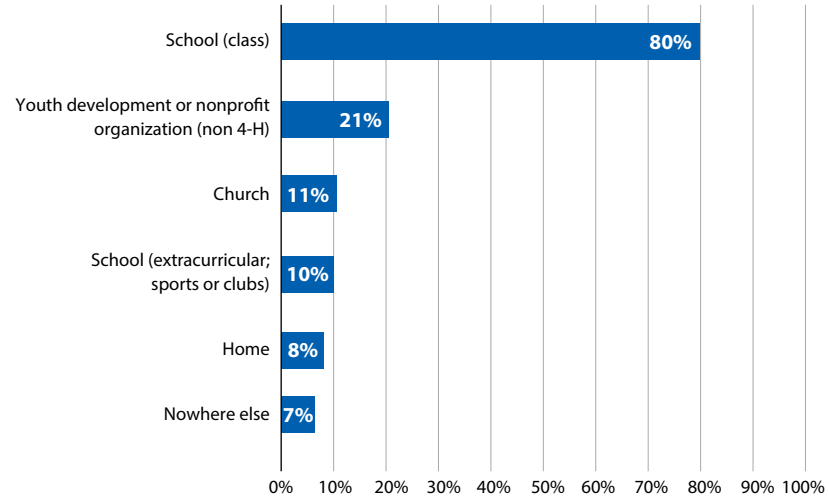

FIG. 4. Places 4-H members reported practicing public speaking besides 4-H.

4-H County Ambassadors speak in front of a large crowd at the Marin County 4-H Achievement Day. *Photo*: Steven Worker.

different types of 4-H public speaking experiences. Additionally, there was only a limited list of demographic variables for which the variation in public speaking self-efficacy was tested. The presence of additional variables in the regression model might change the effect of years in 4-H on the public speaking self-efficacy scores. Furthermore, the response rates were relatively low, given the number of youth who participated in either of the state 4-H presentation days. The response rate may have introduced systematic error into the results, perhaps biasing the resulting public speaking self-efficacy scores higher (or lower). We recommend repeating this study with larger groups of 4-H members.

In closing, numerous studies of 4-H alumni have demonstrated that 4-H strengthens both confidence and efficacy in public speaking, which are critical skills for succeeding in the workforce. The 4-H Youth Development Program plays a vital role in providing opportunities for young people to grow, practice, and improve their public speaking. It is important that 4-H professionals realize the important role they play in these successes and continue providing young people with the opportunities to expand their public speaking skills. CA

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References

Anderson LE. 1997. Public speaking opportunities for elementary school students. Annual Conference and Exhibitor of the Association for Supervision and Curriculum Development, March 22–25, 1997. https://files.eric.ed.gov/fulltext/ED409590.pdf

Bandura A. 1997. ***Self-Efficacy: The Exercise of Control***. W.H. Freeman/Times Books/Henry Holt and Co. 604 p.

Bandura A. 2010. Self-efficacy. In ***The Corsini Encyclopedia of Psychology***. Winer IB, Craighead WE (eds.). John Wiley. p. 1–3. https://doi.org/10.1002/9780470479216.corpsy0836

Borba J, Hill R, Lewis K, Miller, J. 2019. UC 4-H handbook for families. Publication 8671. University of California Agriculture and Natural Resources. https://anrcatalog.ucanr.edu/pdf/8671.pdf

Braun V, Clarke V. 2006. Using thematic analysis in psychology. Qual Res Psychol 3(2):77–101. https://doi.org/10.1191/1478088706qp063oa

Fischer R, Milfont, TL. 2010. Standardization in psychological research. Int J Psychological Research 3(1):88–96. https://doi.org/10.21500/20112084.852

Hunt S, Wright A, Simonds C. 2014. Securing the future of communication education: Advancing an advocacy and research agenda for the 21st century. Commun Educ 63(4):449–61. https://doi.org/10.1080/03634523.2014.926016

Karnes FA, Chauvin JC. 2000. ***Leadership Development Program***. Gifted Psychology Press, Inc. 80 p.

