Exploring the Potential for Water-Limited Agriculture in the San Joaquin Valley

Technical Appendices

CONTENTS

Appendix A. Cost and Return Scenarios for Water-Limited Winter Wheat
Caitlin Peterson and Ellen Hanak

Appendix B. Modeling Water-Limited Wheat Forage Yields Across the San Joaquin Valley
Caitlin Peterson, Cameron Pittelkow, and Mark Lundy

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Appendix A. Cost and Return Scenarios for Water-Limited Winter Wheat

Introduction

Just as there has been little recent agronomic analysis of the production potential for water-limited crops in the San Joaquin Valley, there has been little analysis of their economic potential. To shed some light on this issue, this appendix provides an exploratory analysis of circumstances under which dryland-plus winter wheat might generate positive returns on operating costs. We draw on this study’s analysis of the agronomic potential of dryland-plus winter wheat under different production and harvest scenarios, and on possible production costs and output prices. We find that under some circumstances—e.g., in higher-rainfall areas of the valley, and when harvested for late-stage forage products rather than grain—dryland-plus winter wheat can achieve positive net operating returns with the input costs and output prices that have prevailed in recent years. In some cases, these returns are likely high enough to cover land rental rates and other overhead. Margins would be slimmer with lower prices for forage, and higher in places where water for irrigation is less costly. We also find that the targeted addition of small amounts of irrigation water to aid crop establishment—where feasible—can be a relatively high-return use of water. While more in-depth analysis of the agronomic, operational, and market potential of dryland-plus crops in the San Joaquin Valley is needed, these findings suggest the approach may be promising under some conditions—particularly in light of the other potential benefits of dryland-plus cropping relative to idle land or bare managed fallows, including soil health and water infiltration, dust and weed mitigation, and others (see main report).\(^1\)

We use winter wheat as a case study because of the well-validated crop models that are available for it. However, other crops may be far more robust under dryland or dryland-plus production conditions, which include periodic drought, high salinity, and weed pressure. These crops include other forages such as triticale and ryegrass, legumes such as chickpeas and lentils, or oilseeds such as canola. Still other crops—agave and prickly pear cactus are two examples—may offer similar drought tolerance but higher profit potential than wheat because they can target specialty markets.

Data sources and approach

Below we explore some of the pricing and production cost factors playing into the profitability of dryland (no irrigation) and dryland-plus (4 or 8 inches of irrigation) winter wheat. These scenarios are based on model-estimated yields for soft-dough-stage forage (in this case, marketed as hay) and for grain at four modeled sites in the San Joaquin Valley: Turlock (37.486, -120.670), Visalia (36.425, -119.278), West Side (36.3404, -120.116), and Shafter (35.534, -119.278).\(^2\)

Various groups have performed cost and return studies for winter wheat grain and wheat forage in California over the years. But because dryland production is uncommon, particularly in the San Joaquin Valley, no recent cost/return studies are available for dryland or minimally irrigated wheat. To develop relevant estimates, we consulted cost/return studies for irrigated winter wheat grain in the Sacramento Valley (Mathesius et al. 2016) and

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1. A forthcoming PPIC report will also explore the potential cost of implementing dust mitigation, including cover crop establishment and residue management techniques with parallels to water-limited crop production (Ayres, Kwon and Collins 2022). In many cases, costs to perform these mitigation practices would be lower than costs to implement a dryland or dryland-plus crop as there is no objective to attain a harvestable product.

2. For more details, see Appendix B and the related journal article, available from the authors upon request.
winter wheat grain (Wright et al. 2013a) and silage (Wright et al. 2013b) in the San Joaquin Valley from the University of California Cooperative Extension service. We then adjusted their assumptions considering variations in management approaches that would pertain to water-limited wheat with lower yield potential, and recent price and market conditions. We also explore the sensitivity of the results to other cost and price scenarios. We are grateful to several experts for their input on these adjustments.

**Assumptions on operating costs and product prices**

The cost and return studies referenced above were developed for specific cases, and their cost estimates are tailored for the management objectives of each case, as well as prevailing input costs and output prices. Growers adapt their operations as yields, costs, and prices change. Therefore, any adjustments we made should be treated as illustrative.

