Agricultural and Resource Economics
ARE UPDATE

Giannini Foundation of Agricultural Economics, University of California Vol. 28, No. 1 Sep/Oct 2024

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The Changing Face of Farmland in California's Central Valley: Crop Types and Land Quality

Siddharth Kishore, Mehdi Nemati, Ariel Dinar, Cory L. Struthers, Scott MacKenzie, and Matthew S. Shugart

We examine spatial and temporal trends in crop-specific land-use decisions at the parcel level by land capability class—land quality—in California's Central Valley from 2008 to 2021. Our findings indicate that the land-use share of perennial crops has increased by 9 percentage points since 2008, though this growth varies depending on land quality. Specifically, the land-use share of perennial crops increased 11 percentage points for high-quality lands and 7 percentage points for low-quality lands. The land-use share of annual crops significantly decreased for both high-quality and low-quality land, but only marginally decreased for poor-quality land.

In this article, we show the changes in agricultural land use by land quality, which has important implications for the productivity and environmental sustainability of the agricultural sector. Understanding agricultural production decisions by land quality is crucial for the future viability, sustainability, and resilience of the agricultural sector in California in response to climate change. Crop cultivation on high-quality land is characterized by a few limitations, including physical (such as soil fertility, water-holding capacity, and topsoil depth), topographical, and meteorological. A wider set of constraints on crop production characterizes lower-quality land (e.g., salinity, soil erosion, and water-holding capacity).

The primary goal of this article is to describe how growers in California change their cropping patterns depending on land quality. Our analysis indicated that farmers have adjusted their acreage from annual crops to perennial crops on high-quality land and have expanded perennial crops on less suitable land. Land-use decisions disaggregated by land quality at the parcel level are informative for understanding the potential for climate adaptation.

Land-Use Shares and Land Quality in California

We analyzed a sample of 83,873 geo-referenced farmland parcels in California's Central Valley obtained from ATTOM Data Solutions. For our analyses, we first merged the farm-level data with the annual Cropland Data Layer (CDL) available at a 30-by-30-meter resolution for 2008 through 2021. The cropland data captures the area planted each year.

In a second step, we linked the farm to the land capability class (LCC), a global land evaluation ranking, which groups soils based on their potential for agricultural and other uses. The LCC is used to measure land quality. We obtained LCC data for California from the California Soil Resource Lab at UC Davis, which is available in grid cells of 800 meters. LCC has eight land capability classes from class I through VIII—the constraints on soil suitability for crop cultivation increase from I to VIII. The constraints of the LCCs are characterized by soil erosion and runoff, excess water, root-zone depth, climate limitations, and limitations on mechanized farming activity. Class I soil has a few limitations, which do not restrict its use for crop cultivation, while class VIII soil has severe limitations that reduce the choice of plants that can be grown in it and increase the need for special conservation practices.

Table 1 reports the land-use shares of perennial, annual, and non-cultivated crops (fallowed or idle land and natural vegetation) by land quality and year in the study region. To maintain readability, we grouped the quality of land into three land-capability classes (LCC12: classes I–II, LCC34: classes III–IV, and LCC5678: classes V–VIII) and two time periods (2008–2014 and 2015–2021). Out of the wider range of years that was possible, we selected these two periods to create an equal number of years for both periods. High-quality (LCC12) and low-quality (LCC34) land has an average parcel size of 65 and 76 acres, respectively. The poor quality land (LCC5678), much of which is idle or has natural vegetation, has an average area of 178 acres.

Panel A in Table 1 shows the share of land allocated to perennial crops. The analysis indicates that the share of perennial crops increased in the second period by nearly 11 percentage points in high-quality land and 8 and 4 percentage points, respectively, in lower quality lands (LCC34 and LCC5678). Most of the increase in perennial crops land-use shares across all land qualities can be attributed to almonds, pistachios, and other nuts such as walnuts and pecans in the second period for all land-quality types (between 3–11 percentage points). Meanwhile, grapes and other tree crops land-use shares showed only a slight increase (between 0.5–1.5 percentage points).

Next, we discuss the land-use shares of annual and non-cultivated crops. Although land allocation to annual crops has decreased in all three land-quality types in the second period, the decrease was especially significant in high-quality land (10 percentage points), as shown in Panel B of Table 1. This reduction in the annual crops share in LCC12 and LCC34 is primarily due to the decrease in land-use shares for alfalfa and grains, which are 5 and 4 percentage points, respectively. Vegetables

Table 1. Land-Use Shares by Land Quality and Year in the Study Region

	High-Quality		Lower-Quality			
	LCC12		LCC34		LCC5678	
	2008–2014	2015–2021	2008–2014	2015–2021	2008–2014	2015–2021
Average Parcel Size (in Acres)	64.7	63.5	76.7	76.2	178.7	177.6
A. Land-Use Shares Allocated to Perennial Crops (%)						
Almonds, Pistachios, Other Nuts	28.7	39.6	19.8	27.9	7.1	10.3
Grapes	11.5	11.8	10.7	11.6	1.6	2.3
Citrus, Other Subtropical Fruit	3.3	3.3	11.4	11.3	1.1	1.1
Other Tree Crops	4.7	4.5	4.3	3.9	1.2	1.5
Total Perennial Crops	**48.2**	**59.1**	**46.2**	**54.8**	**10.9**	**15.3**
B. Land-Use Shares Allocated to Annual Crops (%)						
Alfalfa	10.9	6.0	8.0	4.4	1.0	0.8
Grains	11.7	8.8	9.8	7.9	2.9	2.2
Cotton	3.4	2.5	2.4	1.8	0.1	0.0
Tomatoes	3.2	3.0	1.6	1.5	0.1	0.1
Corn	2.4	1.5	1.6	1.1	0.3	0.2
Rice	1.4	1.1	5.8	5.0	23.0	19.3
Hay	1.0	1.3	1.4	1.6	1.9	1.1
Other Vegetables, Berries, Melons, Squash, Cucumbers	2.9	2.9	2.2	2.3	0.7	0.6
Other Field Crops	0.9	0.8	0.8	0.7	0.3	0.2
Total Annual Crops	**37.7**	**27.8**	**33.7**	**26.3**	**30.1**	**24.5**
C. Non-Cultivated Land-Use Shares (%)						
Fallow/Idle	12.4	11.0	14.8	13.1	12.3	10.5
Natural Vegetation	1.7	2.1	5.4	5.8	46.7	49.8
Total Non-Cultivated Land	**14.1**	**13.1**	**20.1**	**18.9**	**59.0**	**60.2**

Source: Authors' calculations based on data from ATTOM Data Solutions, CDL data from NASS USDA for 2008–2021, and LCC data from California Soil Resource Lab at UC Davis. CDL data is available at: https://nassgeodata.gmu.edu/CropScape/. LCC data is available at: https://casoilresource.lawr.ucdavis.edu/soil-properties/.

Note: Mean value is reported. We construct land-use shares by dividing the shares for each crop within a parcel by the total cropland from that parcel. A parcel from our sample may be associated with one or more crops.

and other field crops were either unchanged or had a slight decrease in the second period. For example, tomatoes either remained unchanged or experienced a slight decrease in high- and lower-quality lands in the second period. Hay and other pastures saw a marginal increase in LCC12 and LCC34 (less than half a percentage point).

Finally, Panel C of Table 1 shows the fallow / idle land and natural vegetation share. Fallow / idle land-use shares have declined between 1 and 2 percentage points, while there has been a modest increase (between 0.5–1.5 percentage points) in natural vegetation in LCC34 and LCC5678. In summary, the temporal variations in perennial and annual land-use shares disaggregated by land quality suggest that growers in the Central Valley have substituted annual crops for perennial crops in both high- and lower-quality lands, particularly almonds, pistachios, and other nuts.

Trends in Land-Use Shares by Land Quality

This section presents the trends in annual and perennial crops shares by land capability classes. The vertical axes in the three panels of Figure 1 represent the average land-shares ratio by crop type (perennial and annual crops) and is constructed by dividing the share of each crop type over the base year land-shares (i.e., 2008). The slope of the crop types' land-use shares can be interpreted as the rate at which the acreage of perennial crops within a parcel increases or the rate at which annual crops within a parcel decrease, compared to the baseline. The perennial crops shares within a parcel increased all years in our study across all land quality classes. Specifically, the shares of perennial crops in land class LCC12 and LCC34 experienced a nearly 40% increase between 2008 and 2021, except for 2010 and 2018, which saw a slight dip in the otherwise rising upward trend. The perennial crops share in LCC5678 experienced nearly a 50% increase.

