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# The Financial Viability and Broader Benefits of SGMA-Ready Crops

## Technical Appendices

### CONTENTS

**Appendix A. Carbon Benefits of SGMA-Ready Crops**

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**Appendix B. Particulate Matter from Fallowed and Cropped Lands**

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# Appendix A. Carbon Benefits of SGMA-Ready Crops

## Introduction

This technical appendix evaluates the potential for SGMA-ready crops, and specifically water-limited winter forages, to mitigate the greenhouse gas (GHG) emission impacts of widespread fallowing. An estimated 500–900,000 acres of irrigated cropland will come out of production by 2040 in the San Joaquin Valley due to water supply reductions, primarily driven by groundwater cutbacks under the Sustainable Groundwater Management Act (SGMA; Hanak et al. 2019, Escriva-Bou et al. 2023). Cropland fallowing could have numerous economic, public health, and soil health impacts, and cost anywhere from $12–80 million annually for ongoing maintenance to reduce weeds and dust emissions (Ayres et al. 2022). Transitioning water-limited lands to alternative uses can reduce these impacts. SGMA-ready cropping systems that emphasize winter production and minimal irrigation could be particularly helpful to generate some profit from croplands that would otherwise go fallow, while also reducing soil degradation and dust impacts (Peterson et al. 2022).

In the accompanying policy brief "Economics of Winter Forage as an SGMA Adaptation Strategy," we describe how winter forage crops managed with best practices for water-limited conditions can be profitable in wetter parts of the San Joaquin Valley and in wetter years but may require public support for broader adoption. These include ecosystem services programs that pay growers for the benefits crops provide relative to leaving the land fallow—such as carbon capture or GHG emissions reduction. Our findings may inform California Department of Food and Agriculture (CDFA) and United States Department of Agriculture (USDA) decisions about how to structure incentives for SGMA-ready cropping practices.

## California's natural and working lands are both a source of and a sink for greenhouse gases

Efforts to reduce GHG emissions and sequester more carbon in the state's croplands have significant overlap with land transitions occurring due to reduced availability of irrigation water. California croplands store an estimated 277 million metric tons of carbon, or about 6 percent of the state's total natural and working lands carbon stock. Of the carbon stored in croplands, about three-quarters is in the soil, while the remaining quarter is in biomass such as orchards (CARB 2025).

While croplands provide a natural service by keeping carbon locked up in the soil and biomass, these carbon stocks are not stable—croplands also emit GHGs such as carbon dioxide ($CO_2$) and nitrous oxide ($N_2O$). An estimated 6–8 million metric tons of carbon dioxide equivalent (or $CO_2$eq, a unit that standardizes the warming effect of different gases) are emitted from California's croplands each year (Petek 2021, USDA California Climate Hub n.d.). This is about 22 percent of the agricultural sector's annual GHG emissions (CARB 2022).

GHG emissions and soil carbon storage can be impacted by crop management practices. Research indicates that one particularly relevant practice—cover cropping—could sequester 0.25–0.75 tons $CO_2$eq per acre per year (Tautges et al. 2019; Mitchell et al. 2024; Di Vittorio et al. 2024; though see Chaplot and Smith 2023 for a more conservative estimate). The California Air Resources Board (CARB) estimates that the agriculture sector could avoid emitting about five million metric tons of $CO_2$eq from annual croplands by 2045 by implementing a mix of soil- and climate-friendly practices (CARB 2022). The state has also set several related goals, including increasing use of healthy soils practices to 80,000 acres annually by 2025 (CARB 2022). As of April 2026, CDFA reports that more than 190,000 acres of California farmland and ranchland are now implementing new healthy soils practices through state program support (CDFA n.d.).

## State and federal incentives and voluntary markets could support climate-friendly management practices

One potential avenue for facilitating transitions to SGMA-ready cropping systems includes payments for ecosystem services—such as sequestering carbon in soils or avoiding GHG emissions from fallowed lands. Existing state and federal programs pay growers for using soil- and climate-friendly management practices; selling carbon offsets on voluntary carbon marketplaces can also bring in revenue for growers who generate soil carbon credits. We examine three public programs and voluntary soil carbon markets in this appendix:

- **CDFA's Healthy Soils Program (HSP).** The HSP offers fixed payments for each acre on which participating growers implement eligible practices that improve soil health and reduce greenhouse gas emissions. With an HSP grant, growers can receive payment for up to three years per enrolled acre (CDFA 2024). However, incentive grant funding has not been available since February 2024.
- **USDA Environmental Quality Incentives Program (EQIP) and Conservation Stewardship Program (CSP).** The USDA Natural Resources Conservation Service's EQIP and CSP work in tandem: EQIP supports adoption of new land management practices with large, short-term payments, while CSP supports sustained management through smaller, longer-term incentives. These federal programs also offer fixed payments per acre for eligible practices and, unlike the HSP, have no restrictions on the number of contract renewals. A typical arrangement involves five-year contracts, the first year of which is an EQIP contract with subsequent contracts under the CSP (USDA n.d.a; USDA n.d.b).
- **Voluntary soil carbon markets.** In voluntary markets, buyers pay sellers who sequester carbon or reduce on-farm GHG emissions to offset their own GHG emissions. Growers participating in these markets receive payments based on the estimated amount of GHG emissions they avoid or carbon they sequester (EDF and BCG 2024). These markets are distinct from compliance markets, such as California's Cap-and-Invest Program. Voluntary soil carbon markets have gained the most traction in other states in the Midwest and Great Plains regions. However, they are starting to become available in California. Carbon by Indigo and Eco-Harvest are two of the available offerings (Indigo Ag n.d., ESMC n.d.).[1]

However, there are common concerns across these programs.

- **Benefit verification.** It is challenging to ensure that growers are only paid for verified benefits. In the case of sequestered carbon, it is difficult to estimate how much carbon has been removed from the atmosphere and stored in soil at the field level. Even with accurate estimates of sequestration, evidence suggests that most sequestered carbon stays in the top of the soil profile, where it may readily be re-emitted to the atmosphere (Tautges et al. 2019). In the case of avoided emissions, it is even more difficult to estimate the counterfactual—what GHG emissions would have been emitted from the land if the alternative management practices had not been implemented.
- **Support for SGMA-ready crops.** HSP and EQIP/CSP were not designed to support changes in management practices that evolve under SGMA, and it is unclear whether water-limited crops would be eligible to receive program funding. Similarly, voluntary soil carbon markets have not developed methodologies to generate credits for water-limited systems.

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[1] There are no limitations on the number of years for which growers can sell credits in these programs. A key advantage of these markets is that they are not subject to the uncertainties of state and federal budgets, but there must be willing buyers of the carbon credits generated.

## We estimate GHG balances and benefits for land fallowing and water-limited forage crop scenarios

To estimate GHG balance outcomes for agricultural land use scenarios, we first present estimates of cropland GHG balances for six baseline crops and three future management scenarios. The scenarios include continued business-as-usual management of the baseline crops, bare soil fallow, and winter wheat forage with limited irrigation. Next, we summarize the potential range of GHG benefits provided by implementing water-limited crop management relative to fallowing, including both carbon sequestered in soil and avoided GHG emissions. We evaluate the potential payoff growers could receive for implementing water-limited crops from state, federal, and private programs. And finally, we assess the impact of fallowing SJV croplands on California's ability to meet agricultural sector GHG emission goals, as well as the potential for water-limited crops to help meet these goals. Together, these analyses provide actionable information for agencies interested in incentivizing grower adoption of these practices.

# Cropland Greenhouse Gas Balances

To better understand how land use transitions in the San Joaquin Valley could impact agricultural sector GHG emissions and soil carbon sequestration, we modeled agricultural land use scenarios using COMET-Farm, a GHG accounting and decision support tool (Paustian et al. 2017). COMET-Farm estimates how a change in management practice would alter cropland GHG balances—i.e., quantities of $CO_2$ or $N_2O$ emitted or soil carbon stored relative to business-as-usual management.[2] The model uses soil and climate parameters along with information on crop yields, tillage, fertilizer inputs, and irrigation for a given site to estimate a dynamic baseline of GHG emissions for 10 years of historical management. It then estimates changes in GHG emissions relative to the baseline for 10 subsequent years, comparing outcomes either for business-as-usual management or specified changes in management practices.

