Journal
California Agriculture, 0(0)

ISSN
0008-0845

Authors
Sears, Molly
Jetter, Karen
Takele, Etaferahu

Publication Date
2024-11-04

DOI
10.3733/001c.125429

RESEARCH ARTICLE

For California perennial crops facing climate change, water use stays stable while planting density increases

We can gain more insight about trends in water use for perennial crops when we also consider changes over time in planting density.

by Molly Sears, Karen Jetter and Etaferahu Takele

Online: https://doi.org/10.3733/001c.125429

Abstract

With climate change, there has been increasing concern over allocations of scarce water supplies in California during times of drought. This study looks at how practices in perennial crops have changed over time, specifically related to application of irrigation water and to planting densities. We use University of California Sample Costs of Production Budgets from 1980 to 2021 for all major perennial crops in California to compile information on the commonly implemented irrigation and planting practices across various crops and regions. After controlling for regional variation in water applied due to agroclimatic factors, irrigation water use per acre has remained largely stable for most crops, while planting densities have increased for many crops, including olives, grapes, avocados, plums, and almonds. A notable exception is pistachios in the South San Joaquin Valley, which experienced an increase in water applied, with stable yields and planting densities. Our methods of calculating significant trends in water use, including yields and density of orchards, give further insight into the use of water in California agriculture.

The worst megadrought to hit the Southwest United States and northern Mexico in 1,500 years was declared in 2022 (Williams et al. 2022). With more severe water shortages comes increased attention to the largest water users, including urban and residential areas and agriculture. Agricultural water use in California is estimated to be 40% of all use statewide, though this varies regionally depending on elevation and weather conditions (Mount et al. 2023). In response to uncertainties about water availability in agriculture, whole farm systems have changed over time, including irrigation methods, water application rates, and planting densities. Capturing all these effects is essential to determine the long-run dynamics of how water usage in the crop production system has changed over time as water supplies have become scarcer.

Changes in water usage and increased planting densities are important agricultural management practices that have significant impacts on profits, yields, and resource use. This is especially true of perennial

A vineyard in Paso Robles, Calif. The authors' analysis of cost studies suggests that irrigation use per acre has remained stable over the past 40 years for most perennial crops in California. *Photo*: htrnr, iStock.com.

crops; decisions made during the planting period, such as irrigation technology or planting density, have long-term ramifications in both production and the efficient use of water. However, there is little long-term information on how these trends have shifted over time. Much of this is a data issue; there are no reporting requirements or crop-specific surveys that repeatedly ask about these agricultural practices. In this paper, we use a unique set of data well known by many growers in California, the University of California Sample Costs of Production budgets, to look at crop-specific trends in applied irrigation water and planting density.

One often-prescribed water-conservation solution for high agricultural water use is the adoption of microirrigation, such as drip irrigation. Drip irrigation was introduced in California in the late 1960s in a small, experimental avocado orchard, and was originally adopted by growers looking to improve yields in high-value crops (Taylor and Zilberman 2017). Adoption of the technology expanded rapidly during periods of drought, when water prices increased substantially, and 40% of California's agricultural acreage was microirrigated by 2010 (Tindula et al. 2013). The adoption of microirrigation was driven by perennial tree and vine crops in California, as well as the various financial incentives provided by state and federal agencies.

Similar to the results for water applied per plant, water applied per unit of yield has either decreased or remained about the same over time.

However, while microirrigation in perennial crops has expanded over time, there is limited evidence that this technology increases water conservation. Ward and Pulido-Velasquez (2008) find that subsidies for drip irrigation may reduce on-farm water use, but that overall water depletion may increase, due to an increase in irrigated acres. Pfeiffer and Lin (2014) find that adoption of high-efficiency sprinkler technology leads to both an increase in water use per acre and expanded overall irrigated acreage. However, merely looking at the amount of water applied per acre, without accompanying changes in field management, may present an inaccurate picture of water usage and efficiency. For example, during the same period in which there was increasing adoption of microirrigation, other production practices, such as planting density, may have changed.

How water usage supports the production of food and fiber is an especially relevant problem in California, where agricultural water use is a source of considerable debate (Fuller 2009). In this study, we hope to shed light on how trends in California water use have shifted over the last 40 years, as microirrigation has become more popular. Additionally, we aim to understand how changes in per-acre water application rates over time have impacted per-tree application rates and per-unit yield rates as planting densities have increased.

Crop production budget data

We manually compiled data from all relevant UC Sample Cost of Production studies from 1980 to 2021 to evaluate the long-term trends in irrigation and planting decisions (UCCE 1980–2021). From the reports, we collected the commodity, year, and region studied, along with the quantity of irrigation water applied, its source and distribution system, planting density, and yield. In total, there were 309 cost-of-production studies with sufficient data. Our efforts focused on all major perennial crops in California with regularly updated cost studies, including almonds, apples, avocados, citrus (lemons and oranges), wine grapes, table grapes and raisins, olives, peaches, pears, pistachios, plums and prunes, and walnuts.