Next, the annual crops shares have been continuously declining in all land quality classes since 2011, especially in LCC12 and LCC34 between 2008 and 2021. However the decline in LCC5678 is marginal. This may suggest that high-value perennial crops are replacing annual crops within high-quality parcels of land over the years. Declines in low-value annual crops shares during 2008–2021 may be attributed in part to water scarcity, as this period coincided with several droughts (2008–2009, 2012–2016, and 2020–2021).

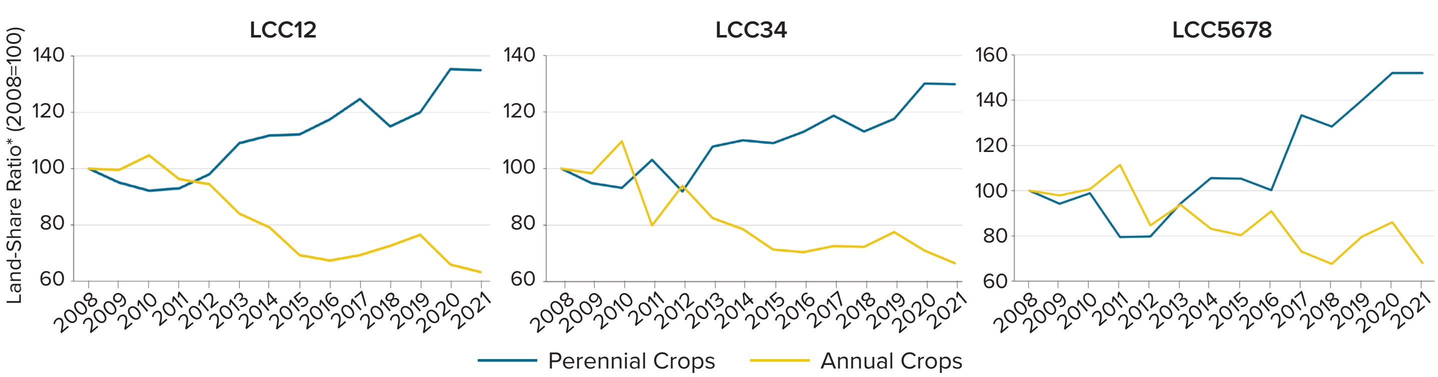
Spatial Variations in Land-Use Shares by Land Quality

This section explores the spatial variation in county-specific land-use shares of perennial and annual crops in the Central Valley by land capability classes. To do that, we first estimated the percentage difference in perennial crops shares (Figure 2, upper panel, on page 4) and the annual crops shares (Figure 2, lower panel) between the first period (2008–2014) and the second period (2015–2021).

We start with the percentage change in the perennial crops shares, as shown in the upper panel of Figure 2. In LCC12, Solano County saw the greatest increase (107%) in land-use shares of perennial crops, followed by Placer County (79%), and Yolo County (54%). In LCC34, Solano County again saw the greatest increase (191%) in land-use share of perennial crops, followed by Kings County (96%), and Placer County (91%). In LCC5678, Merced, Stanislaus, and Solano counties saw an increase in land-use shares of perennial crops by 95%, 78%, and 71%, respectively.

Next, we discuss the percentage changes in the annual crops shares, as shown in the lower panel of Figure 2. In LCC12, Madera (41%), Fresno and Solano counties (38% each), and

Figure 1. Trends In the Land-Use Shares of Perennial and Annual Crops in California Between 2008 and 2021 by Land-Capability Classes.



Source: Authors' calculations based on data from ATTOM Data Solutions, CDL data from NASS USDA for 2008–2021, and LCC data from California Soil Resource Lab at UC Davis.

Note: *The upward and downward trends can be interpreted as the increase in perennial crop acreage and decrease in annual crop acreage, respectively.

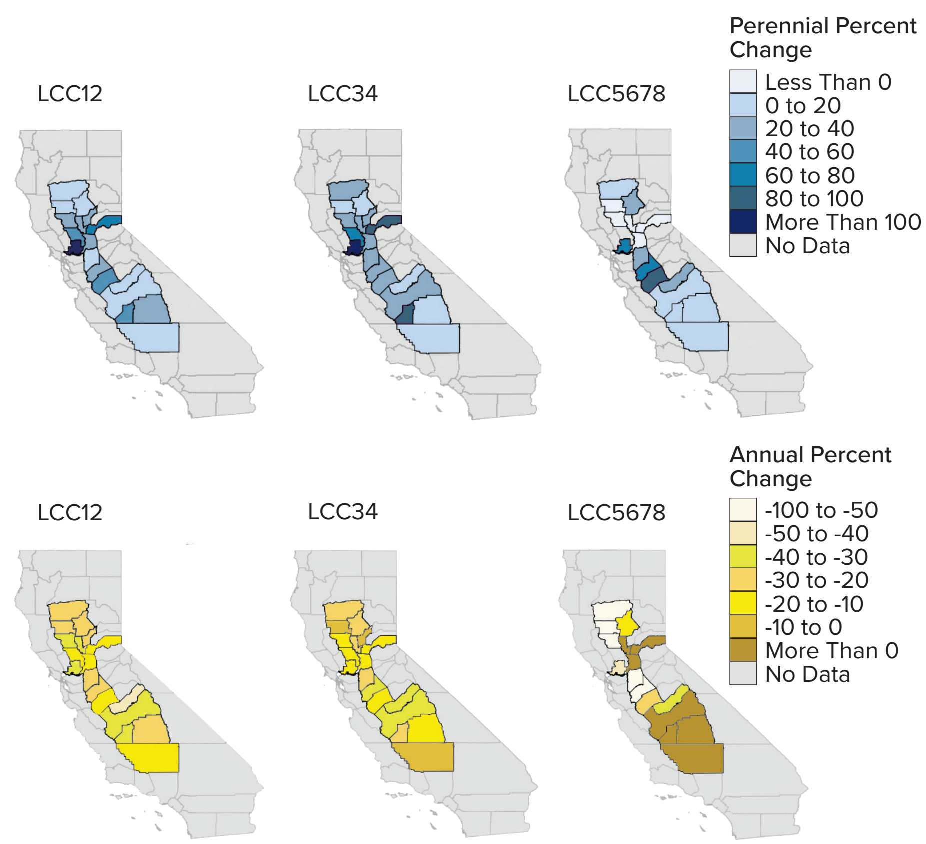
Kings and Colusa counties (34% each) experienced the largest reduction in annual crop shares. In LCC34, Fresno and Stanislaus counties each saw a decline of 36% in the land-use shares of annual crops. In contrast, the changes in land-use shares of annual crops in LCC5678 were mixed, with Placer, Kings, Kern, and Sutter counties experiencing increases.

Together, these maps indicate that the share of perennial crops across land qualities in the Central Valley is increasing, particularly on less suitable land. This could be due in part to the availability and adoption of irrigation technologies and new management practices that go with the new irrigation technologies. Conversely, the share of annual crops decreased significantly in LCC12 and LCC34, but only marginally in LCC5678.

Concluding Remarks

We examined trends in land-use shares by land quality in California between 2008 and 2021, partly explained also by recurring droughts. We showed that perennial crops shares have increased across all land-quality types, but more dramatically in the LCC5678 land-quality type in recent years. It is plausible to assume that the widespread adoption of irrigation technologies, particularly micro- and drip irrigation, in the Central Valley may partially offset the reduction in plant productivity in lower-quality lands. The county-specific spatial variation suggests that perennial crops land-use shares have significantly changed in the central and southern counties of the Central Valley. Despite an overall decrease in annual crops shares in high- and low-quality land, they have only marginally decreased in poor quality lands.

Figure 2. Spatial Variation in the Long-Run Differences in Perennial and Annual Land-Use Shares by Land Quality



Source: Authors' calculations based on data from ATTOM Data Solutions, CDL data from NASS USDA for 2008–2021, and LCC data from California Soil Resource Lab at UC Davis.
Note: The map shows the long-run percentage difference in perennial (upper panel) and annual (lower panel) shares between first period (2008–2014) and the second period (2015–2021).