**Operating costs.** Where possible, we sought to include relatively recent operating costs, and to reflect how the production system might differ under conditions with little or no irrigation. While we may overestimate some costs, particularly where there is uncertainty about management practices and/or input costs, this analysis can be useful as a first-order attempt to quantify some of the economic constraints on dryland and dryland-plus crop production in the valley.

- **Fertilizer.** Cost study estimates for irrigated wheat grain/silage assumed an application of 105–250 pounds of nitrogen (lb N) per acre from various sources, including granular urea, anhydrous ammonia, liquid UN32, aqueous ammonia, and—in the case of silage—raw manure (Mathesius et al. 2016 and Wright et al. 2013a-b). With less irrigation, fertilizer amounts would be lower. We used the amounts applied by the model—which applies fertilizer at times that are physiologically important for the crop—ranging from 50 lbs N for dryland to 150 lbs N with 8 inches of irrigation. In practice, farmers might use less, particularly for a low-yielding, high-risk dryland crop. Water-limited crops would also be unlikely to receive manure applications. The 2013 wheat grain and silage cost studies estimated fertilizer costs at $0.75/lb N for granular urea, while the 2016 grain study assumed $0.53/lb N. From 2017–21 the price of nitrogen was lower, remaining fairly steady at $0.43/lb N, reflecting relatively low prices for natural gas, a key input (DTN nd; Smith 2022). By early 2022 the price had doubled, reflecting energy and other commodity price disturbances related to the war in Ukraine. Considering these disturbances, we retained $0.43/lb N as our base case assumption. For higher-cost scenarios we used $0.75/lb N.

- **Seed.** Seed cost assumptions in the cost studies ranged from $0.43–$0.75/lb for 130–150 lb/acre of seed. For a low-yield crop the manager would opt for low-priced seed where available, so we retained the $0.43 value for our base case.

- **Herbicide.** The 2013 and 2016 cost study estimates for herbicide applications for fully irrigated wheat grain and wheat silage ranged from $18–$54 per acre. The lower estimate reflects two applications using an all-terrain vehicle boom sprayer (Mathesius et al. 2016). The higher estimate reflects one application by air; the cost of air application by commercial helicopter is captured below under “custom services.” As with fertilizer, dryland or dryland-plus crops would likely receive far fewer herbicide inputs, depending on the expected yield and profit potential. A crop with very low profit potential may not have the operating budget to include herbicide at all. Because of this uncertainty, we scaled herbicide inputs down somewhat for dryland/dryland-plus wheat but retained the air application, so this is likely an overestimate.

- **Custom services.** The 2013 cost studies assumed that herbicide would be applied by helicopter. Air application of herbicides would be an unlikely management option in a low-input dryland or dryland-plus system, and a Pest Control Advisor would likely only be consulted if operational budgets allowed for this.
Costs for custom air application and Pest Control Advisor are therefore likely overestimated, but we retain these costs in our base case for lack of a better source.

- **Irrigation water.** Our dryland-plus scenarios assume the delivery of irrigation in one or two 4-inch applications, for a total of 4 or 8 inches per season. The 2013 cost studies assumed that water was delivered by an irrigation district at $100/acre-foot (af) (vs. $90/af for the 2016 Sacramento Valley study). While some farmers in the San Joaquin Valley can still access water at or below this price, we opted to include a much higher price—$300/af—in our base case scenario, to account for increasing water scarcity in the region.³ Net operating returns would be higher than those shown below for farmers with access to less expensive water, and their incentives to use it in dryland-plus farming might also be higher if they are not able to trade this water. To show this, we consider a low-cost scenario with water at $100/af. We also explore scenarios with an even higher water cost of $500/af—reflecting the higher opportunity cost of water in drier years.

- **Labor.** We adjusted labor costs to reflect 2022 hourly wages for large employers. The 2022 California minimum wage is $15/hr for employers with more than 25 employees (US DOL 2022). “Non-machine” labor refers to unskilled labor earning minimum wage. “Machine” labor refers to skilled labor earning wages 20 percent higher than minimum wage ($18/hr). As in the 2013 cost studies, we assumed payroll overhead of 38 percent on top of these costs.