### Baseline crop, model site, and future scenario selection

COMET-Farm assumes that prior land use affects GHG emissions even after a change in management occurs. For example, fallowed land that was formerly planted with an almond orchard may have a different GHG balance than a nearby field with the same soil and climate characteristics that was formerly planted with an annual crop. We therefore modeled potential GHG balances for a range of baseline crops. We also selected four model sites representative of different soil and climate types across the valley.

**Baseline crops.** We estimated GHG balances for a range of typical San Joaquin Valley crops, including both annual and perennial crops. The criteria we used to select our baseline crops included crop class prevalence by acreage across the San Joaquin Valley and expected fallowed acreage by 2040 in each crop class. Based on these criteria, we selected almonds, wine grapes, winter wheat, alfalfa, processing tomatoes, and corn silage as our baseline crops. COMET-Farm requires planting and harvest, irrigation, fertilizer, and tillage inputs for each baseline crop (Table A1).[3] We used typical San Joaquin Valley management approaches for each baseline crop—summarized in Table A1—to generate baseline emissions profiles.

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[2] Methane emissions are also modelled by COMET-Farm but are primarily applicable to rice production systems.

[3] Based on sensitivity analysis, we assumed that tillage intensity has the largest impact on GHG balances. This is consistent with prior COMET-Farm sensitivity analysis (Watnick 2020).

**TABLE A1**

COMET-Farm annual inputs and assumptions for baseline crops

| Crop | Planting/Harvest | Irrigation | Fertilizer | Tillage and Field Operations | Source(s) |
|---|---|---|---|---|---|
| Alfalfa | ▪ Semi-perennial crop grown in four-year cycles<br>▪ Planting occurs in early October every four years<br>▪ Seven cuttings/year monthly from mid-April to mid-October, each ~1.14 tons/acre | ▪ 8 inches of irrigation applied the day after planting<br>▪ 64 additional inches in ten applications from April to October | ▪ Applied pre-planting in establishment years and one month after last cutting in production years<br>▪ 22 lbs. N/acre MAP (11-55-00) per application | ▪ Intensive tillage immediately prior to each planting | ▪ Clark et al. 2016 |
| Almonds | ▪ Perennial crop with a 23-year life span<br>▪ First 5 years establishment, followed by 18 years production | ▪ Production years: 6 inches in early January<br>▪ ~46 additional inches in weekly applications from mid-March to mid-October | ▪ Production years: three APP (10-34-00) applications at 2.6 lbs. N/acre in mid-Feb, mid-Apr, mid-June<br>▪ Five UAN (32-00-00) applications at 50 lbs. N/acre monthly from mid-March to mid-July | ▪ Tillage only in the renewal year<br>▪ Intensive tillage on November 1 of the renewal year | ▪ Haviland et al. 2019 |
| Corn silage | ▪ Planting in mid-May<br>▪ Harvest in mid-September<br>▪ 32 tons/acre yield | ▪ 8 inches pre-planting in mid-April<br>▪ 8 inches weekly to every other week from mid-April to mid-June | ▪ 3 tons/acre manure 2–3 weeks before planting<br>▪ 20 lbs. N/acre APP (10-34-00) day after planting<br>▪ 50 lbs. N/acre UAN (32-00-00) in mid-June, early July, late July | ▪ Intensive tillage pre-planting | ▪ Mitchell et al. 2015<br>▪ Wright, Klonsky, and Stewart 2015 |
| Wine grapes | ▪ Planting on January 1 of year 1<br>▪ Production in year 4+<br>▪ 25-year life span | ▪ 35 inches across 7 monthly irrigations, mid-April to mid-October (production years only) | ▪ Production years: 22.5 lbs. N/acre liquid urea (20-00-00) in mid-April and mid-June irrigations | ▪ Intensive tillage day prior to vineyard establishment<br>▪ Mowed in March, April, June, and October | ▪ Zhuang et al. 2019 |
| Processing tomatoes | ▪ Planting in mid-April<br>▪ Harvest in mid-August | ▪ 36.5 inches in 24 irrigations<br>▪ Weekly irrigations from April to August | ▪ 9 fertilizer applications throughout the year<br>▪ One UAN (32-00-00) at 20 lbs. N/acre 2 months before planting<br>▪ Eight UAN applications at 30.5 lbs. N/acre every four days, mid-May to mid-June | ▪ Intensive tillage day prior to planting each year | ▪ Turini et al. 2018 |
| Wheat | ▪ Planting in late November<br>▪ Harvest in mid-June<br>▪ 130 bu/acre yield; 80% dry matter removal | ▪ 20 inches in five irrigations<br>▪ Irrigations in mid-January, mid-March, early and late April, and mid-May | ▪ One application in mid-January, a few days after the first irrigation<br>▪ Urea (46-00-00) at 120 lbs. N/acre | ▪ Reduced tillage day prior to each planting | ▪ Wright et al. 2013a |

**Model sites.** We selected four model sites to represent the range of soil textures and climates found throughout the valley, including a dry site with coarse soils, a dry site with fine soils, a wet site with coarse soils, and a wet site with fine soils. Dry site precipitation was near the 5th percentile average annual precipitation value for the San Joaquin Valley, between 4.8 and 5.8 inches per year. Wet site precipitation was near the 65th percentile, between 15.0 and 19.0 inches per year. Coarse soil sites had soils classified as sandy loam, while fine soil sites had soils classified as clay. We used the 65th percentile precipitation value because there were no overlaps of clay soils with areas that have average annual precipitation values above the 65th percentile. This range of climate and soil conditions allowed us to assess which types of sites may be more likely to generate GHG benefits from implementing water-limited crops.

**Future scenarios.** We used COMET-Farm to model three different future management scenarios to evaluate their impact on cropland GHG balances. As with the baseline crop parameters, we assumed typical San Joaquin Valley practices for most management variables (Table A2).

- **Business-as-usual.** This scenario assumes no changes to cropping practices for the coming decade. The same crop is continued on the same planting and harvest cycle, with the same amount of irrigation and other inputs.
- **Managed fallow.** This scenario assumes that the land is fallowed—no crops are grown on that land and no irrigation water is applied. However, we assume twice-annual tillage of moderate intensity to manage weeds.
- **Water-limited forage.** This scenario assumes that instead of fallowing, the prior crop is replaced by winter wheat grown with limited irrigation. One four-inch irrigation application is used to aid crop establishment each fall. The crop is harvested in the spring as a forage product.

**TABLE A2**

COMET-Farm inputs and assumptions for future management scenarios

| Crop | Plant/Harvest | Irrigation | Fertilizer | Tillage and Field Operations | Source(s) |
|---|---|---|---|---|---|
| Water-limited forage | ▪ Planting in late November<br>▪ Harvest in early May<br>▪ 80% of the dry matter is removed at harvest<br>▪ Remaining residues on the soil surface to prevent erosion | ▪ 4 inches in late November | ▪ 11 pounds N per acre MAP (11-55-00) in late November pre-planting<br>▪ 70 pounds N per acre as urea (46-00-00) in late January | ▪ Intensive tillage occurs the day before planting each year | ▪ Wright et al. 2013b<br>▪ Campbell-Mathews et al. 2004 |
| Managed fallow | ▪ None | ▪ None | ▪ None | ▪ Two moderate-intensity tillage events per year, in early March and early October | ▪ UC ANR n.d. |

## Cropland GHG balances for selected sites and baseline crops

Fallowed land emitted more GHGs than land planted with water-limited forage regardless of the prior crop or field location (Figure A1).[4] Estimated GHG emissions from fallowed land ranged from 0.25 to 1.32 metric tons $CO_2$eq per acre per year—primarily from lost soil carbon related to tillage.

Compared to fallowed land, water-limited forage crops kept carbon in the ground and in some cases sequestered additional carbon. These crops sequestered a maximum of 0.5 metric tons $CO_2$eq per acre per year, before

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[4] There are interaction effects between baseline crop, soil type, and climate in terms of their effect on GHG balance after the change in management. We present selected site and baseline crop combinations to demonstrate the breadth of possible outcomes.