Suggested Citation:

Kishore, Siddharth, Mehdi Nemati, Ariel Dinar, Cory L. Struthers, Scott MacKenzie, and Matthew S. Shugart. 2024. "The Changing Face of Farmland in California's Central Valley: Crop Types and Land Quality." *ARE Update* 28(1): 1–4. University of California, Giannini Foundation of Agricultural Economics.

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For additional information, the authors recommend:

Kishore, Siddharth, Mehdi Nemati, Ariel Dinar, Cory L. Struthers, Scott MacKenzie, and Matthew S. Shugart. 2024. "Parcel-Level Agricultural Land Use and Climate Change: Evidence from California's Central Valley." University of California, Riverside, School of Public Policy Working Paper Series. Available at: https://bit.ly/3AR9dFY.

Further Trade Wars Will Harm California Agriculture

Colin A. Carter, Sandro Steinbach, and Yasin Yildirim

As protectionist policies gain momentum in the United States, the future of California's agricultural trade faces pessimism. With proposals to expand tariffs on imports from China and other nations, California farmers—who depend on global markets as an outlet for their almonds, wine, and other agricultural goods—are aware that there would be trade retaliation from our trading partners. If a significant new trade war develops, California could see a quarter of its agricultural exports wiped out, costing the state's economy $6 billion annually.

"There is little sign that Ms. Harris would reverse the tariffs maintained by the Trump and Biden administrations." —The Economist August 18, 2024

California agriculture has long been an economic powerhouse, contributing significantly to the state's economy and helping feed the world. But today, this industry faces increasing uncertainty as bipartisan protectionism gains momentum in Washington, DC. Political leaders on both sides of the aisle have proposed new import tariffs and trade restrictions to ostensibly protect American industries and workers. If implemented, these measures will have serious consequences for California's farmers. As policymakers debate whether to expand tariffs on imports from China and other countries, California's agriculture stands to lose billions in export revenue each year.

Over the last two decades, California's farmers have built strong trade ties with China, which became a critical market for the state's agricultural products after China joined the World Trade Organization (WTO) in 2001. By 2023, California's value of yearly agricultural exports to China soared to more than $2.6 billion, up from just $0.2 billion in 2002. This boom in trade has been incredibly beneficial for high-value crops like almonds, a sector that doubled its bearing acreage over the past 20 years due to profitable returns. However, the threat of expanding U.S. protectionism now casts a long shadow over this success.

Recently, California's farmers have experienced financial losses due to trade wars. When the U.S.-China trade conflict was initiated in 2018 during the Trump administration, China retaliated with tariffs on U.S. agricultural goods, hitting California's top farm exports hard. Almond prices, for example, fell from $2.50 per pound before the trade war to just $1.40 per pound during the trade war. While midwestern farmers received significant federal subsidies to cushion the trade war blow they experienced, for political reasons, California's farmers were largely left out of the government compensation schemes. Now, with calls to raise tariffs on imports from not just China but other countries too, there is a growing fear that California's agricultural exports could face even deeper losses in a new potential trade war.

If the worst of the proposed tariffs go into effect, California could see a reduction of up to one-fourth of its agricultural export value, translating to a potential $6 billion in losses annually. This would have a ripple effect across the state, from the large almond orchards in the Central Valley to the small family vineyards scattered throughout wine country.

Potential U.S. Trade Policy Scenarios in 2025

As protectionist trade sentiment rises in the United States, there are various scenarios that could play out. The first, unfolding since May 2024, involves the Biden administration's decision to impose tariffs ranging from 17.5% to 75% on critical imports from China like steel, aluminum, semi-conductors, and electric vehicles.

As the previous quote from *The Economist* suggests, a potential Harris administration would likely continue with the Biden administration trade policies and not revoke the 2018 Trump administration tariffs on China, though it might consider lifting tariffs on European allies. Such measures, while aimed at protecting U.S. industries, carry the risk of retaliatory actions from China, mainly targeting agricultural exports.

The second scenario comes from proposals by the Republican presidential campaign, which is taking a broader and more aggressive approach. In this case, the United States would impose a 10% import tariff on all goods from every country. Unlike Scenario 1, which focuses on specific products from select countries, this blanket tariff would likely trigger a global retaliatory response. Trading partners across the world would increase tariffs on U.S. goods, affecting not only key manufacturing sectors, but also agricultural exports. California's agriculture would be at the center of this global trade conflict.

The third scenario, also originating from the Republican presidential candidate, represents the most extreme form of protectionism, with the United States imposing a 60% tariff on Chinese goods and a 10% tariff on imports from all other countries (see https://

bit.ly/3Ye4WVe). This escalation would almost certainly lead to widespread trade disruptions, with retaliatory tariffs implemented globally. Unlike the more targeted tariffs in Scenario 1, this scenario risks a trade war involving multiple trading partners. The global nature of these disruptions would introduce substantial uncertainty for California's agriculture.

Table 1 provides a breakdown of the three scenarios, including the proposed U.S. actions and the expected retaliatory responses from other countries. These scenarios present varying levels of risk for California's agricultural industry.

Table 1. Summary of 2025 Trade Policy Scenarios

Scenarios	Potential U.S. Action	China's Response	ROW* Response
Scenario 1	17.5% to 75% import tariff on steel, aluminum, semiconductors, electric vehicles, and other goods imported from China	20% import tariff on U.S. goods	None
Scenario 2	10% tariff on all goods from all countries	10% import tariff on U.S. goods	10% import tariff on all U.S. goods
Scenario 3	60% tariff on all Chinese goods and a 10% tariff on goods from all countries	60% import tariff on U.S. goods	10% import tariff on all U.S. goods

Source: Information for these scenarios come from the White House, the U.S. International Trade Commission, and the Republican National Committee.
Note: Based on historical actions from China and other countries, we assume tit-for-tat retaliations on U.S. agricultural exports. *ROW refers to the rest of the world.

High Costs of Potential Tariffs for California Agriculture

To estimate the potential export losses for California under each of the three scenarios, we first project 2025 export values for key agricultural commodities using a first-order autoregressive model with a stochastic component to account for expected volatility. We then applied product and industry-specific elasticity estimates from previous studies to measure California's expected export losses. Table 2 presents the details of estimated trade losses for major commodities.

Some of the most vulnerable commodities are pistachios, dairy, wine,

Table 2. Projected Annual Export Losses for California (in Millions of Dollars)

		Scenario 1			Scenario 2			Scenario 3		
Commodity	**2025 Baseline Projections**	**Lower Bound**	**Point Estimate**	**Upper Bound**	**Lower Bound**	**Point Estimate**	**Upper Bound**	**Lower Bound**	**Point Estimate**	**Upper Bound**
Almonds	4,539.2	-20.4	-61.1	-91.7	-108.1	-323.4	-485.1	-526.8	-721.7	-868.1
Dairy	3,410.9	-84.7	-110.3	-133.0	-434.6	-565.9	-682.5	-724.6	-843.1	-948.4
Pistachios	2,728.9	-41.3	-123.7	-185.5	-65.0	-194.4	-291.6	-912.2	-1,000.4	-1,066.7
Wine	1,345.4	-44.9	-49.5	-54.1	-308.8	-340.4	-372.0	-384.1	-413.5	-442.8
Walnuts	1,495.8	-0.8	-2.3	-3.4	-35.6	-106.6	-159.8	-51.3	-121.5	-174.2
Processed Tomatoes	705.5	-4.9	-5.4	-5.9	-161.9	-178.5	-195.1	-170.1	-186.5	-202.8
Rice	704.4	-2.2	-2.4	-2.7	-161.7	-178.2	-194.8	-165.4	-181.8	-198.2
Beef	691.7	-22.2	-38.4	-51.7	-54.8	-94.5	-127.1	-184.1	-215.8	-241.8
Table Grapes	670.8	-4.0	-4.6	-5.2	-65.7	-76.8	-86.0	-84.0	-94.8	-103.7
Oranges	562.5	-17.2	-20.1	-22.5	-55.1	-64.4	-72.1	-134.1	-142.0	-148.5
Strawberries	485.0	-0.9	-1.0	-1.1	-47.5	-55.5	-62.2	-51.5	-59.5	-66.1
Cotton	436.0	-15.8	-29.4	-40.1	-35.0	-65.3	-89.0	-125.3	-148.8	-167.2
Lettuce	371.8	0.0	0.0	0.0	-32.5	-55.7	-71.6	-32.5	-55.7	-71.6
Hay	368.1	-37.3	-43.1	-48.4	-53.7	-62.0	-69.7	-163.0	-168.5	-173.4
Others	6,618.7	-23.0	-25.4	-27.7	-1,519.0	-1,674.5	-1,830.1	-1,557.6	-1,712.0	-1,866.4
Total	**25,134.7**	**-319.6**	**-516.8**	**-673.1**	**-3,138.8**	**-4,036.0**	**-4,788.7**	**-5,266.8**	**-6,065.5**	**-6,740.1**

Source: Authors' calculations based on California Agricultural Statistics Review reports and tariff elasticities from previous economic studies.
Note: All projections are based on China's import share of California's agricultural exports, averaged from 2020 to 2022. The lower and upper bounds represent the 90% confidence interval.