- **Fuel (diesel).** We used median 2021 California retail prices for No. 2 diesel of $4.16/gallon for the base case scenario (US EIA). Prices in 2022 have been much higher, reflecting recent commodity price disturbances related to the war in Ukraine. In our higher-cost scenario we include diesel at $5/gallon.

- **Machinery.** Costs for machinery maintenance were minor in the cost studies, and while they may have increased somewhat since 2013–16, we held them constant at $9/acre for simplicity.

- **Interest.** Similarly, for interest on operating capital we retained the assumption from the 2013 San Joaquin Valley costs studies of a 5.75 percent interest rate. This amounted to a constant cost of $12/acre across scenarios. Note that this may be an underestimate for scenarios with higher up-front input costs.

- **Harvest.** Harvest costs differ by product. For hay, no recent cost studies detailing harvest costs were available, but our experts estimated current costs of $50/ton for cutting, swathing, raking, baling, and stacking the harvested biomass in the valley.⁴ Note that this means the cost of harvest will increase with increasing yields. For wheat grain, we assume that the producer contracts out the harvest at $40/acre (custom combine), slightly higher than the $32/acre assumed by the 2013 San Joaquin Valley grain cost study.

**Overhead costs.** Our cost estimates are restricted to operating costs, which is an important limitation. Unlike the 2013 and 2016 cost studies, we do not include cash overhead (e.g., office expense, land rent) and non-cash overhead (capital cost recovery on buildings and equipment). As a frame of reference, the 2013 San Joaquin Valley cost studies put these costs at $169–$315/acre, with the largest components for land rental ($125–$250/acre) and office expenses ($25–$50/acre). Land rental costs continued to increase in the last decade, reaching an average price of $387/acre for the San Joaquin Valley for irrigated cropland (USDA NASS 2017). Currently, high land rental costs represent a challenge for water-limited agriculture due to its lower profit potential, emphasizing the need for growers to be able to keep operating costs at a minimum. However, land rental costs in

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³ In some areas with senior water rights, water can still be purchased at less than $50/af, while for more junior contractors dependent on Delta imports, costs of regular irrigation deliveries can exceed $200/af (Aquaoso 2021). Farmers also purchase some water on the transfer market at prices that are typically higher than the prices paid for regular deliveries. During droughts, market prices can be quite high—with some growers paying more than $500/af for additional water to keep their orchards alive or maintain production of highly profitable annual crops. Costs of using groundwater are often lower than for surface water—although as the region implements the Sustainable Groundwater Management Act (SGMA), pumping charges and pumping restrictions will be raising groundwater costs.

⁴ The 2016 wheat grain cost study included a cost of $32/acre for swathing, baling, and hauling wheat stubble.
particular are evolving in the San Joaquin Valley and trends will depend on a variety of factors, including the value of land with reduced access to water for irrigation as the region adapts to groundwater sustainability requirements. For instance, a 2018 appraiser report indicated that land values for acreage that could not be developed for irrigation were already declining, even before the first groundwater sustainability plans under SGMA had been completed (Cal-ASFMRA 2018).

**Product price assumptions.** Commodity prices can fluctuate widely depending on a variety of market forces ranging from global to local. The 2013 San Joaquin Valley grain cost study assumed a price of $220/ton for grain, and a 2016 report on the costs of milk production put the price of non-alfalfa hay at $120/ton (CDFA 2016).\(^5\) Prices for hay in particular have increased considerably in recent years, a reflection of ongoing drought in major hay-producing regions, increasing input costs, and other supply chain issues. Hay prices are also influenced by demand from the dairy sector and tend to track with milk prices (Hatzenbuehler et al. 2021). Forage can be harvested for a wet product such as silage as well; prices for silage tend to track closely with hay prices (adjusted for the higher water content in silage). The higher water content makes silage costlier to transport, so it tends to be grown in proximity to dairies. The 2013 cost and return study for silage assumed that dairies directly harvested the product.

For our base case, we priced outputs at $165/ton for hay and $200/ton for grain. These prices represent conditions in recent years (prior to 2022), which are somewhat higher than long-term averages. We also explore a scenario for higher commodity prices: $200/ton for hay and $400/ton for grain, which approximate current levels (USDA 2022a). For hay, we explore how net returns vary over a range of yield and output price levels—including prices as low as $100/ton—under our base case, lower water cost, and higher production cost scenarios.