There are several advantages to using these data. The crop cost and return budgets are repeated measures of production information, typically conducted every 3 to 5 years in each region. There is consistency in reporting and methodology, and they cover production aspects ranging from irrigation quantities and planting densities to projected yields and potential profitability. We use these data because the researchers who constructed the studies consult with local growers in order to provide realistic production numbers. Many of the crop budgets are developed by the same authors for decades, leading to reasonable continuity of information-gathering methods within a crop and region.

However, there are some drawbacks to the use of these budgets. Cost studies are developed by consulting with focus groups of agricultural producers to come up with "typical averages" for the region. While the focus groups are designed to be representative, variation in the composition of focus groups and the self-reported nature of the data could lead to inconsistencies over time. There is also some variation from researcher to researcher in reporting methods, leading to differences in data collection strategies, including the frequency of collecting new cost information and publishing updated budgets. Some cost studies, especially studies before 1980, use the same numbers from report to report, making it difficult to discern how current the data are, or when changes in crop production practices occurred. To address this, we limit our sample to years after 1980, as reporting and data quality substantially improved after that time. Altogether, however, these data provide a comprehensive look at production practices across California over an extended time horizon.

Data collected include the year of the study, region, planting density, irrigation method, quantity of water applied, water source, yield, and water price per acre-foot. We use the interquartile range method to remove outliers in acre-inches applied. We also removed budgets that focused on hedgerow planting methods, as their planting density and water use varied significantly from traditional orchards. After cleaning the data, we retain 252 cost studies across 13 different crops in nine different regions (fig. 1) from 1980 through 2021.

Changes over time in water use

Given the variation in water applied by region, merely capturing statewide averages of the trend in water usage over time may result in inaccurate estimates. To account for this, we estimate how water applied by crop has changed over time, relative to the average irrigation water applied in each region, to see whether water use is increasing, decreasing, or remaining constant over time. To compare regions to each other, we look only at regional deviations from their means (variations from averages). By removing region-specific averages from our analysis, we aim to make regions more comparable with each other, as well as to reduce the differences that region-specific reports may exhibit. For context, table 1 shows average acre-inches applied per acre by crop and by region of study.

Formally, for each crop, we first run a simple linear regression that regresses acre-inches applied per unit on regional fixed effects, as shown in Equation 1 (Evenson and Mwabu 2002).

$$\gamma_{ir} = \beta_{ir} R_r + \varepsilon_{ir}$$

Here, γ_{ir} is the dependent variable, which is either acre-inches of water for crop *i* in region *r* applied per acre, per tree, or per ton, depending on the specification. R_r are dummy variables for each region, and β_{ir} represents the average acre-inches applied for each crop in region *r*. We are interested in ε_{ir}, the residuals, which is the remaining variation in the data after controlling for the region-specific averages.

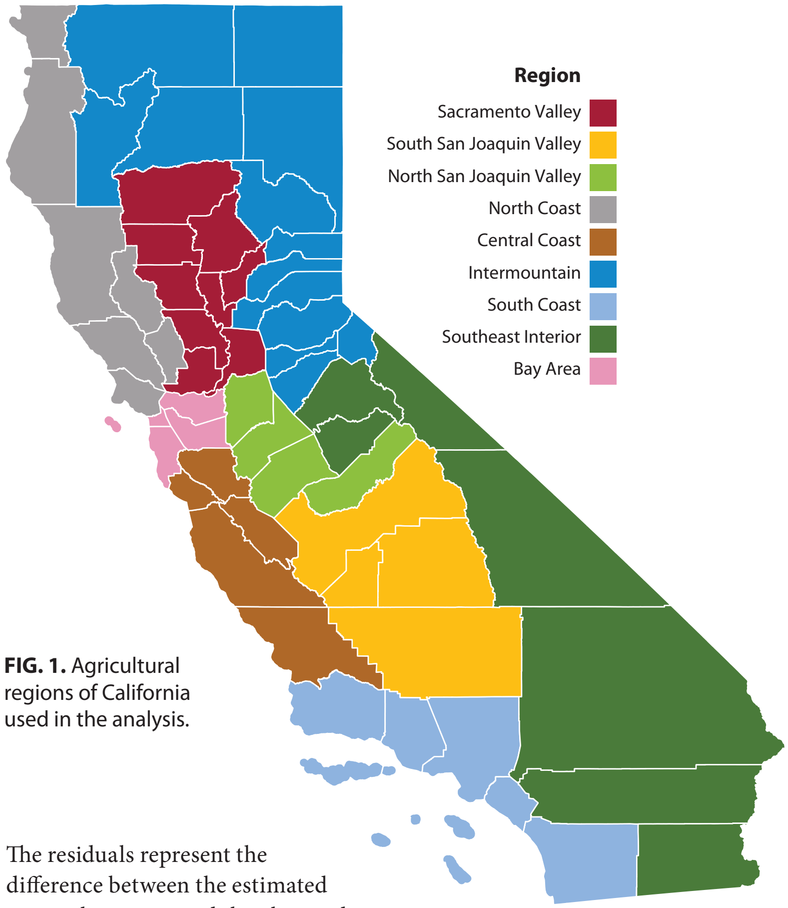

FIG. 1. Agricultural regions of California used in the analysis.