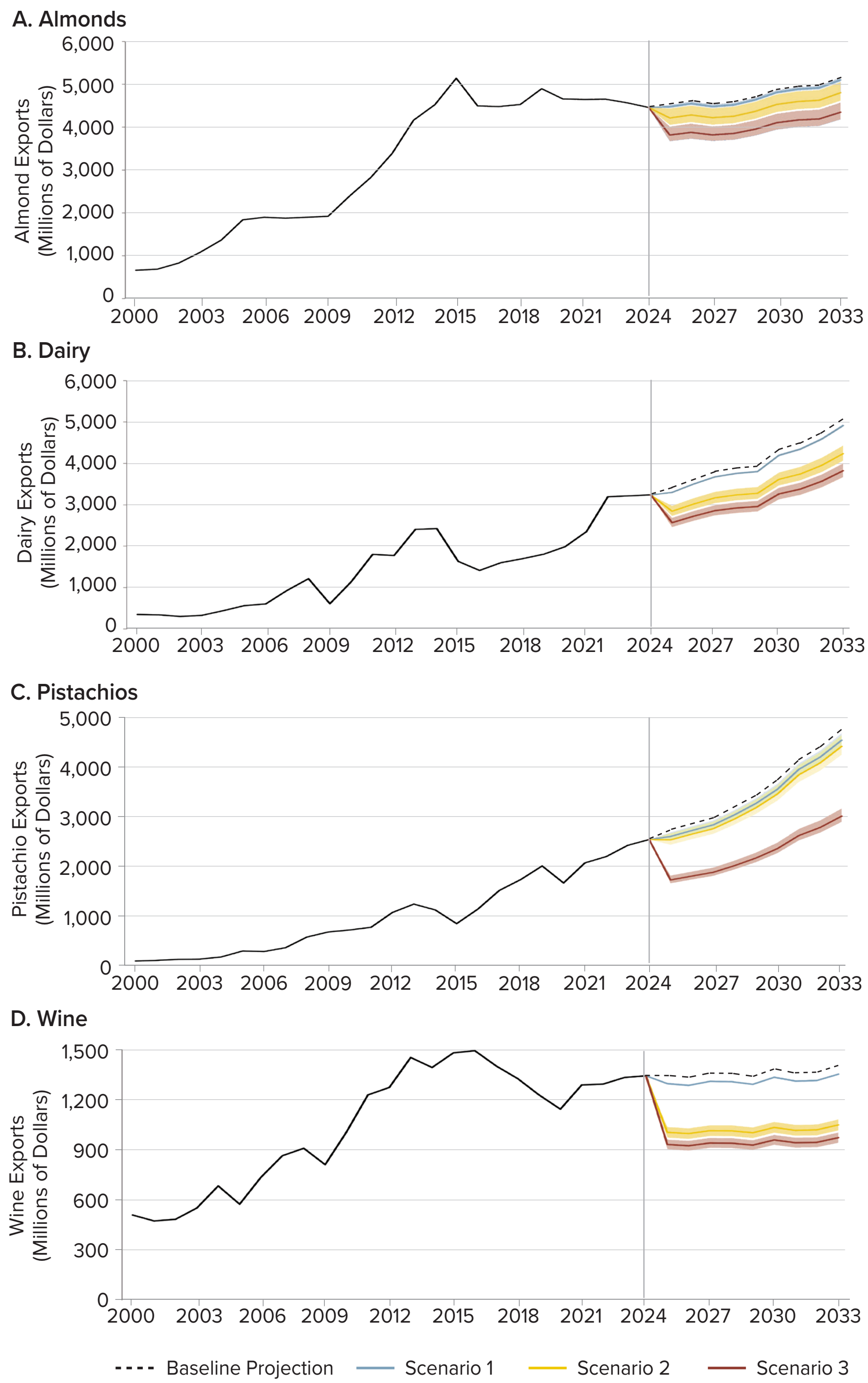
and almonds, all of which heavily depend on China's import demand. In contrast, commodities like lettuce, grapes, and strawberries, which are less reliant on the Chinese market, are projected to be more resilient under higher tariffs.

In Scenario 1, our point estimate suggests California agriculture would experience annual export losses exceeding half a billion dollars, with pistachios and dairy experiencing the largest negative impacts—estimated at $123 million and $110 million, respectively. Scenario 2, with broader global tariffs, would result in a more severe outcome, with annual export losses projected to reach $4 billion. In this scenario, dairy, wine, and almonds are among the most affected commodities, with projected losses of $566 million, $340 million, and $323 million, respectively. Scenario 3, the most extreme case, projects total export losses climbing by 25%, potentially reaching $6 billion per year. In this scenario, pistachio exports alone could suffer losses of up to $1 billion, while the combined damage to tree nuts could reach $1.8 billion.

Figure 1 shows the potential long-term impacts on California's agricultural exports for a few key products. In Scenario 1, where only China imposes retaliatory tariffs, the effects are more moderate but still disruptive. However, the more aggressive scenarios show far greater potential damage, with significant losses expected for the four high-value commodities depicted in Figure 1. If global trade tensions escalate, California's agriculture could face lasting challenges, with shrinking export markets and declining revenues that would damage the industry for years to come.

Figure 2 (on page 8) maps the county-level export losses projected under each scenario. Fresno, Kern, Tulare, Merced, and Imperial counties, which are key producers of almonds, beef, cotton, dairy, grapes, oranges, and pistachios, are expected to bear the brunt of these losses. Together, these five counties account for 53% of the estimated total state-level export loss. In the worst-case scenario, Fresno and Kern counties could face combined losses of up to $710 million from pistachio exports alone. When

Figure 1. Long-Term California Agricultural Export Projections



Source: Authors' calculations based on California Agricultural Statistics Review reports and tariff elasticities from the previous economic studies.
Note: We compare the projections with a baseline scenario that assumes no tariff increase, represented by a dashed line. The lower and upper bounds for each scenario, shown as lighter-colored lines surrounding the solid blue, yellow, and red lines, represent the 90% confidence intervals.

considering all agricultural products, these five counties could see total reductions of $983 million, $842 million, $691 million, $464 million, and $213 million, respectively. Other counties, such as Stanislaus, San Joaquin, Madera, and Monterey, are also expected to experience significant export revenue losses under these scenarios.

Conclusion

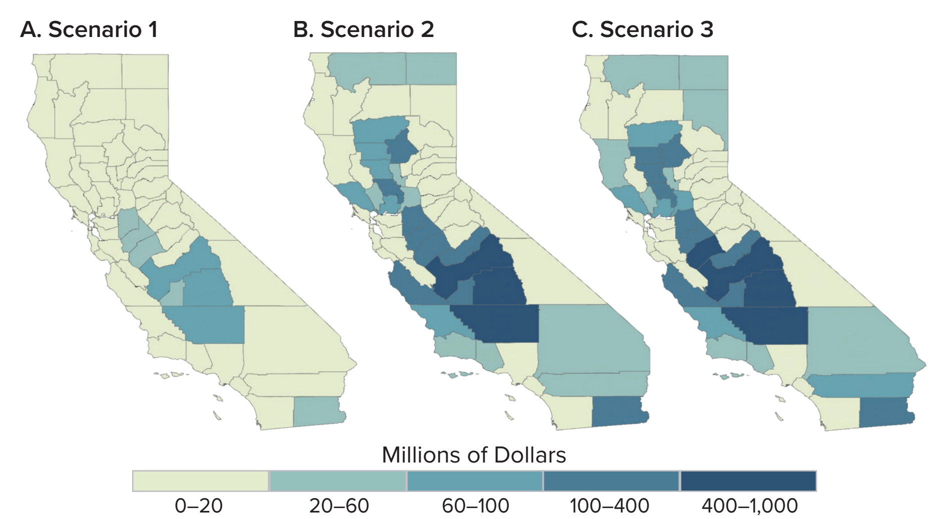
California's agriculture faces a looming threat as protectionist trade policies escalate in the nation's capital. Many of the potential losses could be mitigated or even avoided with smarter approaches to international trade. While some efforts have been made to explore new markets in regions like India, Japan, and South Korea, these initiatives have been limited in scope. Without a more aggressive push to diversify export markets, California's farmers remain heavily reliant on China, a vulnerability that could lead to significant losses if retaliatory tariffs escalate with a new trade war.