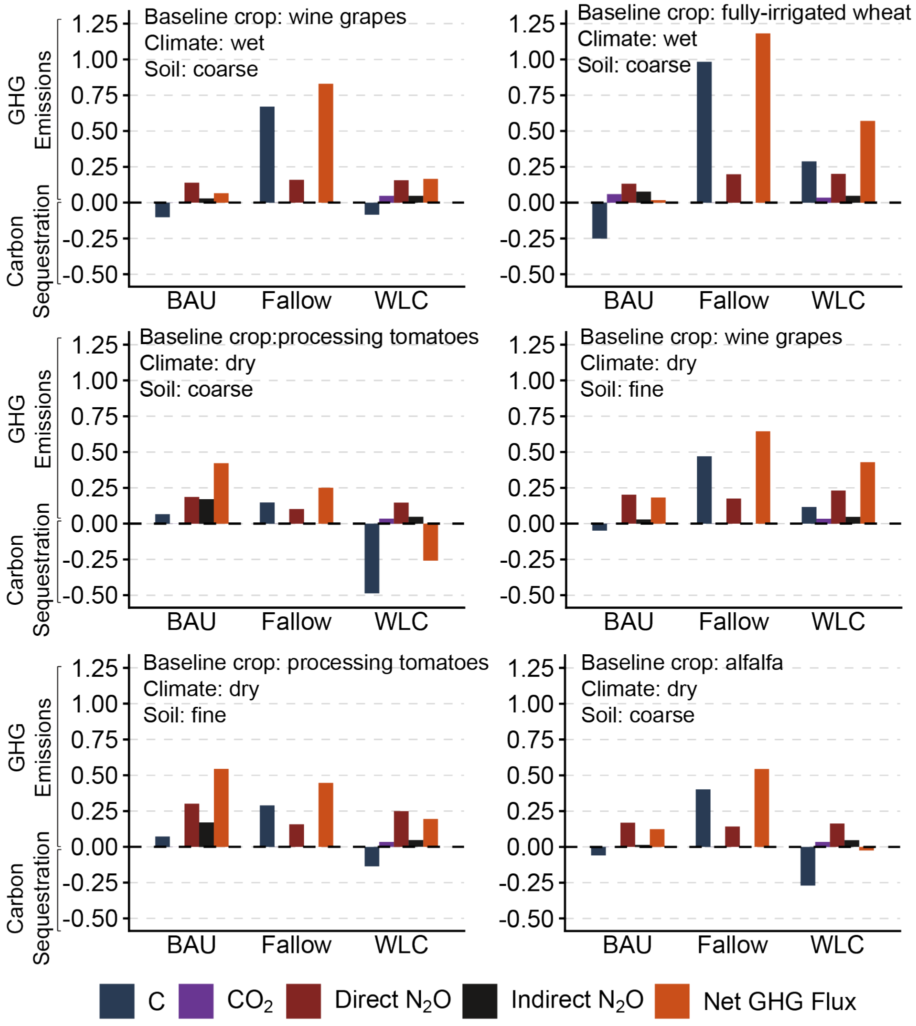
considering emissions from applied fertilizer (Figure A1). Fertilizer applications for winter forages resulted in some $N_2O$ emissions that did not occur on fallowed lands—about 0.4 metric tons $CO_2$eq per acre per year at most.

Other research has estimated carbon sequestration benefits of cover crops—an analogous cropping system to winter wheat forage—ranging from 0.25 to 0.75 metric tons per acre per year (Tautges et al. 2019, Mitchell et al. 2024, Di Vittorio et al. 2024). The larger sequestration values in this range assume minimal to no tillage is used and sufficient quantities of nitrogen fertilizer are applied.

**FIGURE A1**

Water-limited forages emit GHGs, but less than fallowed land

Metric tons $CO_2$eq per acre per year



SOURCE: Author estimates using COMET-Farm (GHG emissions).

NOTES: Each plot represents a unique combination of baseline crop (the crop that is assumed to be currently grown on the land with full irrigation), climate (dry is 5th percentile and wet is 65th percentile annual precipitation for the San Joaquin Valley), and soil texture (fine is clay and coarse is sandy loam). Shown here are six of the 24 modeled combinations that capture the range of carbon benefits provided by water-limited forages relative to fallow. $CO_2$eq is shorthand for carbon dioxide equivalent, a standard unit used to compare different types of GHG emissions. Positive values on the y-axis indicate GHG emissions. Negative values on the y-axis indicate carbon sequestration. BAU is business-as-usual, or the continuation of current cropping practices for the next decade. Fallow assumes a shift from current practices to a managed fallow, with twice-annual moderate intensity tillage. WLC is water-limited cropping, which assumes a shift from current practices to a winter forage crop grown with four total inches of irrigation per acre per year. C represents changes in the organic carbon content of the top 30cm of the soil profile, $CO_2$ emissions are from urea fertilizer application, direct $N_2O$ is nitrous oxide emissions from fertilizer that enter the atmosphere directly from the field, and indirect $N_2O$ includes nitrous oxide emissions that occur off the field from volatilization and leaching/runoff processes. The net GHG flux category is the sum of these four fluxes.

## GHG Benefits of Water-Limited Cropping

There are two different types of GHG benefit from implementing a water-limited forage system instead of fallowing. The first benefit is sequestration—the net amount of carbon that moves from the atmosphere to the soil. Sequestration benefit is the negative portion of the net GHG flux bars shown in Figure A1. Water-limited forage systems could also help *avoid* GHG emissions that would otherwise occur if the land is fallowed. These avoided emissions are the difference between fallow and water-limited forage scenario net GHG fluxes. The state, federal, and private programs we evaluated each pay growers for avoided GHG emissions in addition to sequestered carbon.

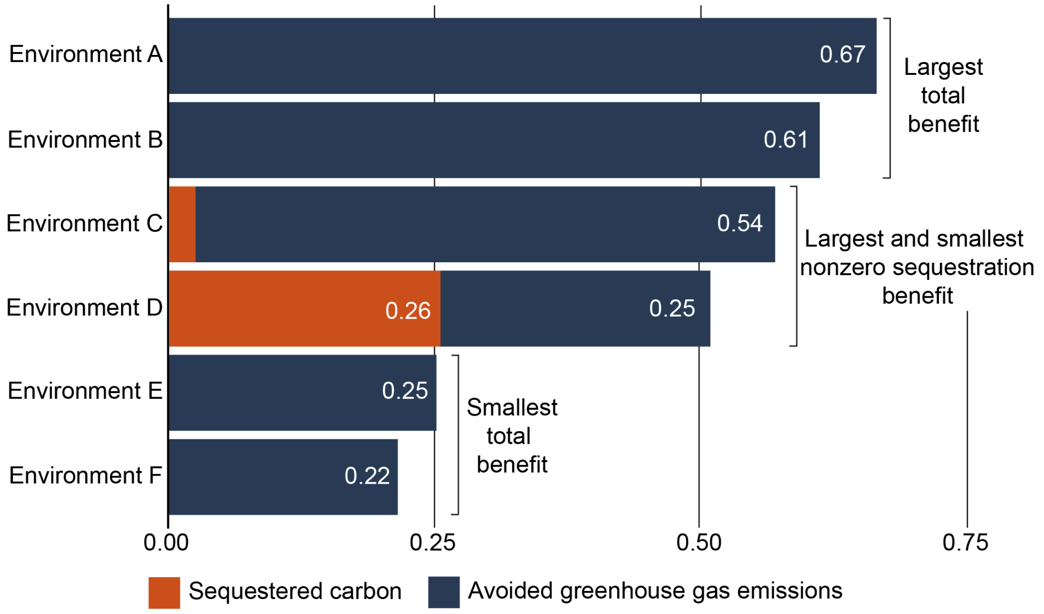
Water-limited forages offered some GHG benefit compared to fallowed land regardless of field location, prior crop, and water availability. The total GHG benefit—including both sequestered carbon and avoided GHG emissions—ranged from 0.2 to 0.7 metric tons $CO_2$eq per acre per year (Figure A2). Water-limited forages mostly provided avoided emissions benefits, with sequestration benefits occurring only under certain conditions. The maximum sequestration benefit, after considering emissions from applied fertilizer, was about 0.26 metric tons $CO_2$eq per acre per year.