**Scenarios for net operating returns from dryland/dryland-plus wheat**

Table A1 details our base case assumptions for input quantities, operating costs per acre, commodity prices, and model-estimated yields. These assumptions are presented for the three irrigation scenarios: dryland (zero inches), dryland-plus-4 inches, and dryland-plus-8 inches of irrigation. These assumptions are also presented for two potential crop outputs: soft-dough-stage forage marketed as hay, or grain. Figures A1–A4 illustrate net operating returns per acre for the two products and three irrigation levels under the base case assumptions as well as three additional price/cost scenarios illustrating: 1) higher costs for water, fuel, and fertilizer; 2) higher costs and higher commodity prices; and 3) lower costs for water. Finally, Table A2 shows the sensitivity of net operating returns for hay to yields and commodity prices for the base case and the higher- and lower-cost cases.

**Base case results with water at $300/acre-foot**

Under our base case scenario (Figure A1), net returns on operating costs were mostly negative for wheat grain—except under 4–8 in. of irrigation at the two wetter sites (Turlock and Visalia). In contrast, wheat hay netted positive returns in all cases except for the zero-inch irrigation scenario at the two drier sites (West Side and Shafter). Net returns for hay with irrigation approached or exceeded $400/acre in Turlock ($447 with 4 in., $376 with 8 in.) and Visalia ($383 and $336, respectively). In the drier, more southerly sites, they were less than half as high: $164 and $156 in West Side, and $149–$147 in Shafter. In at least some of these cases—especially where land rents are low—the returns may be high enough to cover overhead and yield a net profit.

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\(^5\) Hay prices vary by type and quality, and only limited information is available for non-alfalfa hay, typically sold at a lower price than alfalfa.
### TABLE A1
Commodity price and input cost assumptions for the base case

#### Input quantity per acre

<table>
<thead>
<tr>
<th>Input</th>
<th>Unit</th>
<th>Cost/Unit</th>
<th>Hay</th>
<th>Grain</th>
<th>Hay</th>
<th>Grain</th>
<th>Hay</th>
<th>Grain</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fertilizer (46-0-0)</td>
<td>lb N</td>
<td>$0.43</td>
<td>50</td>
<td>50</td>
<td>100</td>
<td>100</td>
<td>150</td>
<td>150</td>
</tr>
<tr>
<td>Wheat seed</td>
<td>lb</td>
<td>$0.43</td>
<td>130</td>
<td>130</td>
<td>130</td>
<td>130</td>
<td>130</td>
<td>130</td>
</tr>
<tr>
<td>Herbicide</td>
<td>oz</td>
<td>$26</td>
<td>0.08</td>
<td>0.08</td>
<td>1.08</td>
<td>1.08</td>
<td>2.08</td>
<td>2.08</td>
</tr>
<tr>
<td>Custom air applic.</td>
<td>pass</td>
<td>$8</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Pest Control Advisor</td>
<td>pass</td>
<td>$10</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Water</td>
<td>af</td>
<td>$300</td>
<td>0</td>
<td>0</td>
<td>0.33</td>
<td>0.33</td>
<td>0.67</td>
<td>0.67</td>
</tr>
<tr>
<td>Non-machine labor</td>
<td>hr</td>
<td>$21</td>
<td>0.6</td>
<td>0.6</td>
<td>0.6</td>
<td>0.6</td>
<td>0.6</td>
<td>0.6</td>
</tr>
<tr>
<td>Machine labor</td>
<td>hr</td>
<td>$24.84</td>
<td>0.91</td>
<td>0.91</td>
<td>0.91</td>
<td>0.91</td>
<td>0.91</td>
<td>0.91</td>
</tr>
<tr>
<td>Diesel</td>
<td>gal</td>
<td>$4.16</td>
<td>5.97</td>
<td>5.97</td>
<td>5.97</td>
<td>5.97</td>
<td>5.97</td>
<td>5.97</td>
</tr>
<tr>
<td>Machinery</td>
<td></td>
<td>$9</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Interest (5.75%)</td>
<td>$12</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Custom combine</td>
<td>pass</td>
<td>$40</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Swath, rake, bale, stack</td>
<td>ton</td>
<td>$50</td>
<td>varies</td>
<td>0</td>
<td>varies</td>
<td>0</td>
<td>varies</td>
<td>0</td>
</tr>
</tbody>
</table>