The last U.S.-China trade war showed just how much California agriculture can lose in such conflicts. Between 2018 and 2019, a trade war led to retaliatory tariffs that caused exports and prices for agricultural commodities to plummet, resulting in billions of dollars in lost revenue. If a new wave of aggressive protectionist policies is enacted, California's agricultural exports could face similar consequences—up to $6 billion in annual losses—especially in key industries like pistachios, dairy, and wine.

Rather than pursuing policies that invite global retaliatory measures, the United States should work toward more balanced trade agreements that protect domestic industries without sparking harmful trade wars. California's farmers would benefit from policies that prioritize market access and stability, ensuring that they remain competitive on the global stage. Proactively seeking trade negotiations, rather than escalating conflicts, could help maintain critical export channels and prevent long-term damage to the state's economy.

In the face of these uncertain times, it's clear that California's agricultural future depends on diversifying markets and avoiding costly trade conflicts altogether. Policymakers should be more strategic in their approach, weighing the benefits of protectionist measures against the real risks of damaging key export industries. The lessons from the past are clear: All countries involved in a trade war lose, and California agriculture simply cannot afford another trade war.

Figure 2. Projected 2025 County-Level Export Losses



Source: Authors' calculations based on data from USDA NASS and California Agricultural Statistics Review reports.
Note: To estimate the impact at the county level, we multiplied the change in the commodities' export values by a county's production share of each commodity in 2022. For the "other products" category, we used the share of bearing acres of counties in the same year.

Suggested Citation:
Carter, Colin A., Sandro Steinbach, and Yasin Yildirim. 2024. "Further Trade Wars Will Harm California Agriculture." *ARE Update* 28(1): 5–8. University of California Giannini Foundation of Agricultural Economics.

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Colin A. Carter and Sandro Steinbach. 2020. "Impact of the U.S.-China Trade War on California Agriculture." *ARE Update* 23(3): 9–11. Available at: https://bit.ly/2vX1Nje.

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As Mexican Farmworkers Flock North, Will U.S. Farms Head South?

Alexandra E. Hill and James E. Sayre

The changing demographics of U.S. and Mexican farmworkers are linked with worker shortages. The H-2A visa program offers a solution but with steep costs. With revenues lagging behind rising labor costs, some farms have incentives to move production into Mexico.

Most farms in the United States have faced major employee-related issues in recent years—too few workers and rising labor costs. In this article, we discuss these issues and their implications for U.S. agriculture. We overview trends in the demographics of U.S. and Mexican (MX) farmworkers that are linked with worker shortages. We also discuss the potential of the H-2A visa program, which grants legal authorization for foreign workers to engage in temporary work on U.S. farms, to alleviate these shortages. However, this comes at a high cost for farm employers. New data reveal sizable gaps between what farmworkers can currently earn in Mexico versus under the H-2A program: H-2A workers are legally entitled to a minimum hourly wage that differs by state (the adverse effect wage rate) and ranges from 5 times to 14 times the average hourly agricultural wage in Mexico.

Due to this wage gap, we posit that the H-2A program will continue to attract MX farmworkers, but U.S. employers claim that the costs of the program are unsustainable. Many argue that rising labor costs will reduce U.S. agricultural competitiveness, particularly for more labor-intensive crops. This could shift agricultural production from the United States to Mexico, which offers lower payroll costs and suitable growing conditions for many of the crops grown in the United States.

Using data from recent U.S. and MX Censuses of Agriculture (which we refer to as US-CoA and MX-CoA, respectively), we show that there is credence to this claim. Across many crops, particularly labor-intensive specialty crops, operations in Mexico have lower payroll costs relative to their sales than their U.S. counterparts. In turn, many U.S. farms producing the same commodities have seen large increases in their payrolls relative to sales over the last 20 years.

We identify and analyze twin "pull" and "push" factors affecting agricultural operations in the United States and Mexico: Earnings potential under the H-2A program "pulls" Mexican workers to the United States, and potential for higher profits due to lower payroll costs relative to revenues "pushes" U.S. farming operations to move production to Mexico.

Farmworker Demographics and Employment

Trends in demographic characteristics of farmworkers and their relative numbers in the population are useful for understanding patterns underlying worker shortages.

The National Agricultural Workers Survey (NAWS) is the premier source of information on non-H-2A U.S. crop workers. Data from the NAWS show two key trends in the characteristics of the U.S. crop workforce with implications for worker availability.

First, fewer workers are engaging in follow-the-crop migration as they become more settled. Migrant workers have historically played a pivotal role in U.S. crop agriculture, appearing when and where they are most needed in accordance with crop- and location-specific seasons of production. According to the NAWS, in 2000, nearly 50% of U.S. crop workers were classified as migrants, 30% had children born in the United States, and the average worker had lived in the country for 8 years. In 2022, only 15% of U.S. crop workers were classified as migrants; far more (44%) had U.S.-born children and were living in the United States for longer (an average of 21 years).

Second, fewer new immigrant workers are joining the non-H-2A U.S. crop workforce. Young immigrant workers from farming communities have historically been crucial for U.S. farms. In 2000, 83% of U.S. crop workers were foreign-born, whereas in 2022, 68% were foreign-born. This varies across the United States, with shares being the highest in California, with 96% of its workforce foreign-born in 2000 versus 90% in 2022. This is also apparent from changes in average farmworker age, which rose from 30 to 40 years old over this period.

Economists studying migration dynamics have pointed to increases in U.S. immigration enforcement, along with declining population sizes and rising education levels in countries that have historically provided immigrant labor as some of the major deterrents to continued flows of new, and often unauthorized, immigrant workers joining the U.S. farm workforce.

The Mexican population censuses (Censo de Población y Vivienda) and inter-census surveys (Encuesta Intercensal) provide information on employment and demographics of Mexican residents. We identify agricultural workers in these data based on industry (agriculture) and occupation (workers in crop agriculture) and use them to study trends in Mexico's agricultural employment.

These data similarly unveil two key trends with ramifications for the U.S. farm labor market: Fewer people are working in Mexican agriculture and the workforce is aging, as Mexico's economy has diversified out of agriculture and into manufacturing and service industries. The share of the Mexican labor force working in agriculture fell from 16% in 2000 to 9% in 2020, while the average age of farmworkers rose from 38 to 43. These factors reduce the availability of young immigrant farmworkers who are able and willing to join the U.S. farm labor market.

U.S and Mexican Farmworker Wages and Earnings

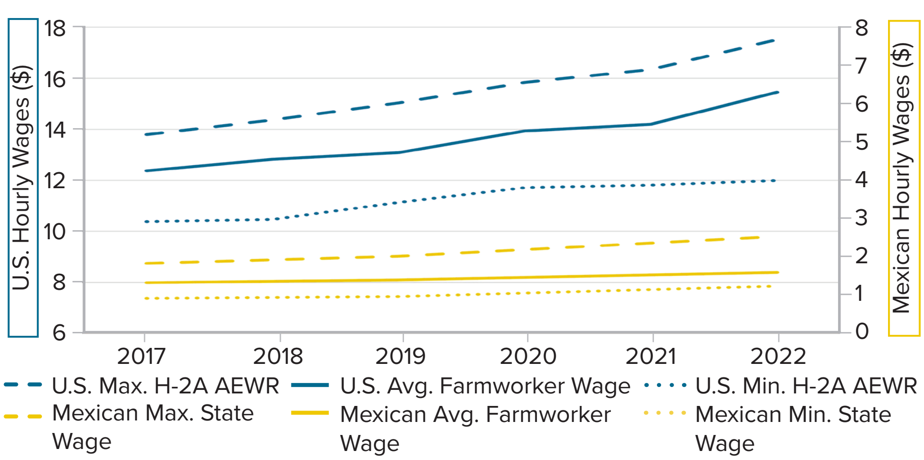
Despite fewer Mexican residents with experience in agriculture, comparing U.S. and Mexican wage and earnings data unveils one clear factor "pulling" Mexican workers into U.S. farm work: They can earn substantially more in the United States, particularly under the H-2A temporary worker visa program.