Climate was a key factor influencing GHG benefits from water-limited forages; the most substantial benefits occurred in fields in wetter parts of the San Joaquin Valley. Fields that were formerly planted with fully irrigated wheat, corn, or alfalfa also generated larger benefits than fields previously planted with other baseline crops. While most GHG benefits were in the form of avoided emissions, we found that sequestration benefits occurred in a few instances, such as when the prior crop was processing tomatoes or alfalfa.

**FIGURE A2**

Water-limited crops emit fewer GHGs than fallowed land, but do not remove much carbon from the atmosphere

Metric tons $CO_2$eq per acre per year



SOURCE: Author estimates from COMET-Farm (GHG emissions).

NOTES: Carbon benefit is expressed as carbon sequestration + avoided GHG emissions (metric tons $CO_2$eq per acre per year). Avoided emissions represent the difference in net GHG flux between the water-limited forage and fallow scenarios. We modeled 24 baseline crop-soil-climate combinations; here we show a subset of results that demonstrate the range of benefit values. Environment A is wine grape baseline crop, coarse soils, and wet climate; B is fully irrigated wheat, coarse soils, wet climate; C is alfalfa, coarse soils, dry climate; D is processing tomatoes, coarse soils, dry climate; E is processing tomatoes, fine soils, dry climate; F is wine grapes, fine soils, dry climate.

## Potential Grower Earnings for Carbon Benefits

Voluntary soil carbon markets, state, and federal programs differ in several respects, including payment structure, current availability in California, payment duration, quality of carbon benefits, reliability for growers, and dependence on the state budget. We evaluated how much growers could expect to earn from each of these programs for the carbon benefits they generate. We considered carbon revenue alongside expected forage product revenue to see if carbon payments could improve profitability. To standardize incentive payments across programs, we analyzed grower revenues per acre averaged across a 10-year period. This matches the duration of potential payments from USDA programs.

We found that growers could earn \$3–37 per acre per year for carbon benefits, depending on the program. Including these revenues with crop revenues estimated in the accompanying policy brief (Franklin et al. 2026), growers could earn up to \$179 per acre per year with 4 inches of supplemental irrigation in wet years. But they could lose as much as \$263 per acre in dry years depending on local conditions. Figure A3 shows how the best- and worst-case returns vary based on the incentive program.

**CDFA HSP could pay about \$37 per acre.** The HSP pays growers a predetermined amount per acre for implementing eligible NRCS conservation practices. We used the HSP cover crop payment rate from the 2024 incentive grant solicitation as a proxy for water-limited forage. The cover crop payment rate is \$120 per acre for 3-year contracts under this program (CDFA 2024).[5]

**USDA NRCS EQIP and CSP could pay about \$36 per acre.** These NRCS programs pay growers a predetermined amount per acre for implementing NRCS conservation practices, similar to the HSP. We also used cover crops as a proxy for water-limited forage when determining potential payments from this program. Growers could earn about \$63 per acre per year for a 5-year EQIP contract, then about \$8 per acre per year for subsequent 5-year CSP contracts (USDA n.d.c, USDA n.d.d).

**Voluntary soil carbon markets, if available in California, would offer less than state and federal programs.** In contrast to practice-based state and federal programs, voluntary markets typically pay based on outcomes—or estimated metric tons of carbon benefit. Based on the current literature, we assumed growers could earn \$15 per metric ton $CO_2$eq from selling credits on a voluntary soil carbon market (Plastina, Jo, and Wongpiyabovorn 2024; Procton 2025). We found that growers could earn \$3–10 per acre based on this payment rate and a total carbon benefit range of 0.20–0.70 metric tons $CO_2$eq per acre per year.

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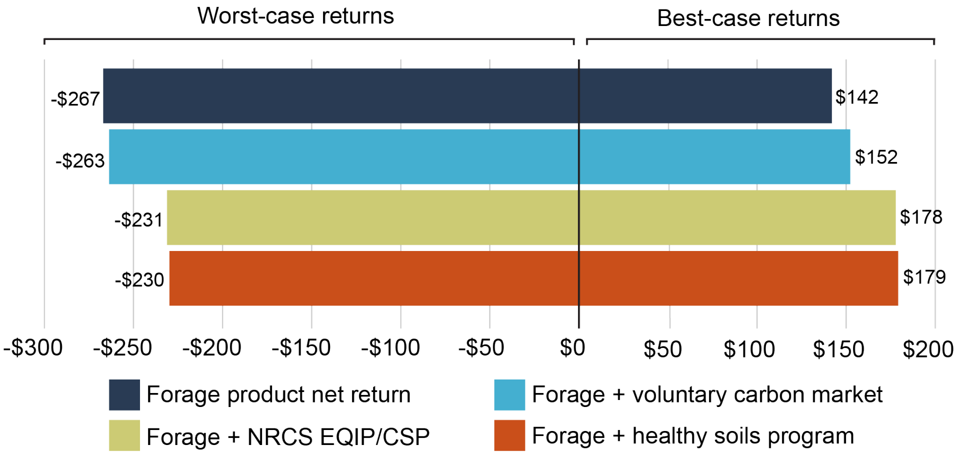
[5] Previous HSP applicants are eligible to re-apply for funding in future grant cycles, but not for the same practice on the same field.

**FIGURE A3**

Growers could earn a profit selling water-limited forage in wet years, but revenue from GHG benefits would do little to help in dry years



SOURCES: USDA (n.d.c) and USDA (n.d.d) for EQIP and CSP payment rates. CDFA (2024) for HSP payment rates. Procton (2025) and Plastina, Jo, and Wongpiyabovorn (2024) for voluntary soil carbon market payment rates. Franklin et al. (2026) for forage product net returns.

NOTES: Payment rates for GHG benefits are based on contract totals distributed across 10 years for consistency across payment timeframes. Healthy Soils, EQIP, and CSP provide payments for a range of NRCS conservation practices. We selected cover cropping as the closest equivalent to water-limited forage production. We assume growers are paid at the EQIP payment rates ($63.69 per acre per year in FY2025 for a basic cover crop) for their first 5-year contract, then at the CSP payment rates ($8.19 per acre per year in FY2025 for a basic cover crop) for a second. We assume that $15 per metric ton $CO_2$eq is the price growers could expect to receive for carbon credits from growing water-limited crops. We multiplied this price by metric tons of total benefit—including both sequestration and avoided emissions—that we estimated using COMET-Farm to get voluntary market payment rates over a 10-year contract period. The best-case returns assume higher average yields in wet year conditions. The worst-case returns assume lower average yields in dry year conditions. Assumptions about costs of inputs and commodity price for forage are the same for both best- and worst-case return scenarios.

## Fallowed land's impact on statewide GHG emission goals

The agricultural sector plays an important role in California's carbon neutrality goals. Several related goals exist for GHG emission reductions from croplands and the agricultural sector:

- The 2022 Natural and Working Lands Climate Smart Strategy lays out a goal to sequester or reduce 15–20 million metric tons $CO_2$eq through land management by 2030 (CNRA 2022).
- CARB's 2022 Scoping Plan for Achieving Carbon Neutrality aims to avoid about five million metric tons $CO_2$eq from annual croplands by 2045 (CARB 2022).
- CDFA's Climate Resilience Strategy for California Agriculture aims to implement healthy soils practices on 3.4 million acres of croplands (CDFA 2026).
- A coalition of environmental groups recommended a carbon neutrality goal for the agricultural sector by 2030, which would involve eliminating or offsetting the sector's approximately 32 million metric tons $CO_2$eq of annual GHG emissions (Healthy Soils Roadmap 2019; CARB 2022).

To estimate valley-wide cropland GHG emissions, we used results from our model setup for the six baseline crops detailed in Table A1 to represent emissions profiles from crops in the same crop family (e.g., deciduous orchard crops were assigned the same emissions profile as the almond baseline crop; truck crops were assigned the same emissions as the processing tomato baseline; Figure A4). This gives us a rough estimate of 1 million metric tons $CO_2$eq per acre per year from San Joaquin Valley croplands—less than half of statewide cropland GHG emissions (6-8 million metric tons $CO_2$eq per acre per year; Petek 2021; USDA California Climate Hub n.d.).