The residuals represent the difference between the estimated regional averages and the observed values. With the residuals, we can compare crop budgets between different regions, evaluating how water use recommendations have changed over time. To do so, we create graphs that plot the residuals of water use. Finally, we add in linear

TABLE 1. Average acre-inches/acre applied via irrigation, by crop and region, 1980–2021 (number of observations in parentheses)

Crop	Bay Area	Central Coast	Intermountain	North Coast	North San Joaquin Valley	Sacramento Valley	South Coast	South San Joaquin Valley	Southeast Interior	Range
Almonds					42 (21)	35 (9)		49 (10)		27–62 (40)
Apples		21 (7)	34 (3)	15 (4)	48 (2)					6–60 (16)
Avocados		26 (4)					33 (13)		39 (2)	18–45 (19)
Citrus		(2)				36 (1)	30 (10)	32 (13)	54 (4)	24–28 (30)
Grapes, other								40 (14)		28–48 (14)
Grapes, wine	12 (2)	13 (2)	7 (3)	8 (15)	42 (1)	16 (3)	18 (1)	36 (1)	12 (1)	2–42 (29)
Olives		30 (1)		30 (1)		36 (10)		28 (5)		6–48 (17)
Peaches			30 (1)					42 (6)		30–44 (7)
Pears			36 (1)	48 (6)		36 (9)				30–48 (16)
Pistachios					24 (1)			38 (8)		24–50 (9)
Plums								40 (7)		24–44 (7)
Prunes		20 (1)				33 (11)		45 (4)		20–50 (16)
Walnuts		15 (2)		24 (1)	42 (11)	36 (12)		50 (6)		18–68 (32)

trendlines with 95% confidence intervals to the plots, to see whether irrigation water applied has increased or decreased over time.

The rationale for using residuals for our analysis comes from a challenge with our data. Because the Sample Cost of Production studies are typically updated every 4 to 5 years for each region, taking an annual average of water applied across all regions would provide inconsistent and noisy results. An example from our data is the Prune Cost of Production studies. In the South San Joaquin Valley (SSJV; average applied water of 45 acre-inches/acre), budgets were updated in 1989, 1994, and 1997, while the other regions (average applied water of 33 acre-inches/acre) had budgets updated in 1982, 1988, and 1998. If we used these data directly, we would see a spike in average annual water use in 1989, 1994, and 1997, but this would be due to the timing of the budgets from the SSJV, not because average water use actually increased during those times.

By taking the residuals, we can compare regions to each other. When we control for region-specific fixed effects, we are accounting for each region-specific average. So, in the above example, estimating a model with region fixed effects would account for the 45 acre-inches/acre applied on average in the SSJV, the 33 acre-inches/acre applied in the Sacramento Valley, and the average water use in all other regions. After the removal of the fixed effects, the remainder (the residuals) shows how an individual report varies from the region-specific average. In the SSJV, they reported water use of 36 acre-inches/acre in 1989, 46 acre-inches/acre in 1994, and 50 acre-inches/acre in 1997. Therefore, the residuals would show that water use in the SSJV in the 1989 report was 9 acre-inches/acre lower than average, and water use in 1997 was 5 acre-inches/acre above average; this is an increasing regional trend during the period of our study. Since the residuals show all regions' deviations from their "normals," they can be compared to each other to show an increasing or decreasing trend over time.

Irrigation water per acre

Examining the changes in irrigation water applied by crop over time (fig. 2) shows no obvious universal trends. Irrigation water applied per acre has significantly increased over time for almonds and