The H-2A visa program allows U.S. agricultural employers to recruit foreign workers for temporary or seasonal farm work when there are not enough qualified workers available domestically. Not surprisingly, H-2A usage has risen dramatically in the past decade, driven, at least in part, by local worker shortages.

To prevent H-2A workers from displacing U.S. farmworkers, the program requires employers to pay visa holders the highest rate between the applicable minimum wage and the H-2A minimum wage—called the adverse effect wage rate (AEWR). The AEWR differs across states and is updated annually by the U.S. Department of Labor to reflect regional prevailing agricultural wages. This updating process has been highly controversial because it has led to rapid increases in the AEWR. For example, in California the AEWR rose from $7.27 in 2000 to $17.51 in 2022, whereas state hourly minimum wages rose from $5.75 to $13.

Today, incentives to enter the United States for farm employment under the H-2A program far outweigh those from immigrating without proper work authorization; H-2A workers benefit from higher hourly wage rates, employer-provided housing, and legal work authorization. Further, the H-2A program offers an attractive option for Mexican residents wishing to earn money in the United States but return home with the extra earnings.

Figure 1. Hourly Farmworker Wages in the United States and Mexico



Source: Authors' calculations using data from the NAWS, H-2A programmatic data, the 2017 and 2019 Encuesta Nacional Agropecuaria, and the 2022 Mexican Census of Agriculture. Hourly wages for farmworkers in Mexico are converted from pesos to USD using annual average exchange rates.

We use data from the NAWS and H-2A programmatic data to illustrate trends in non-H-2A and H-2A wages. We complement these with two unique datasets that provide more precise and detailed information on the Mexican farming industry than was previously available: the 2017 and 2019 National Agricultural Survey (Encuesta Nacional Agropecuaria, or ENA) and the 2022 Agricultural Census (Censo Agropecuario, or MX-CoA). These data provide valuable insights into Mexico's farming industry and its employees with a high degree of detail in terms of geography and crop but are limited in that they are only available in recent years.

Figure 1 compares the average hourly wages of U.S. farmworkers (all non-H-2A workers, including those who are U.S. natives, foreign-born documented, and foreign-born undocumented) with what H-2A workers earn under the highest and lowest AEWRs, and with what hired day laborers, or jornaleros, earn on Mexico's farms. These data reveal stark differences between farmworker earnings in the United States and Mexico. In 2022, the average non-H-2A U.S. farm worker earned $15 an hour; H-2A workers in California (the state with the highest AEWR that year) were required to be paid at minimum $17.51; and H-2A workers in Alabama, Georgia, and South Carolina (the states with the lowest AEWR in 2022) were required to be paid at minimum $11.99. By comparison, the average hired farmworker in Mexico earned the equivalent of $1.59 an hour in 2022. In the highest wage-paying state in Mexico, Colima, the average worker earned $2.53 an hour, a quarter of the minimum AEWR in that year.

Considered in percentage change terms, U.S. and Mexican farmworker wages have risen similarly from 2017 to 2022. Increases in the U.S. hourly wages range from 16% (change in the minimum AEWR) to 27% (change in the maximum AEWR). Increases in the average hourly wage of farmworkers in Mexico range from 20% (change in the MX average wage) to 38% (change in the MX state maximum wage). As wages have risen in tandem, the fact remains that farmworkers can earn far more in the United States than in Mexico.

Farm Payrolls and Revenues

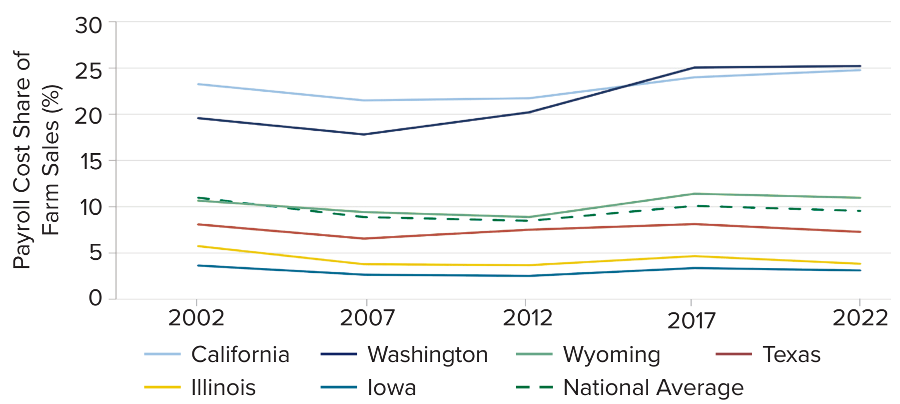
Not surprisingly, U.S. farm payrolls (which include wages and benefits) have risen with worker wages. Some of these additional costs have been offset by higher farm sales, but there are notable differences in the evolution of payroll costs and farm sales by state and by crop. Using data from the US-CoA, we illustrate national and select state trends in payroll expenses as a share of farm sales, which sheds light on the sectors most impacted by these workforce trends. We then draw on 2022 data from both the US-CoA and MX-CoA to demonstrate the sectors that differ most substantively in terms of the payroll's share of total farm sales on either side of the border. Figure 2 shows trends in U.S. total payroll costs divided by total farm sales nationally and for select states. Nationally, growth in the value of farm sales has slightly outpaced growth in payroll costs, leading to a small decrease in the payroll's share of farm sales from 11% in 2002 to 9.5% in 2022.

Payroll costs tend to account for a larger share of both farm revenues and total farm expenditures in states that produce more labor-intensive crops, for example California and Washington. Payroll expenses as a share of revenues in these states have generally been rising over time, though at different rates. In California, the payroll's share of farm sales rose only 2 percentage points, from 23% to 25%, from 2002 to 2022. In Washington, which had among the largest increases in payroll expenses of any state over this period, payroll's share of sales rose from 19% to 25%. The payroll share of total sales tends to be lower in central, southern, and eastern states compared with western states, and is lowest in the corn belt. Figure 2 shows trends in farm payroll's share of sales in Wyoming, Texas, Illinois, and Iowa as some examples to emphasize such differences in levels and trends across the United States.

Geographic differences in the payroll share of sales are, in part, driven by differences in types of production, and unfortunately differences between the US-CoA and MX-CoA restrict trend comparison by crop for this period. However, we can draw comparisons across commodity sectors using the most recent US-CoA and MX-CoA data from 2022. One limitation of the MX-CoA is that it only reports wages for hired day laborers (jornaleros) and not more permanent workers. The 2017 and 2019 ENA data suggest that payments to jornaleros comprised roughly 30% of total farm payroll in Mexico, with no clear differences across broad sectors (although there is some variation across individual crops, with bananas and coffee having a higher share of hired day labor, and avocados and lemons having a lower share). To account for this, we also include estimates of the payroll share of farm sales assuming that jornaleros account for only 30% of the total farm payroll.

We summarize these data in Table 1 and draw several insights. Not surprisingly, in the United States, payroll costs as a share of total farm sales are larger in sectors using more labor. The share is largest for farms producing fruits and tree nuts and lowest for those producing oilseeds and grains, which are typically highly mechanized. The opposite is the case in Mexico: Oilseeds and grains have the highest payroll share of farm sales

Figure 2. Trends in Payroll Share of Farm Sales in the United States



Source: Authors' calculations using data from the U.S. Census of Agriculture on payroll costs and sales for all farms and ranches.