Our estimate of cropland emissions relies on simplifying assumptions about crop type, crop management, and local climate and soil conditions. Given that about half of California's irrigated croplands are located in the San Joaquin Valley, we likely underestimate actual valley-wide cropland emissions (Cole, Hanak, and Peterson 2024).

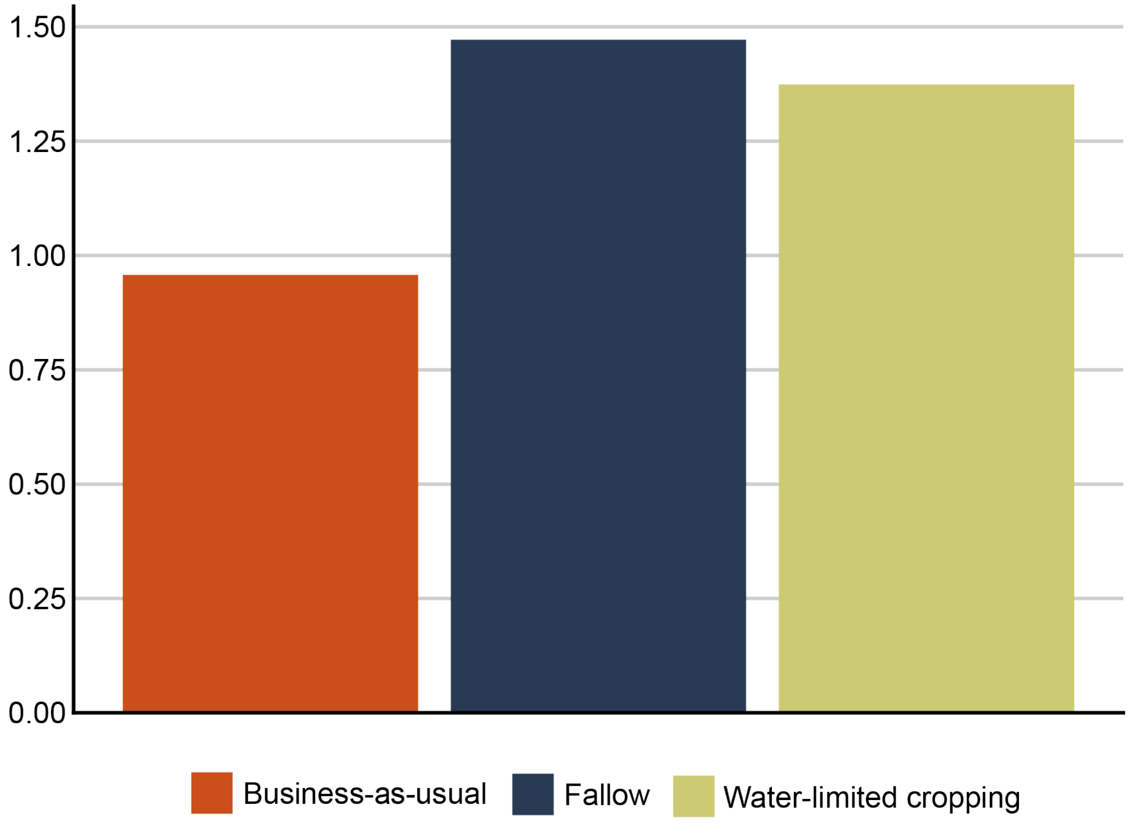
However, this exercise can serve to illustrate trends and relative changes in emissions with land use transitions at the valley scale, even if absolute emissions estimates are conservative.

Anticipated land fallowing in the San Joaquin Valley in response to groundwater cutbacks may increase cropland GHG emissions by over 50 percent relative to cropland GHG emissions under current crops and management practices (Figure A4). While this is a large increase relative to baseline emissions, cropland would remain a small slice of all agricultural sector GHG emissions (about 32 million metric tons $CO_2$eq per year; CARB 2022). If water-limited forages were implemented on 25 percent of lands that would otherwise go fallow, this would reduce projected increase in GHG emissions to about 43 percent above current crops and management practices. Implementing water-limited winter forages may avoid only a small portion of potential emissions increases from SGMA-related fallowing, but other co-benefits—including reduced dust emissions, added flexibility in crop management options, and supplemental grower income—could justify providing incentives for these practices.

**FIGURE A4**

Land fallowing will increase GHG emissions relative to business-as-usual agriculture

GHG emissions from San Joaquin Valley cropland (millions of metric tons $CO_2$eq per year)



SOURCE: Author estimates from COMET-Farm (GHG emissions); Hanak et al. (2019) and Escriva-Bou et al. (2023) (land fallowing)

NOTES: BAU is business-as-usual, or GHG emissions under current cropping practices. Fallow scenario assumes fallowing of about 900,000 acres. Water-limited cropping assumes that 25 percent of otherwise-fallowed land ends up in water-limited winter forages. The values shown are estimates of GHG emissions across the San Joaquin Valley, including GHG emissions from land that remains in fully irrigated production after some lands see fallowing or crop changes. GHG balances were modeled for a subset of San Joaquin Valley crops, including almonds, wine grapes, winter wheat, alfalfa, processing tomatoes, and corn silage. To estimate valley-wide GHG emissions, these six crops were used as proxies for crops in the same crop family.

## REFERENCES

Ayres, Andrew, Jaymin Kwon, and Joy Collins. 2022. *Land Transitions and Dust in the San Joaquin Valley*. Public Policy Institute of California.

CARB. 2022. *Scoping Plan for Achieving Carbon Neutrality*. California Air Resources Board.

CARB. 2025. *Natural and Working Lands Carbon Inventory*. California Air Resources Board.

CDFA. n.d. *Healthy Soils Week: Partner Toolkit*. California Department of Food and Agriculture.

CDFA. 2024. *Healthy Soils Program Incentives Grant Awards Procedures Manual*. Office of Environmental Farming and Innovation, California Department of Food and Agriculture.

CDFA. 2026. *Climate Resilience Strategy for California Agriculture*. California Department of Food and Agriculture.

CNRA. 2022. *Natural and Working Lands Climate Smart Strategy*. California Natural Resources Agency.

Campbell-Mathews et al. 2004. *Sample Costs to Produce Winter Forage for Silage*. UC Davis Agricultural and Resource Economics.

Chaplot, Vincent, and Pete Smith. 2023. "Cover crops do not increase soil organic carbon stocks as much as has been claimed: What is the way forward?" *Global Change Biology* 29 (22): 6163–6169.

Clark, Nicholas et al. 2016. *Sample Costs to Establish and Produce Alfalfa in Tulare County*. UC Davis Agricultural and Resource Economics.

Cole, Spencer, Ellen Hanak, and Caitlin Peterson. 2024. *Agricultural Land Use in California*. Public Policy Institute of California.

Di Vittorio, Alan V. et al. 2024. "Soil management practices can contribute to net carbon neutrality in California." *Environmental Research Letters* 19 (6): 064034.

ESMC. n.d. "EcoHarvest by ESMC: Regenerative Agriculture Rewards." Website, Ecosystem Services Market Consortium.

EDF and BCG. 2024. *Mitigating Agricultural Emissions Through Carbon Credits: Current Status of the Voluntary Carbon Offset Market and the Path Ahead*. Environmental Defense Fund and Boston Consulting Group.

Escriva-Bou, Alvar, Ellen Hanak, Spencer Cole, and Josué Medellín-Azuara. 2023. *The Future of Agriculture in the San Joaquin Valley*. Public Policy Institute of California.

Hanak, Ellen et al. 2019. *Water and the Future of the San Joaquin Valley*. Public Policy Institute of California.

Haviland, David R. et al. 2019. *Sample Costs to Establish an Orchard and Produce Almonds with Double-Line Drip Irrigation in the Southern San Joaquin Valley*. UC Davis Agricultural and Resource Economics.

Indigo Ag. n.d. "Carbon by Indigo." Website, Indigo Ag, Inc.

Mitchell, Jeff, Karen Klonsky, and Don Stewart. 2015. *Sample Costs to Produce Silage Corn with Conservation Tillage in the Northern San Joaquin Valley*. UC Davis Agricultural and Resource Economics.