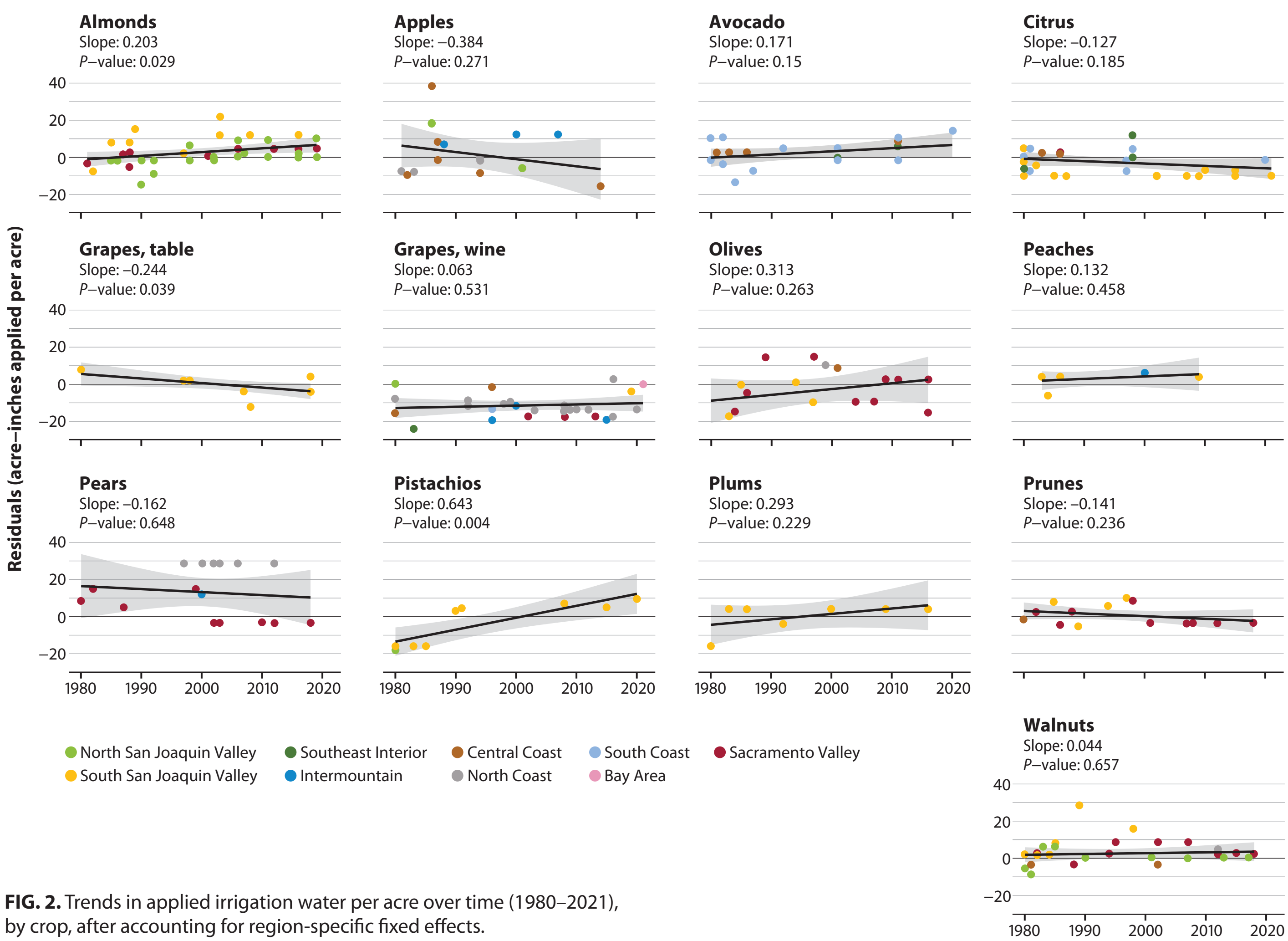

FIG. 2. Trends in applied irrigation water per acre over time (1980–2021), by crop, after accounting for region-specific fixed effects.

pistachios. In contrast, table and raisin grapes show less water being applied per acre over time. Based on the empirical strategy outlined above, we test to see whether a trend is significant by looking at the *P*-value of the slope coefficient, after accounting for the region fixed effects. All slope coefficients and their respective *P*-values are shown in figures 2 to 6. For discussion, we report that an effect is significant if the slope coefficient has a *P*-value under 0.05. While water applied per acre shows general declines for apples and pears, and increases for plums and olives, the noisy standard errors and insignificance of the slope coefficient indicate that these trends may be unreliable. Other crops, including wine grapes, peaches, and walnuts, have remained relatively stable in their irrigation water applied per acre.

Changes in planting densities

Changes in water applied per acre are only part of the story. It is worth digging deeper into what else has changed over time, such as planting densities and yields, and how that affects the evaluation of changes in water applied over time. Summary statistics for planting density and yield, by crop, can be found in table 2. For most of the perennial tree and vine crops included in this analysis, including almonds, avocados, citrus, grapes (table and wine), olives, pears, plum, prunes, and walnuts, planting density has stayed the same or increased over time (fig. 3). Only pistachios have shown a slight decline in the number of trees planted per acre, with crop budgets moving from 12 feet by 24 feet spacing to 17 feet by 20 feet spacing over time.