Table 1. 2022 Payroll Share of Farm Sales in the United States and Mexico by Farm Sector

Sector (Classified by NAICS)	United States All Workers	Mexico Jornaleros* Only	Mexico All Workers**
Oilseed and Grain	4.2%	8.0%	26.0%
Vegetable and Melon	22.2%	4.5%	15.0%
Fruit and Tree Nut	36.0%	4.5%	15.0%
Other Crop	14.2%	5.0%	17.0%

Source: Authors' calculations using data from the 2022 US-CoA on payroll costs and sales for all crop farms, the 2022 MX-CoA on payroll costs for all crop farms, and Mexican Agrifisheries Information Service (SIAP) yearly production data on crop level sales. Estimates for payroll costs of Mexico farms that include all hired workers inflate the jornalero wage bill by multiplying by 3.33, reflecting that jornaleros account for approximately 30% of total labor costs.
Note: *Jornaleros=hired day laborers. **Estimated payroll shares.

while fruits and tree nuts have among the lowest. These differences are due to a combination of factors. In Mexico, oilseed and grain production is less mechanized, often used for home consumption, and these crops are produced by smaller and less efficient operations while fruits and tree nut tree production have economies of scale and a higher percent of the crops are exported.

These data are useful for illuminating the sectors with the highest potential gains from moving production out of the United States and into Mexico. They suggest that the largest labor cost savings are in the fruit and tree nut sector. However, labor costs are certainly not the only factor in the costs of operations, which include input costs, transportation, trade restrictions, and potential challenges to U.S. firms conducting business abroad such as language barriers, lack of infrastructure, or heightened security risks.

Although the decision of where to produce crops is complex, information on Mexican production and exports to the United States highlight rapid growth of crops with the highest potential for labor cost savings. For example, Mexico's production of crops within the fruit and nut sector, has risen dramatically. From 2003 to 2022, the value of blueberry production in Mexico increased more than 2,600-fold; that is, the value of production in 2022 was 2,600 times its value in 2003. Over this same period, the value of raspberries grew 140-fold, pistachios 46-fold, strawberries 13-fold, and olives 10-fold.

These commodities have also experienced a large growth in exports from Mexico to the United States. From 2003 to 2022, Mexican exports to the United States of blueberries grew 21,100-fold, raspberries and blackberries 43-fold, strawberries 16-fold, and unprocessed olives 2-fold. Mexico began exporting pistachios to the United States in 2021, and future export growth in that crop remains to be seen.

Overall from 2003–2022, Mexico's crop production and exports to the United States increased most rapidly for labor-intensive crops, many of which are widely produced in California. These trends are less pronounced in other sectors. For example, the value of Mexico's corn production in 2022 was only 5-times its value in 2003 and soybean production was only 4 times greater, and their associated growth in export values were 3-fold and 11-fold, respectively.

For crops less commonly produced in the United States, production increases and export growth were also slower. For example, the value of Mexico's banana and mango production increased 4-fold from 2003 to 2022 and experienced somewhat lower export growth: 19-fold for banana and 5-fold for mango.

Conclusion

Data from the United States and Mexico offer cautious evidence of a narrative on the future of U.S. farms. The domestic supply of U.S. farmworkers likely will continue to decline, while the H-2A program, through its continued attractiveness to workers from Mexico, will increasingly serve as a source for U.S. farm labor. While the high costs associated with the H-2A program will "pull" in workers, they may also "push" farms out of the United States. Comparative evidence on farm payroll costs relative to sales, production, and trade in the United States and Mexico offer some support for this narrative, although a richer accounting of these issues is required to draw causal conclusions about the U.S.-Mexico agricultural relationship.

Finally, the opposing effects from the H-2A program introduce a notable policy implication for its minimum wage rates, or AEWRs. State AEWRs are adjusted annually based on survey estimates of farm wages that include the wages of H-2A workers. As H-2A workers comprise a larger share of the U.S. farm workforce, their AEWRs will lead to higher AEWRs the next year, putting a self-enforcing upward pressure on wages.

Suggested Citation:

Hill, Alexandra E. and James E. Sayre. 2024. "As Mexican Farmworkers Flock North, Will U.S. Farms Head South?" *ARE Update* 28(1): 9–12. University of California Giannini Foundation of Agricultural Economics.

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Some of the data from Mexico presented in this article were generated under INEGI project number LM2555. The conclusions and opinions expressed therein are solely that of the authors and do not constitute official statistics of INEGI nor that of the National System of Statistical and Geographical Information (SNIEG).

For additional information, the authors recommend:

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California's Quest for Cleaner Cattle: Science, Economics, and Policy

Mark Agerton and Sophia Salzer

We review the biology of methane emissions from dairy and beef cattle, highlighting factors that influence emissions. We discuss estimates of California cattle methane emissions, and emissions reduction strategies, including their benefits and costs, and policy implications.

Methane (CH_4) policy primarily targets the oil and gas sector, which has the lowest cost abatement opportunities; however, agriculture is the largest global source of anthropogenic (human-caused) methane emissions (40%). According to the state's greenhouse gas inventory, 52% of California's 2021 anthropogenic methane emissions—800,000 metric tons (mt)—came from dairy and beef cattle alone. This is equivalent to the annual CO_2 emissions from 5 million passenger vehicles. Methane's powerful short-term warming effect implies that near-term reductions can buy time for longer-term decarbonization efforts. The Environmental Protection Agency (EPA) currently estimates that each metric ton of methane emitted in 2024 causes $2,305 in global climate damages at current prices, far exceeding carbon dioxide (CO_2) damages ($246/mt).

Biology Basics

Livestock agriculture emits methane via enteric fermentation and manure management. Enteric fermentation is part of the digestive process in ruminants like cattle, sheep, and goats. Methanogenic microbes in a ruminant's forestomach decompose fibrous matter and release methane as a byproduct. Animals expel methane primarily through belching. Enteric emissions rise with caloric intake. Large, mature, and productive animals have greater energy needs and thus higher enteric emissions rates.

Livestock manure in waste management systems also emits methane. Many California dairy farms use liquid slurry systems, where anaerobic conditions promote methane production. Some systems use anaerobic digesters to capture emissions from decomposing manure, generating biogas that can be flared or sold as renewable fuel. The remaining digestate can be processed into fertilizer, soil amendments, and animal bedding. Beef cattle manure, usually dried and stored in solid form, decomposes aerobically with minimal methane emissions. While not discussed here, nitrogen from manure management also interacts with the environment to produce nitrous oxide (N_2O), another powerful greenhouse gas, and airborne particulate matter.

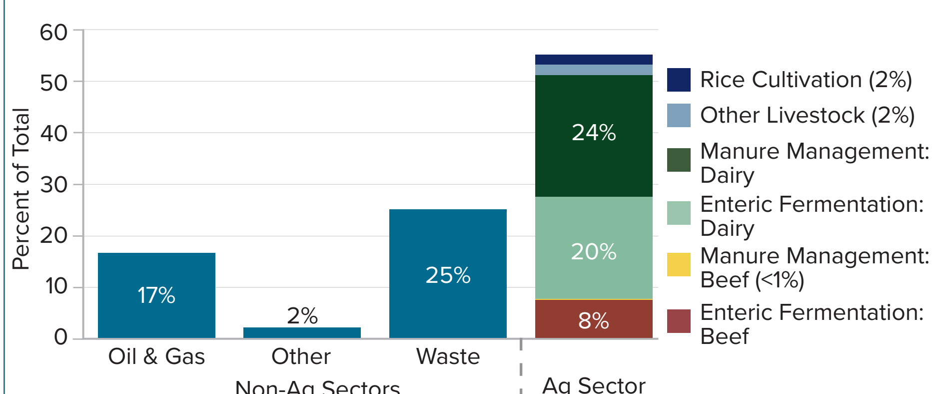
How Much Do California Cows Emit?

Livestock emissions are estimated using bottom-up inventories and empirical measurements. Bottom-up inventories count emissions sources, multiply sources by an "emissions factor," and sum these values. Empirical measurements cost more and encompass an animal, site, or region. These can inform emissions factors and validate inventories but are not used for continuous farm-level monitoring.

While inventories are detailed, uncertainty persists regarding sources and the accuracy of emissions factors. Studies disagree on whether inventories under- or overestimate emissions. One review finds annual enteric methane emissions estimates for dairies range from 34 to 78 kilograms (kg)/head for beef cattle and 118 to 171 kg/head for lactating dairy cows. Empirical estimates of manure emissions also vary, but generally suggest inventories are underestimates.