Mitchell, Jeffrey P. et al. 2024. "No-tillage, surface residue retention, and cover crops improved San Joaquin Valley soil health in the long term." *California Agriculture* 78 (2).

Paustian, Keith et al. 2017. "Field- and farm-scale assessment of soil greenhouse gas mitigation using COMET-Farm." In *Precision Conservation: Geospatial Techniques for Agricultural and Natural Resources Conservation*, edited by J.A. Delgado, G.F. Sassenrath, and T. Mueller. CSSA, and SSSA.

Petek, Gabriel. 2021. *Assessing California's Climate Policies—Agriculture*. Legislative Analyst's Office.

Peterson, Caitlin, Cameron Pittelkow, and Mark Lundy. 2022. *Exploring the Potential for Water-Limited Agriculture in the San Joaquin Valley*. Public Policy Institute of California.

Plastina, Alejandro, Haeun Jo, and Oranuch Wongpiyabovorn. 2024. "The business case for carbon farming in the USA." *Carbon Balance and Management* 19 (1): 7.

Procton, Alex. 2025. *State of the Voluntary Carbon Market.* Ecosystem Marketplace.

Tautges, N. E. et al. 2019. "Deep Soil Inventories Reveal That Impacts of Cover Crops and Compost on Soil Carbon Sequestration Differ in Surface and Subsurface Soils." *Global Change Biology* 25 (11): 3753–66.

Healthy Soils Network. 2019. *Carbon Neutral Agriculture in California By 2030: A Pathway to Economic, Ecological, and Social Resilience*. The Climate Center.

Turini, Tom, Donald Stewart, and Jeremy Murdock. 2018. *Sample Costs to Produce Sub-Surface Drip Irrigated Processing Tomatoes in Fresno County*. UC Davis Agricultural and Resource Economics.

UCANR. n.d. *Integrated Weed Management: Small Grains*. UC Statewide Integrated Pest Management Program, UC Agriculture and Natural Resources.

USDA California Climate Hub. n.d. "California Agriculture Greenhouse Gas Emissions." Workshop materials, US Department of Agriculture.

USDA. n.d.(a). "Environmental Quality Incentives Program (EQIP)." Website, US Department of Agriculture Natural Resources Conservation Service.

USDA. n.d.(b). "Conservation Stewardship Program (CSP)." Website, US Department of Agriculture Natural Resources Conservation Service.

USDA. n.d.(c). *FY25 California Conservation Stewardship Program Renewals*. US Department of Agriculture Natural Resources Conservation Service.

USDA. n.d.(d). *FY25 California Environmental Quality Incentives Program*. US Department of Agriculture Natural Resources Conservation Service.

Watnick, Darya. 2020. "COMET-Farm Sensitivity Analysis Report." Master's capstone, Yale School of the Environment.

Wright, Steven D., Robert Hutmacher, Karen M. Klonsky, and Richard L. De Moura. 2013(a). *Sample Costs to Produce Irrigated Wheat for Grain in the Southern San Joaquin Valley*. UC Davis Agricultural and Resource Economics.

Wright, Steven D. et al. 2013(b). *Sample Costs to Produce Small Grain Silage in the Southern San Joaquin Valley*. UC Davis Agricultural and Resource Economics.

Wright, Steve, Karen Klonsky, and Don Stewart. 2015. *Sample Costs to Produce Field Corn in the Southern San Joaquin Valley*. UC Davis Agricultural and Resource Economics.

Zhuang, Shijian et al. 2019. *Sample Costs to Establish a Vineyard and Produce Wine Grapes in the Southern San Joaquin Valley*. UC Davis Agricultural and Resource Economics.

# Appendix B. Particulate Matter from Fallowed and Cropped Lands

## Introduction

This technical appendix to the Policy Brief "The Economics of Winter Forage as a SGMA Adaptation Strategy" details our evaluation of the potential for water-limited cropping systems to alleviate windblown dust risks from lands that may otherwise be left fallow. This effort builds upon a previous PPIC analysis estimating land cover associations with local air pollution and discusses additional results with relevance to water-limited cropping. It also describes an exercise to forecast the effect that maintaining crop cover would have on mitigating dust emission increases that might otherwise accompany SGMA-related fallowing.

## Estimating the Relationship Between Local Particulates and Land Cover

Both agricultural operations and windblown dust from exposed soils can contribute to particulate matter pollution in rural areas. Fallowed agricultural fields may be especially prone to dust emissions during windy times of year, as they expose disturbed soils to wind erosion and are typically kept clear of vegetation that might disrupt erosion processes. Accordingly, fallowing to achieve groundwater sustainability under the Sustainable Groundwater Management Act (SGMA) poses a significant dust risk; however, water-limited cropping systems that enable owners to continue productive agriculture on their lands may help to mitigate these risks, in particular by maintaining vegetative cover that reduces dust generation. We build on previous work (Ayres et al., 2022; Ayres, 2022) that combined data on land cover types and particulate matter (PM) concentrations to shed light on drivers of PM concentrations in the San Joaquin Valley's rural areas. Here we make use of new data and ask more targeted questions relevant to water-limited cropping systems.

### Data Sources and Empirical Approach

The data sources used for this analysis mirror those used by Ayres (2022). These include geospatially explicit particulate matter concentration data from the NASA Socioeconomic Data and Applications Center (SEDAC), the USDA Cropland Data Layer (CDL), Land IQ crop mapping layers, and wildfire burn acreages from Cal Fire. We describe these in brief below, but for more detailed information on these sources, see Ayres (2022).

Local particulate concentrations from NASA developed by Di et al. (2021) include modeled particulate matter ($PM_{2.5}$) concentrations at 1-kilometer resolution.[6] Model outputs are based on analysis of satellite imagery and monitoring data alongside additional geographic and meteorological information. In calculating local particulate matter concentrations, we omit information from within urban areas as defined by the Federal Highway Administration (FHWA).

We use the USDA CDL to measure land cover acreages for seven major land cover types: almonds, other orchards (incl. pistachios, citrus, etc.), two types of annual crops (single- and double-cropped), idled or fallowed lands, pastureland, and other unmanaged rangeland. We break out almonds individually because almond orchards have already been identified by stakeholders and regulatory agencies as uniquely meaningful sources of particulates. In addition, we analyze pastureland and unmanaged rangeland separately by differentiating between areas identified as pasture in the CDL and marked as actively managed agricultural lands in the 2016 Land IQ

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[6] We use fine particulate matter ($PM_{2.5}$) for this analysis, although windblown dust also contains significant (often dominant) proportions of coarser particulates (e.g., $PM_{10}$). Data limitations drive our choice, and Ayres (2022) discusses interpretation of our results given prevailing relationships between $PM_{2.5}$ and $PM_{10}$ in the valley.

crop mapping layer. Those not marked are treated as "unmanaged rangeland" following our earlier review of satellite imagery and discussions with local stakeholders. Due to our focus on the potential for water-limited crops to mitigate dust by maintaining vegetative cover, and because the estimated relative contributions of different land covers to local particulate concentrations are similar to those found in Ayres (2022), we only report results for selected land cover types below.

We control for idiosyncratic shifts in particulate generation from wildfires using fire perimeter data from Cal Fire's Fire and Resource Assessment Program (FRAP) (Cal Fire 2025). We follow previous work and aggregate burned acreage by month for two subregions defined by the Tulare Lake and San Joaquin River hydrologic regions. (Burned lands include those in headwater forest areas.)

We extend the previous data sources and analysis in several ways. First, we collect NASA SEDAC $PM_{2.5}$ concentrations from years prior to 2010. Accordingly, our panel dataset now spans 2007–2016 (3 additional years). Second, we re-calculate all variables at a finer scale of spatial resolution. We adopt 49 local areas as defined by Escriva-Bou et al. (2023) as cross-sectional units for analysis. These areas represent agricultural production areas with relatively similar local surface water availability for irrigation, and they cover all lands overlying the valley's groundwater subbasins. We now also include local areas from three subbasins previously excluded: Eastern San Joaquin, Tracy, and White Wolf. These extensions enable greater statistical precision, a sample that represents a wider range of conditions in the valley, and a new modeling approach.