TABLE 2. Summary statistics for planting density and yield, by crop (1980–2021)

Crop	Mean	SD	Min	Max	*n*
Planting density (trees/vines per acre)					
Almonds	101.2	19.7	75	130	40
Apples	273.5	56.9	202	340	13
Avocados	148.8	72.9	100	430	19
Citrus	122.8	26.6	90	218	25
Grapes, other	534.8	54.7	450	605	13
Grapes, wine	873.0	352.7	450	1,555	28
Olives	222.8	226.1	90	726	17
Peaches	172.7	138.4	108	453	6
Pears	221.3	49.7	134	272	16
Pistachios	144.0	23.4	115	180	9
Plums	155. 7	38.7	108	202	6
Prunes	137.3	30.5	90	183	16
Walnuts	60.0	12.2	35	90	31
Yield (tons/acre)					
Almonds	1.0	0.25	0.5	1.5	37
Apples	16.0	6.6	1.8	25.0	14
Avocados	5.1	1.6	3.1	8.1	12
Citrus	14.6	4.7	7.5	22.5	23
Grapes, other	7.6	5.2	2.0	17.1	14
Grapes, wine	6.2	3.4	1.0	20.0	24
Olives	3.9	1.2	1.6	5.0	15
Peaches	12.1	5.0	6.0	17.3	7
Pears	9.1	4.8	1.9	18.0	15
Pistachios	1.1	0.37	0.5	1.4	8
Plums	11.4	1.5	9.8	12.6	7
Prunes	5.0	3.1	1.5	11.0	16
Walnuts	2.2	0.72	0.81	3.0	26

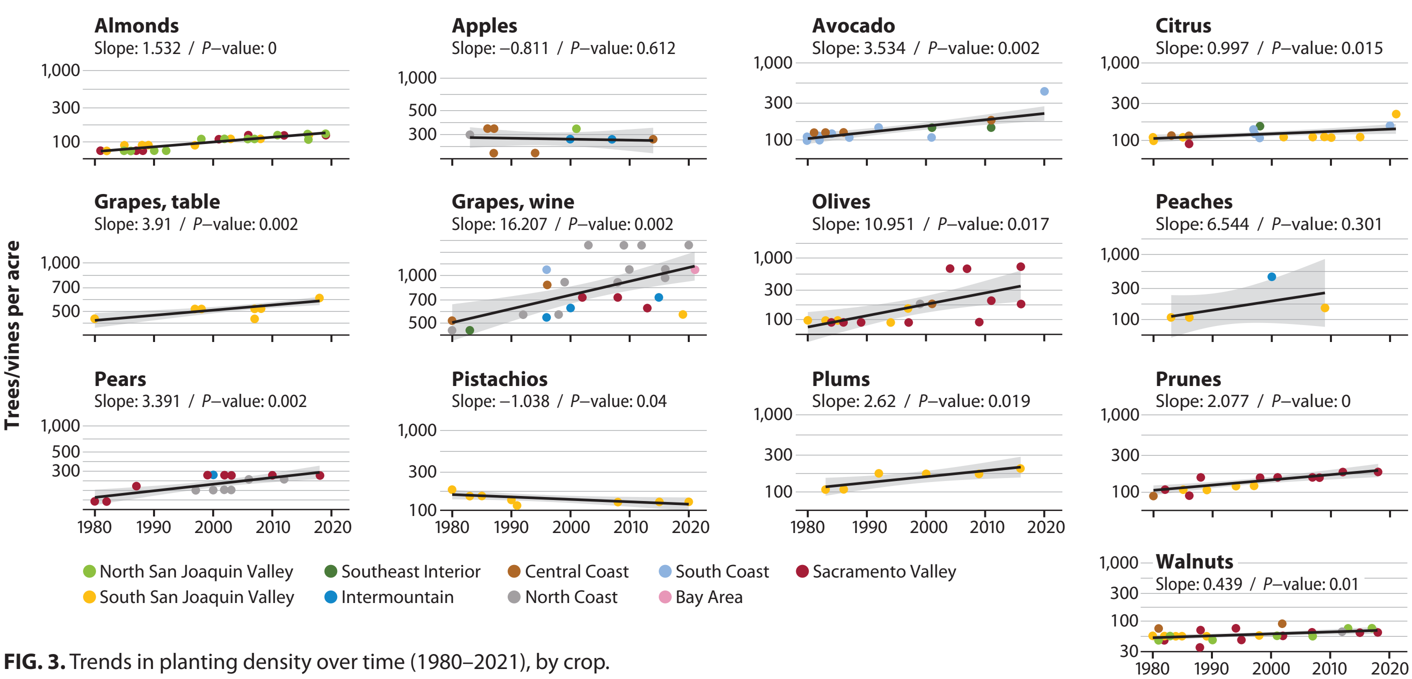

FIG. 3. Trends in planting density over time (1980–2021), by crop.