Kellam K. 2018. Middle school students' confidence in public speaking. Capstone Projects and Master's theses, 296. California State University, Monterey Bay. https://digitalcommons.csumb.edu/caps_thes_all/296

Maas SE, Wilken CS, Jordan J, et al. 2006. A comparison of 4-H and other youth development organizations in the development of life skills. J Extension 44(5). https://archives.joe.org/joe/2006october/rb2.php

Marshall-Wheeler N, Meng Y, Worker S. 2022. Exploring public speaking self-efficacy in the 4-H presentation program. J Extension 60(4). Article 12. https://doi.org/10.34068/joe.60.04.12

McCain L. 2012. ***Public Speaking Fear? 21 Secrets to Succeed in Front of Any Crowd***. Melrose, FL: Laurenzana Press.

Phan HP, Ngu BH. 2016. Sources of self-efficacy in academic contexts: A longitudinal perspective. School Psychol Quart 31:548–64. https://doi.org/10.1037/spq0000151

Radhakrishna R, Doamekpor P. 2009. Teaching leadership and communication skills and responsibilities: A comparison of 4-H and other youth organizations. J Extension 47(2). Article v47-2a6. https://archives.joe.org/joe/2009april/a6.php

Raja F. 2017. Anxiety level in students of public speaking: Causes and remedies. J Education and Educational Development 4(1):94–110. https://files.eric.ed.gov/fulltext/EJ1161521.pdf

Silliman B. 2009. Youth views of experiences and benefits of public speaking. J Youth Development 4(2):85–94. https://doi.org/10.5195/jyd.2009.266

Tucker ML, McCarthy AM. 2001. Presentation self-efficacy: Increasing communication skills through service-learning. J Managerial Issues 13(2):227–44. www.jstor.org/stable/40604346

University of California 4-H Youth Development Program. 2021. University of California 4-H Presentation Manual. University of California Agriculture and Natural Resources. https://ucanr.edu/sites/UC4-H/files/2193.pdf

Warren JL. 2011. The Relationship between Service Learning and Public Speaking Self-Efficacy: Toward Engaging Today's Undergraduates. Doctoral dissertation, University of Kentucky. https://uknowledge.uky.edu/comm_etds/1/

Wessel T, Wessel M. 1982. ***4-H: An American Idea, 1900-1980: A History of 4-H***. National 4-H Council.

Worker SM, Meng Y, Marshall-Wheeler N. 2020. 2020 Virtual State 4-H Field Day Evaluation Report. University of California Agriculture and Natural Resources. https://ucanr.edu/sites/sfd/files/333685.pdf

Worker SM, Meng Y, Marshall-Wheeler N, Nayak RK. 2021. 2021 State 4-H Field Day Evaluation Report. University of California Agriculture and Natural Resources. https://ucanr.edu/sites/sfd/files/359782.pdf

Zekeri AA. 2004. College curriculum competencies and skills former students found essential to their careers. College Student Journal 38(3):412–22.

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UC ANR Classes and Events

Blue Oak Management Field Day

https://ucanr.edu/2023blueoaks

Date: June 3, 2023
Time: 8:30 a.m. to 2:30 p.m.
Location: McKenzie Table Mountain Preserve, 22477 Auberry Road, Clovis
Contact: Billy Freeman, billy@sierrafoothill.org

Drone Camp 2023

https://dronecampca.org/

Date: June 26–30, 2023
Time: 8:30 a.m. to 5:00 p.m.
Location: CSU Monterey Bay and online (Zoom)
Contact: info@dronecampca.org

AG-VENTURE Day Camp

https://surveys.ucanr.edu/survey.cfm?surveynumber=39549

Date: July 2023
Time: 8:00 a.m. to 5:00 p.m.
Location: Sutter County Ettl Hall, 1333 Butte House Road, Yuba City
Contact: UC Cooperative Extension Sutter-Yuba, sutteryuba@ucanr.edu or 530-822-7515