Finally, we split the annual crops category into two: single-rotation annuals and lands double-cropped with a winter crop. This distinction allows us to more accurately estimate the possible effects of water-limited cropping systems on windblown dust generation, as double-cropped systems typically have established vegetation during the winter/spring periods of the year that water-limited crops might be grown.

Adopting local areas as our unit of analysis instead of groundwater subbasins enables more precise estimation of particulate matter concentrations in rural areas; however, it also increases the likelihood that land cover decisions in one area, insofar as they control or generate particulate matter, impact outcomes in neighboring areas. To account for this, we adopt a spatial autoregressive modeling (SAR) approach, described in the next subsection.

## Estimating Equation

The SAR model allows for flexibility in modeling the extent to which neighboring areas, as defined in a spatial weighting matrix, share similar outcomes for particulate matter concentrations at any given point in time. It also allows modeling of spillover effects from land cover decisions according to a similar spatial weighting matrix. We adopted a composite contiguity and inverse-distance spatial weighting matrix, which allows for shared outcomes and/or spillovers across neighboring areas and weights these relationships according to the inverse distance between them (i.e., areas with closer centroids are assumed to have stronger relationships).

Relationships between the extent of land cover (in 1,000s of acres) and local particulate matter concentrations are estimated for a pooled monthly sample. The following model is estimated for 5,880 location-month observations:

$$y_{im} = [W]\boldsymbol{y} + \beta_0 Burn_{jm} + \sum_{s=1}^{7} \beta_s\, Acres_{ist} + \sum_{s=1}^{7} \theta_s\, [W] * Acres_{ist} + \gamma_i + \mu_k + \tau_t + \varepsilon_{im}$$

- $y_{im}$ is the local particulate matter concentration in area $i$ in month $m$, measured for rural areas only;
- $\boldsymbol{y}$ is the vector of local monthly particulate matter concentrations in other areas;
- [W] is a composite contiguity and inverse-distance spatial weighting matrix;
- $Burn_{jt}$ is the acreage burned in region $j$ in month $m$;

- $Acres_{ist}$ is the acreage of crop $s$ in area $i$ in year $t$;
- $\gamma_i$ is a set of area fixed effects;
- $\mu_k$ is a set of month-of-year fixed effects;
- $\tau_t$ is a set of year fixed effects;
- and $\varepsilon_{im}$ is an error term.

We calculate marginal effects for all acreage types based on our estimated coefficients related to land cover and any spillovers from land cover ($\hat{\beta}_{1-7}$ and $\widehat{\theta}_{1-7}$). These estimated effects are conditioned on long-term baselines and common idiosyncratic shocks to particulate matter concentrations at the month-of-year and year levels, such as regular winter-time temperature inversions that trap pollutants in the valley. The model conditions local particulate matter concentrations on observed wildfire activity as well, to account for idiosyncratic wildfire activity that may be associated with land cover decisions (such as regional drought conditions).

Results from the pooled estimation accord with those found in Ayres (2022) regarding the relative magnitude of relationships between land cover types and particulate matter. Idled and some other unmanaged lands show the strongest links to local particulates. Almonds and other orchards also show a significant relationship, possibly due to harvest-time emissions.[7] Annual crops are less associated with particulates, and double-cropped lands show the lowest overall association across the year. Coefficient estimates from our pooled sample suggest that each 1,000 acres of additional idled land may increase average fine particulate matter concentrations by between 0.2 and 0.25 $\mu g/m^3$ (roughly 1–2% of average annual concentrations); in comparison, associations for annual crops and double-cropped lands are roughly 25 percent and 35 percent lower across the year, respectively. These figures reflect both links to local particulate matter concentrations (within a local area, the "direct" effect) as well as potential spillovers to neighboring local areas (the "indirect" effect); for most crop types, indirect effects are a major factor, contributing over 50 percent of the total effect.

We also estimate the model separately by month as in Ayres (2022). Figure B1 plots monthly effects for three land cover types: fallowed lands that might accommodate winter and early spring vegetative cover, annuals that also may be bare during these months, and double-cropped lands that retain vegetative cover at those times. We present estimated effects for the winter and spring months; these include the windiest months in the valley (March through June). Relationships during winter months are difficult to identify and not statistically significant; in contrast, the windier spring months show statistically significant relationships for idled and single-cropped lands, both of which are often bare during this period. Double-cropped lands show much lower point estimates and are statistically indistinguishable from zero, suggesting much lower but also noisy relationships with local particulate matter. Estimated relationships for these crop types in other months are clustered near zero and not statistically significant. Overall, differences in the relationships between our land covers of interest (idled lands and double-cropped lands) and local particulate matter appear to be driven by deviations in the windiest springtime months.

These results clarify when and to what extent maintaining vegetative cover might reduce local particulate matter pollution; accordingly, they shed some light on the possible role of water-limited cropping systems in reducing windblown dust. However, it is important to note that our data do not include observations of water-limited systems and that double-cropped systems may vary in crucial ways. Most importantly, double-cropped systems are often harvested later than water-limited systems. If water-limited systems are harvested in late March, dust reduction benefits achieved by double-cropped systems in the windiest month (esp. April and May) may not

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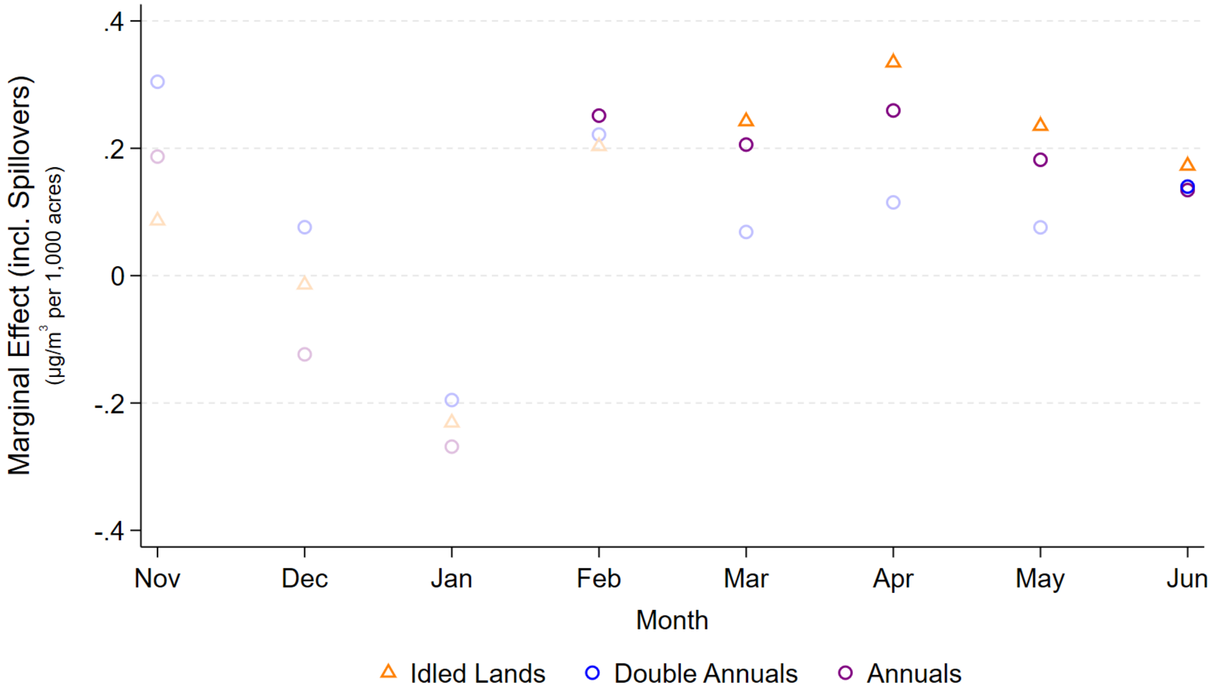
[7] As noted in Ayres (2022), our data cover years prior to the introduction of the San Joaquin Valley Air Pollution Control District's Low-Dust Nut Harvester Replacement Program. This program subsidizes uptake of new equipment that reduces dust emissions from the sweeping and collection portions of almond (and some other nut) harvesting processes. Accordingly, the current relationship between almond acreage and local particulates may be weaker.

materialize; given our monthly analysis, this suggests that any harvest flexibility or residue management actions that maintain vegetative cover later into the year may be critical for ensuring dust mitigation benefits of water-limited systems. Accordingly, our results should be viewed as insightful regarding the actual performance of observed double-cropped systems but conjectural regarding water-limited systems.