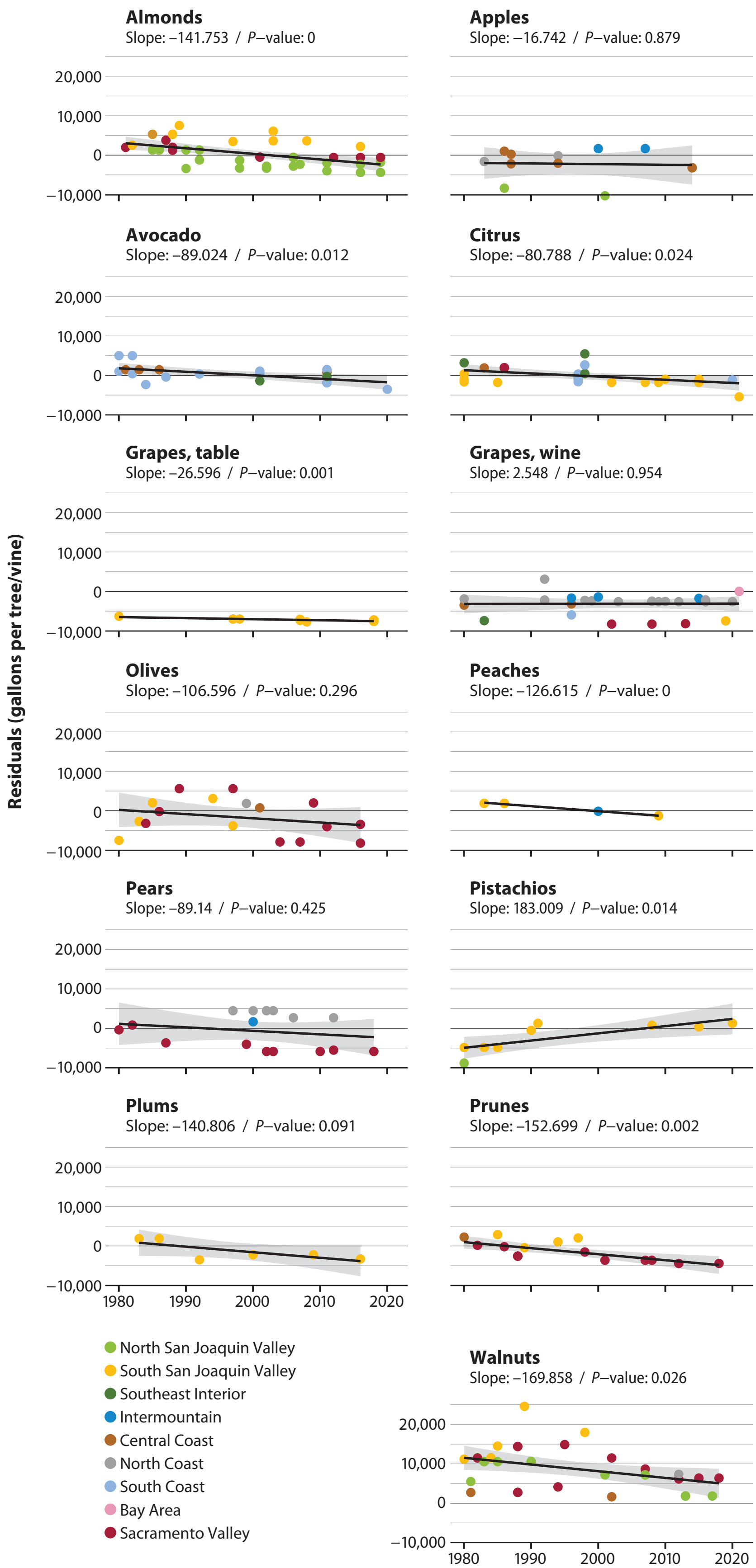

FIG. 4. Trends in irrigation water applied per tree/vine over time (1980–2021), by crop, after residualizing on region-specific fixed effects.

Given that most perennial crops have increased the number of trees or vines planted per acre, it is valuable to consider how much water applied per tree or vine has changed. Similar to figure 2, after accounting for the region-specific averages, the residuals in water applied per tree are plotted, with trendlines, slope coefficients, and *P*-values (fig. 4). The results show that water applied per tree has remained unchanged or diminished over time for many crops, including almonds, avocados, citrus, table grapes, peaches, prunes, and walnuts. Pistachios are the only crop that shows an increase in water use per tree. This result is expected, because pistachios were the only crop that showed a significant decline in trees per acre while increasing water use per acre. Similarly, we expected to see a decline in water use per vine for table grapes, as water applied per acre declined while planting density increased.

For other crops, these results provide a more complete description of changes in water usage when combined with the results in figure 2. For example, water usage per acre has increased over time for almonds; however, when considering the increase in the number of almond trees planted per acre, water applied per tree for almonds has actually declined. For other crops, including avocados, citrus, pears, prunes, and walnuts, the decrease in water applied per tree is due to an increase in planting density, rather than declines in water use per acre.

Water use relative to yield

It is also useful to consider changes in yield during this period. Over time, new varieties appear that are able to produce higher yields. It is important to test whether these increases in yield require changes in water use per acre. Avocados, table grapes, olives, plums, and walnuts all show increases in the yield per acre over time, while the remaining crops have remained relatively stable since 1980. Pears and apples exhibit negative yield trends, but these are not statistically significant, and the confidence intervals are large (fig. 5).