#### Estimated cost per acre

<table>
<thead>
<tr>
<th>Commodity</th>
<th>Hay</th>
<th>Grain</th>
<th>Hay</th>
<th>Grain</th>
<th>Hay</th>
<th>Grain</th>
</tr>
</thead>
<tbody>
<tr>
<td>Turlock</td>
<td>$338</td>
<td>$227</td>
<td>$674</td>
<td>$374</td>
<td>$855</td>
<td>$522</td>
</tr>
<tr>
<td>Visalia</td>
<td>$281</td>
<td>$227</td>
<td>$646</td>
<td>$374</td>
<td>$838</td>
<td>$522</td>
</tr>
<tr>
<td>West Side</td>
<td>$223</td>
<td>$227</td>
<td>$551</td>
<td>$374</td>
<td>$759</td>
<td>$522</td>
</tr>
<tr>
<td>Shafter</td>
<td>$203</td>
<td>$227</td>
<td>$545</td>
<td>$374</td>
<td>$755</td>
<td>$522</td>
</tr>
</tbody>
</table>

#### Commodity prices and model-estimated yields

<table>
<thead>
<tr>
<th>Commodity price ($/ton)</th>
<th>Hay</th>
<th>Grain</th>
<th>Hay</th>
<th>Grain</th>
<th>Hay</th>
<th>Grain</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average yield: Turlock</td>
<td>6,028</td>
<td>1,895</td>
<td>13,584</td>
<td>4,482</td>
<td>14,916</td>
<td>5,411</td>
</tr>
<tr>
<td>Average yield: Visalia</td>
<td>3,760</td>
<td>1,220</td>
<td>12,468</td>
<td>3,435</td>
<td>14,227</td>
<td>5,171</td>
</tr>
<tr>
<td>Average yield: West Side</td>
<td>1,451</td>
<td>370</td>
<td>8,675</td>
<td>2,332</td>
<td>11,096</td>
<td>3,396</td>
</tr>
</tbody>
</table>

**SOURCES:** Author estimates based on expert input and model simulations; UC Cooperative Extension cost studies for irrigated wheat grain and small grain silage (Wright et al. 2013a,b and Mathesius et al. 2016); CDFA Cost of Milk Production Annual; USDA California Direct Hay Report; USDA California Grain Bids Report; DTN; Aquaoso; US Department of Labor; US Energy Information Administration. See text for a description and reference list for full citations.

**NOTES:** These numbers form our base case for cost of production for dryland and dryland-plus wheat grain and forage. Detailed input descriptions are available in Wright et al. (2013a,b) and Mathesius et al. (2016). Average yields are APSIM-modeled estimates based on 20-year (2000–20) historical weather time series for each site. Sites are listed in order of highest (12 in.) to lowest (6 in.) average annual rainfall. Hay and grain yields are presented at 12 percent moisture content. “Pass” refers to an implement or equipment pass (e.g., combine, helicopter).
FIGURE A1
Net operating returns under base case assumptions

**Base case ($165/ton hay price, $300/af water)**

SOURCES: Author estimates based on information in Table A1.
NOTES: Costs do not include overhead. See text for discussion.

Results with higher operating costs (including $500/acre-foot water)
A second scenario shows results with higher operating costs ($500/af for water, $0.75/lb for N fertilizer, and $5/gal for diesel), while holding commodity prices constant (Figure A2). This lowers net operating returns across the board. At the drier sites, the results for wheat hay become borderline—slightly positive with 4 inches of irrigation ($61/acre in West Side, $46/acre in Shafter), and slightly negative with 8 inches (-$30 and -$39, respectively). In Turlock and Visalia, growing hay with 4 inches of irrigation can still generate around $300/acre in net operating returns ($344/acre in Turlock, $279/acre in Visalia); those values fall below $200/acre with the additional costs for fertilizer and water in the 8-inch scenario ($190 in Turlock, $150 in Visalia).
**FIGURE A2**  
Net operating returns under higher cost assumptions