**FIGURE B1**

Winter and spring particulate matter relationships for selected land cover types



SOURCES: Developed by the authors using data from NASA (particulate matter), USDA (land cover), Land IQ (land cover), and Cal Fire (burn acreage).

NOTES: Plotted points reflect estimated relationships between land cover types and local particulate matters concentrations; the displayed total effects include impacts on both local concentrations ("direct effect") and those in neighboring areas ("indirect effect"). Plotted points displayed in full color saturation are statistically significantly different from zero at the 10 percent level.

## Forecasting Potential Dust Mitigation Benefits of Vegetative Cover

We use the SAR model results to quantify the potential for particulate matter improvements from maintaining vegetative cover on lands that could come out of irrigated production under SGMA. We rely on existing estimates of likely SGMA fallowing at the local-area level and focus on the possible role of vegetative cover in controlling dust generation, using double-cropped lands as a proxy for the potential of water-limited forage systems.

We construct six scenarios by combining three SGMA fallowing scenarios with two supplemental irrigation scenarios. We then model particulate outcomes for each relative to its unmitigated SGMA baseline.

1. First, we adopt fallowing scenarios from Escriva-Bou et al. (2023) that characterize possible responses to SGMA under different assumptions about water trade. These determine how much occurs in a given local area. Specifically, we base our estimates on expected fallowing of annual crops.
2. Second, we estimate potential maintenance of vegetative cover by considering lands that could profitably adopt water-limited forage systems (as defined in this Policy Brief) under two different supplemental irrigation scenarios from Peterson et al. (2022). They determine how much land in any given local area

might be suitable for dust mitigation via vegetative cover, and we assume that all suitable (profitable) lands are managed to maintain vegetative cover. Combining these two scenarios with the three fallowing scenarios yields six total scenarios.

3. Third, we compare modeled particulate matter outcomes using the SAR model given no adoption of vegetative cover (i.e., SGMA fallowing) and given adoption of double-cropping under the profitability conditions described in (2). This yields six different estimates of potential dust mitigation for each local area. In each, the relevant comparison is between a SGMA future without crop cover on fallowed lands (higher particulate matter) and with cover (lower particulate matter).

Results are summarized in Table B1. They are calculated as follows: each local area's particulate matter reduction is converted to a percentage reduction relative to 2007–2016 average PM concentrations. Then, these percentages are averaged for all areas within a groundwater subbasin using total agricultural acreage within the local area as weights. These reflect the subbasin-level average results reported in Table B1.

Because we do not observe winter/spring water-limited forage systems in our data, we compare conditions using year-round bare fallow to those achieved under double-cropping systems. As discussed earlier in this appendix, water-limited forage may be harvested earlier than observed double-cropped systems, and thus some of the potential dust mitigation benefits forecasted when using the double-cropped category may not materialize. This is particularly important because the windier months in the valley (March through June) are when empirical relationships with particulate matter for lands with and without vegetative cover are most pronounced. Accordingly, these results likely do not represent outcomes under water-limited forage systems without intentional harvest or residue management actions to maintain vegetative cover during key windy months. Our calculated results from Table B1 should thus be viewed as an upper bound on the potential PM reductions of these systems.

The results reveal that large PM improvements are driven by site-specific conditions and spillover effects. For example, areas in the drier southern portions of the valley see fewer benefits because, even with supplemental irrigation, water-limited forage is not profitable and thus lands remain fallowed. Accordingly, most gains are found in the northern and central portions of the valley and scale with supplemental irrigation available where more irrigation potential meaningfully increases potentially profitable acreage. Different trading scenarios shift the incidence of fallowing across local areas, and it is often the case, especially in the wetter northern parts of the valley, that trading moves water away from areas that can more easily maintain vegetative cover to those that cannot—such that trading leads to a net reduction in local PM concentrations.

In addition, mitigation is driven by spillover effects. Across some scenarios, a given local area or subbasin may not increase its local adoption of vegetative cover—either because it does not fallow more land or because, if it does increase fallowing, it has no more potentially profitable winter forage lands—yet PM concentrations may still decrease. For example, the Merced subbasin sees little additional vegetative cover maintenance across fallowing scenarios under either 4 or 8 inches of supplemental irrigation (roughly 15,000 and 18,000 acres of fallowed annuals are mitigated via vegetative cover, respectively), yet potential mitigation benefits increase (ranging from 4.9 to 6.2% and 11.8 to 18.8%, respectively). Water trading under these scenarios causes water use to shift in the neighboring Turlock subbasin from areas with plentiful supplies *and* promising conditions for water-limited cropping to those without. The net effect is more vegetative cover maintenance on fallowed land in Turlock, and spillover benefits from avoided dust generation accrue in Merced. Our adoption of the SAR model underscores how windblown dust mitigation can take on not just a local but regional character.

**TABLE B1**

Potential rural particulate matter reductions relative to SGMA baselines

| Subbasin | Various Fallowing Scenarios (Range) | |
|---|---|---|
| | 4 in. | 8 in. |
| Chowchilla | 1.8 – 2.2% | 6.2 – 9.5% |
| Delta-Mendota | 1.4 – 2.2% | 4.7 – 8.1% |
| Eastern San Joaquin | 0.9 – 1.6% | 1.1 – 2.7% |
| Kaweah | 0.0% | 1.0 – 2.0% |
| Kings | 0.1 – 0.2% | 1.0 – 1.9% |
| Kern | 0.0% | 0.3 – 0.5% |
| Madera | 0.6 – 0.9% | 2.9 – 5.4% |
| Merced | 4.9 – 6.2% | 11.8 – 18.8% |
| Modesto | 1.4 – 2.9% | 3.0 – 6.5% |
| Tule | 0.0% | 2.4 – 3.6% |
| Tulare Lake | 0.1% | 1.7 – 2.8% |
| Tracy | 1.1 – 1.6% | 3.0 – 4.6% |
| Turlock | 4.2 – 5.4% | 8.8 – 13.2% |
| Westside | 0.2 – 0.3% | 1.2 – 2.6% |
| White Wolf | 0.0% | 0.1% |

SOURCES: Estimated by the authors using fallowing estimates from Escriva-Bou et al. (2023), winter forage suitability from this report, and the particulate matter impacts produced as part of this analysis.

NOTES: Figures represent the reduction in particulate matter concentrations achieved by maintaining vegetation under different scenario assumptions, relative to bare fallow. Reductions are presented in percentage terms relative to baseline average particulate matter concentrations (2007-2016). Ranges reflect variation across fallowing scenarios, presented separately by supplemental irrigation scenario (4 or 8 inches of supplemental irrigation available). Subbasin-level results reflect acreage-weighted averages of model predictions at the local area level (for local area definitions, see Escriva-Bou et al. (2023)). Reductions are computed for average annual concentrations calculated from model-predicted monthly averages of daily means. Percentages were rounded to nearest decimal point.

## REFERENCES

Ayres, A., J. Kwon, and J. Collins. (2022). *Land Transitions and Dust in the San Joaquin Valley*. Public Policy Institute of California.

Ayres, A. (2022). *Technical Appendix A: Estimating Land Cover Emissivity and Dust Risk Geography*. Public Policy Institute of California.

Cal Fire. (2025). Fire and Resource Assessment Program (FRAP): Fire Perimeters. Cal Fire.

Di, Q. et al. (2021). Daily and Annual PM2.5 Concentrations for the Contiguous United States, 1-km Grids, v1 (2000–2016) [data set]. NASA Socioeconomic Data and Applications Center (SEDAC).

Escriva-Bou, A., E. Hanak, S. Cole, and J. Medellín-Azuara. (2023). *Policy Brief: The Future of Agriculture in the San Joaquin Valley*. Public Policy Institute of California.

Peterson, C., C. Pittelkow, and M. Lundy. (2022). *Exploring the Potential for Water-Limited Agriculture in the San Joaquin Valley*. Public Policy Institute of California.

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