Both the trends in yields and water applied per acre present a challenge to discovering a discernable trend over time. However, when the trend in water applied per acre is analyzed, a clear trend appears. Similar to the results for water applied per plant, water applied per unit of yield has either decreased or remained about the same over time. Almonds, grapes, and walnuts all show a slight decrease in the amount of water applied per ton harvested. This indicates that producers are using water efficiently, by maintaining or increasing output under the same quantity of water.

Less water per tree or vine

The study of water use in perennial crops is of substantial importance for California agriculture. Perennial crops make up 60% of California's irrigated

FIG. 5. Trends in crop yields over time, 1980–2021.

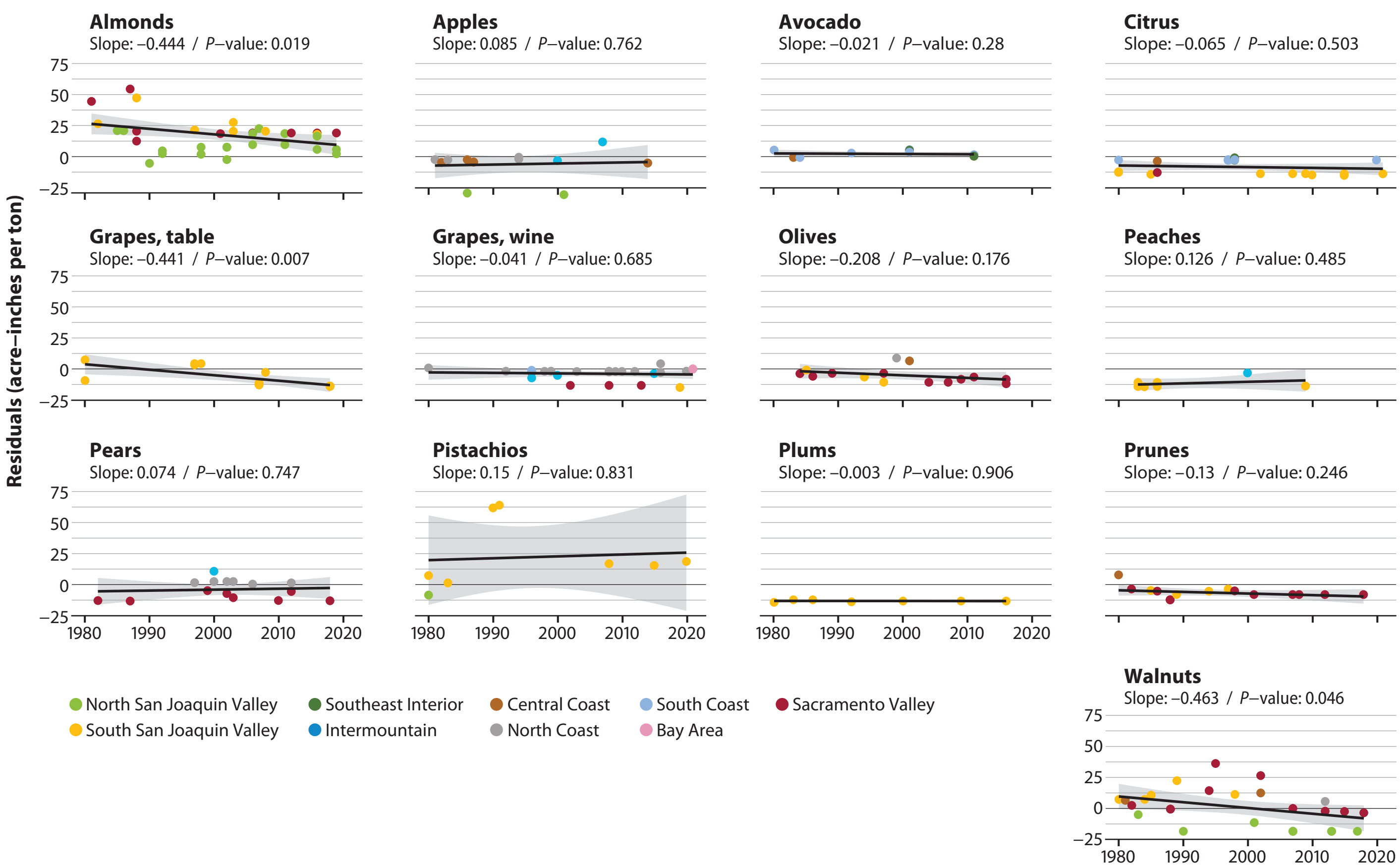

FIG. 6. Trends in irrigation water applied per ton of production over time (1980–2021), after residualizing on region-specific fixed effects, by crop.

land area, and approximately 80% of the state's agricultural revenue (Mall and Herman 2019). However, these crops use a substantial amount of water resources. Understanding how these patterns may or may not have shifted over time is crucial for future water management planning. Policymakers may be able to use such information in their decision-making framework when developing water policy. Using University of California Sample Cost of Production studies, we find that water use per acre for perennial crops has increased on average for nut crops and decreased for table grapes. However, once we consider planting density, which has increased or remained unchanged for most perennial crops during our sample period, the quantity of irrigation water applied per tree or vine has diminished in most crops, aside from pistachios.