![Graph showing net operating returns in Turlock, Visalia, West Side, and Shafter under higher costs assumptions.](image)

**SOURCES:** Author estimates based on information in Table A1 and text.

**NOTES:** Relative to the base case (Figure A1), this scenario increases water costs from $300 to $500/af, N fertilizer costs from $0.43 to $0.75/lb, and diesel from $4.16 to $5/gal. Costs do not include overhead. See text for discussion.

**Results with higher operating costs and higher commodity prices**

A third scenario looks at these higher operating costs alongside higher commodity prices—with values approximately at their 2022 levels (Figure A3). Net operating returns generally increase relative to both prior scenarios—and with high commodity prices, grain now looks favorable, generating roughly $400/acre in net operating returns in Turlock and Visalia with 4 inches of irrigation. Among the alternatives, hay continues to look most promising—with net operating returns of $400–$600/acre in these two locations, and $150–$200/acre in West Side and Shafter.⁶

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⁶ Grain becomes slightly more remunerative than hay if hay prices are held constant and grain prices are increased—to see this, compare hay in Figure A2 with grain in Figure A3.
FIGURE A3
Net operating returns under higher cost and higher output price assumptions

**SOURCES:** Author estimates based on information in Table A1 and text.

**NOTES:** Relative to the base case (Figure A1), this scenario increases water costs from $300 to $500/af, N fertilizer costs from $0.43 to $0.75/lb, and diesel from $4.16 to $5/gal, and increases output prices from $165 to $200/ton for hay and $200 to $400/ton for grain. Costs do not include overhead. See text for discussion.

**Results with lower water costs ($100/acre-foot)**

Finally, Figure A4 shows results when we retain all base case assumptions but reduce the cost of water to $100/af. Net operating returns per acre generally increase in the irrigated scenarios; going from 4 to 8 inches of irrigation now increases returns per acre, particularly at the drier sites where the additional yield boost is higher. Net operating returns range from $450 to more than $500/acre in Turlock and Visalia; with 8 inches of irrigation, they approach $300/acre at West Side and Shafter—nearly double the values in the base case with water at $300/acre-foot.
**FIGURE A4**
Net operating returns under lower cost assumptions

**Lower costs ($100/af water)**

- **Turlock**: Hay > Grain
- **Visalia**: Hay > Grain
- **West Side**: Hay > Grain
- **Shafter**: Hay > Grain

**Economic value of irrigation water**

Figures A1–A4 show that a dryland-plus approach can improve net operating returns per acre—sometimes considerably—with the most promising results for late-stage forage (shown marketed as hay). Given the importance of irrigation in San Joaquin Valley agriculture—and the growing scarcity of this resource—it is useful to explore further what these results imply for the economic value of water in dryland-plus systems, and farmers’ incentives to use water for this purpose.

**Interpreting changes in net returns across different irrigation levels**

First, a caveat is in order regarding estimated changes in net returns at different levels of irrigation. The agronomic model explored moving from zero to one or two applications of irrigation (at four inches per application), applied strategically when the crop needed it most. While modeled average yields generally increase with these small, targeted increments of water (Table A1), the biggest yield boost occurs when going from zero to four inches of irrigation—in part because this substantially reduces years with crop failures. Modeled yield increases from a second irrigation pass are larger at the drier sites, reflecting the greater water limitations at these sites. Moving from four to eight inches of irrigation also entails additional costs (more water and potentially also more fertilizer),
which can affect the bottom line. As our different scenarios show, the net change in returns between four and eight inches is sensitive to the price of water.

In our base case (with water at $300/acre), net returns per acre remain relatively constant with four or eight inches of irrigation in the drier sites, where the yield boost is more substantial (West Side and Shafter); at the wetter sites where there’s less of a yield boost, net returns per acre decline slightly (Figure A1). At lower water costs ($100/acre foot), the additional irrigation pass looks even more favorable at the dry sites, and per-acre returns do not fall (Figure A4). But at high water costs growers will have less incentive to apply a second 4-inch irrigation unless substantial yield boosts are expected (Figures A2 and A3).