Figure 1 breaks down California's 2021 methane emissions. Enteric fermentation and manure management alone accounted for over half of the state's emissions, with most of this coming from dairy cattle. In Table 1 (on page 14), we calculate average methane emissions per animal using

Figure 1. 2021 California Methane Emissions by Industry (Percent of Total)



Source: Authors' calculations and CARB. Available at: https://bit.ly/4gNVrEF.
Note: We separate included inventory emissions by category and by subcategory for agriculture. Emissions from other livestock include bulls and non-cattle livestock.

2020 California values from the EPA's 2023 U.S. Greenhouse Gas Inventory, as well as the social cost of associated climate damages. Emissions vary throughout an animal's lifecycle, and our calculations are for a representative animal. Adult dairy cows emit more than our averages below: 150 kg/year via enteric pathways and 184 kg/year via manure. Based on the United States Department of Agriculture's Pacific Region Milk Production Report, which estimates annual milk production at 2,821 gallons/cow, each gallon of milk causes $0.27 in climate damages. For beef, we assume lifecycle emissions of 482 grams of methane/kg carcass weight and a 66% conversion to salable products. This means that a one-third pound hamburger is associated with $0.25 in climate damages, primarily from enteric methane.

Methane Policies and Pathways

Methane emissions originate from many sources and are costly to measure precisely and comprehensively, making them similar to non-point-source pollutants (like nitrogen runoff) versus easily-measured point-source pollutants (like power plants). Control strategies for non-point-source pollutants often target observable production factors, such as waste management, feed, or herd size, rather than directly measured pollutants. Indeed, current U.S. and California policies do not target measured, farm-level greenhouse gas emissions; instead, they subsidize inputs or practices that may reduce emissions. Policies also subsidize the capture and sale of agricultural methane, termed renewable natural gas, which has complex effects on net emissions.

Manure Management

Low-emissions alternatives to anaerobic digesters, such as dry manure storage, pasture-based systems, and liquid-solid separation, are often used to manage manure. In California, however, federal and state subsidies primarily promote digesters that capture and prevent methane emissions from wet waste management systems. Because renewable natural gas can replace fossil natural gas, the U.S. Renewable Fuel Standard and California's Low Carbon Fuel Standard (LCFS) further incentivize digesters. They increase the market value of renewable natural gas by mandating a share of transportation fuel be sourced from "low carbon" sources, despite the lower cost of traditional fossil fuels. These standards effectively act as a subsidy for renewable fuels and a tax on fossil fuels.

To compare the climate benefits and costs of a digester, we take capital and maintenance costs from Cowley and Brorsen for digesters servicing 500 to 4,500 cattle. We ignore capital subsidies. We inflate costs to 2024 prices and amortize them over the digester's lifespan at the 2% discount rate used for federal benefit-cost analyses. This implies annual costs of $445 to $175/head (costs decrease with scale). Scientific studies estimate annual methane emissions from uncovered lagoons are 20 to 120 kg/head. Assuming a 52% emissions reduction, avoided climate damages range from $24 to $143/head. Based on these figures alone and disregarding additional revenue streams from digester byproducts, it remains uncertain whether even the largest dairy digesters pass a climate benefit-cost test.

Critics have raised concerns about current policies promoting digesters. California's LCFS inflates the implied subsidy for methane from dairy digesters relative to landfills. Policymakers rationalize this because dairy methane emissions are largely unregulated, while landfills face additional emissions regulations. Thus, in theory, marginally increased methane capture by dairy digesters represents larger emissions reductions relative to a world without the LCFS. However, this differential treatment raises questions of both equity and economic efficiency. Additionally, critics argue that subsidizing methane production from digesters undermines emissions reductions by incentivizing wet waste management, which generates more methane than dry management. The economies of scale required for digesters also favor larger herds, potentially promoting consolidation and disadvantaging smaller operations.

Enteric Fermentation

Enteric fermentation generates the majority of methane emissions from both dairy and beef cattle. Abatement options—feed additives and selective breeding—are promising but costly and less developed.

Feed additives can significantly reduce enteric methane emissions. In 2024, the Food and Drug Administration approved Bovaer, a feed additive containing 3-nitrooxypropanol (3-NOP). According to manufacturers, a quarter teaspoon of Bovaer can reduce enteric emissions by 30% in dairy cows and 45% in beef cattle. Annual costs are estimated at $56–$100/head,

Table 1. Methane Emissions and Climate Damages From an Average California Bovine in 2020

Methane Source	Methane Emissions (kg/head/year)		Climate Damage (2024 USD/head/year)	
	Dairy	Beef	Dairy	Beef
Enteric	84.5	56.1	$195	$129
Manure	84.6	1.3	$195	$3
Total	**169.1**	**57.4**	**$390**	**$132**

Source: Authors' calculations using data from the U.S. Greenhouse Gas Inventory Annex 3.10-3.11.

compared to climate benefits of $104/head for California dairy and $72/head for beef cattle. Another promising additive, red seaweed of the genus *Asparagopsis* contains high levels of bromoform ($CHBr_3$), which inhibits methanogenesis. Studies suggest *Asparagopsis* may reduce methane more than Bovaer, but the additive is not yet ready for mass application. Symbrosia (a company producing a red seaweed feed additive) estimates the additive will cost around $584/head annually, exceeding the climate benefit of reduced emissions: $51–$232/head for dairy and $57–$158/head for beef. Further research is needed on *Asparagopsis*'s impact on methanogenesis, animal and human health, and the environment.

Federal and state policies for enteric methane reductions lag behind manure policies but are evolving. The 2022 Inflation Reduction Act funds agricultural conservation programs targeting feed additives.

Selective breeding could promote low-emitting cows, though the strategy is not currently part of major U.S. or California policies. One study reports that approximately 21% of methane production variation is genetic. Current breeding practices often favor higher-emitting cows due to their productivity. However, another study estimates that incorporating methane reduction into breeding goals could decrease dairy cattle emissions by 24% by 2050.

Economic Analysis

Though current policies rely on input and output subsidies, standard market-based instruments (like taxes or cap-and-trade) could price methane emissions. Under certain conditions, these policies could achieve pollution reduction at the lowest economic cost.

The United States and California have no stated plans to tax agricultural methane. Denmark recently proposed a tax on cattle emissions beginning in 2030, but has yet to provide much detail. Comprehensive emissions measurement would not be feasible, but an inventory-based approach would be. If the tax uses detailed production information from farmers and considers factors like waste management, feed composition, and feed additives, it could incentivize emissions reductions. However, applying a uniform emissions factor to all cattle would be blunt, inflexible, and costly, potentially reducing herd sizes and raising commodity prices.

Because they rely on inventories, current policies target inputs, not measured pollution. Policies may be less effective if the relationship between inputs and pollution deviates from emissions factors. Variation in actual relationships will mean policy over-targets low emitters and under-targets high emitters. As technology and production decisions change in response to prices and policies, emissions factors and the implied tax rates will require updating to remain accurate. Slow updating will discourage innovation: If emissions accounting doesn't recognize new technologies or practices, then policies targeted based on inventory estimates won't motivate farmers to adopt them.

The global trade of beef and dairy also poses challenges for market-based policies that penalize emissions rather than subsidize reductions. If domestic- or state-level policies raise prices for farmers, farms may relocate to unregulated jurisdictions and export products back to regulated regions. Border adjustment mechanisms, like tariffs on unregulated imports, could counteract this.

Conclusion

In May 2024, the California Air Resources Board predicted California will meet only 56% of its 2030 dairy and livestock methane emissions reduction target. Barriers to effective policy include the lack of low-cost abatement options and the inability to comprehensively and continuously measure methane emissions. Technology may lower costs in coming years, particularly around enteric emissions. The oil and gas sector offers a potential model for overcoming measurement limitations by using a portfolio of policies: technical standards on inputs and a new emissions tax. Regulators currently calculate this tax using inventory-based estimates but intend to increasingly incorporate measured emissions. As innovation enhances livestock methane abatement options, a portfolio of policies and improved measurement may facilitate deeper reductions.

Suggested Citation:

Agerton, Mark and Sophia Salzer. 2024. "California's Quest for Cleaner Cattle: Science, Economics, and Policy." *ARE Update* 28(1): 13–15. University of California Giannini Foundation of Agricultural Economics.

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Agricultural and Resource Economics
ARE UPDATE
Giannini Foundation of Agricultural Economics, University of California

Department of Agricultural and Resource Economics
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One Shields Avenue
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GPBS

ARE UPDATE is published six times per year by the Giannini Foundation of Agricultural Economics, University of California.

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