As planting density has increased, it is likely that yield has also changed during this time. Therefore, we also examined whether changes in yields play a role in the results. Yields have increased for almonds, table grapes, olives, plums, and walnuts, and have remained stable for most other crops. We find evidence that irrigation water applied per ton has decreased for almonds, table grapes, and walnuts. From our analysis, it seems likely that the decreases in water applied per ton come from increases in yield for table grapes, as well as a combination of increased yield and reductions in the amount of water applied per tree for almonds and walnuts. It is possible that improvements stem from improved cultivars, allowing for increased yield with the same water use. For example, in the studies for walnuts, we see movement over time toward the planting of Chandler walnut trees and other late-leafing varieties.

We note that these results look at broad trends in agricultural water use. We look to see whether average irrigated water use is increasing or decreasing over time across California. What we cannot examine is whether one region is strongly decreasing its water use relative to another. This is due to our limited sample size in each region (see table 1), since cost of production studies are designed to represent an average grower rather than many individual studies and are completed every few years. Table 1, however, reports differences in average water use across regions, to provide some background for the regional variation.

This analysis provides important context for considering the "water footprint" of high-value agricultural crops produced in California. We see evidence that water use per tree or unit of yield is declining for many crops over time, and we work to disentangle possible mechanisms for these results. However, further questions remain. This analysis is on a field-level basis and does not consider aggregate water use (or changes in land use). It would also be interesting to evaluate how the amount of irrigation water applied has shifted with the type of irrigation system used. Our data are rather rudimentary on this front, but it would provide valuable insight to the currently thin literature on the subject. In sum, we hope to provide insight on how trends in irrigation water use have shifted over the past 40 years, and how this may continue in the future. CA

M. Sears is Assistant Professor in the Department of Agricultural, Food, and Resource Economics at Michigan State University; K. Jetter is Research Economist, UC Agriculture and Natural Resources; E. Takele is Area Farm Management Advisor, University of California Cooperative Extension, San Bernadino County.

The study was funded by a grant from the University of California Agriculture and Natural Resources. The authors wish to thank Ellen Bruno, Gail Feenstra, Mehdi Nemati, Richard Snyder, and Doug Parker for their comments and discussions. All opinions are those of the authors.

References

Evenson RE, Mwabu G. 2002. The effect of agricultural extension on farm yields in Kenya. Afr Dev Rev 13(1):1–23. https://doi.org/10.1111/1467-8268.00028

Fuller BW. 2009. Surprising cooperation despite apparently irreconcilable differences: Agricultural water use efficiency and CALFED. Environ Sci Policy 12(6):663–73. https://doi.org/10.1016/j.envsci.2009.03.004

Mall NK, Herman JD. 2019. Water shortage risks from perennial crop expansion in California's Central Valley. Environ Res Lett 14(10):104014. https://doi.org/10.1088/1748-9326/ab4035

Mount J, Hanak E, Petersen C. 2023. Water Use in California. Fact Sheet April 2023. Public Policy Institute of California. www.ppic.org/wp-content/uploads/jtf-water-use.pdf (accessed Oct. 23, 2023).

Pfeiffer L, Lin C-Y C. 2014. Does efficient irrigation technology lead to reduced groundwater extraction? Empirical evidence. J Environ Econ Manag 67(2):189–208. https://doi.org/10.1016/j.jeem.2013.12.002

Taylor R, Zilberman D. 2017. Diffusion of drip irrigation: The case of California. Appl Econ Perspect P 39(1):16–40. https://doi.org/10.1093/aepp/ppw026

Tindula GN, Orang MN, Snyder RL. 2013. Survey of irrigation methods in California in 2010. J Irrig Drain Eng 139(3):233–8. https://doi.org/10.1061/(ASCE)IR.1943-4774.0000538

[UCCE] University of California Agriculture and Natural Resources Cooperative Extension. University of California Sample Cost of Production Studies. 1980–2020. https://coststudies.ucdavis.edu/archived/commodities

Ward FA, Pulido-Velazquez M. 2008. Water conservation in irrigation can increase water use. P Natl Acad Sci USA 105(47):18215–20. https://doi.org/10.1073/pnas.0805554105

Williams AP, Cook BI, Smerdon, JE. 2022. Rapid intensification of the emerging southwestern North American megadrought in 2020–2021. Nat Clim Change 12:232–4. https://doi.org/10.1038/s41558-022-01290-z