Modeled yields assume that water for the one or two irrigation passes is applied at the optimal times. In practice, growers must manage their operations to mitigate risk and plan for unforeseen conditions in the coming season. Where eight inches of water are available and not too costly, many would likely opt to apply the full amount to hedge against poor rainfall periods. Additionally, it may be infeasible for some growers to apply as little as four inches in a single irrigation event—as we have assumed—depending on the efficiency of their irrigation system.\(^7\)

**Considering the value of water per acre-foot**

Net returns per acre provides an overall measure of potential profitability, considering the range of inputs used. But when water is a scarce resource, another relevant metric is the marginal value of irrigation water for alternative uses, on a per acre-foot basis. In our base case, going from zero to 8 inches of irrigation increases net operating returns for hay by roughly $200–$300/acre. This translates to $320–460 per acre-foot of applied water.\(^8\)

On a per-acre-foot basis, these values are comparable to the marginal value of irrigation water for some of the San Joaquin Valley’s more profitable crops (Escriva-Bou 2019, Medellín-Azuara et al. 2019). These results reinforce the idea that in an increasingly water-scarce environment, using a small amount of water strategically on water-limited crops could make good business sense and offer relatively competitive value for water under some cost and price scenarios.

**Sensitivity of net returns to commodity prices and yields**

The outcomes of different scenarios depend on operating costs, commodity prices, and ultimately crop yields. At higher hay prices, positive net operating returns may be possible across a wide range of yields. But at lower price points, higher yields are required to keep operations in the black. To illustrate this, Table A3 looks at how net operating returns vary across a wide range of yields and prices for dryland-plus hay production with 4 and 8 inches of irrigation; panel A uses our base case production costs, panel B uses our higher cost scenario, and panel C uses our lower cost scenario.

In all three cost scenarios and with four inches of irrigation, 4-ton hay yields result in positive net operating returns except when hay prices fall to $120/ton or less. Five-ton hay yields result in more comfortable margins across a wider range of hay prices, although when costs are higher (Table A3, panel B), prices below $120/ton for hay still result in negative net operating returns. In contrast, with eight inches of irrigation, 4-ton hay yields only result in positive net operating returns when prices for hay are relatively high and costs are moderate (panel A) or low (panel C). A 5-ton harvest with eight inches of irrigation can result in net positive operating returns across a wider

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\(^7\) The agronomic modeling (described in Appendix B and the main report) did not explicitly consider scenarios where a single irrigation pass applied eight inches, and the yield responses would likely be somewhat different than those shown here.

\(^8\) This is calculated as the change in net revenues per acre when going from zero irrigation to 8 inches of irrigation, divided by the incremental volume of water used (8 inches). The marginal value of irrigation water depends on changes in costs and revenues, so it is lower than the base case in our high-cost scenario (Figure A2), higher in our low-cost scenario (Figure A4), and in a similar range to the base case in our scenario with high costs and high prices (Figure A3).
range of prices and costs—including the price and cost assumptions in our base case (panel A at $165/ton of wheat).

As a frame of reference, the average modeled yields for forage at our four sites were generally high enough to generate positive net operating returns under different cost assumptions at our base case price of $165/ton, but with lower hay prices this would no longer be true for the drier sites. Since our base case estimates of operating costs are likely higher than what some farmers would pay—especially for water but possibly also for inputs like fertilizer—the picture could be more favorable in some places. But because our cost estimates do not cover overhead, net operating returns will need to be adequate to clear a profit. In wetter areas like Turlock and Visalia, where modeled average yields are highest, the potential for profitability is also highest.

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9 Average modeled hay yields with 4 inches of irrigation range from more than 6 tons/acre at the wetter sites (6.8 tons/acre in Turlock, 6.2 in Visalia) to just over 4 tons/acre at the drier sites (4.3 in West Side, 4.2 in Shafter). With 8 inches of irrigation, the wetter sites attain more than 7 tons per acre (7.5 in Turlock, 7.1 in Visalia), and the drier sites both average 5.5 tons/acre (Table A1). Extrapolating these results across the valley, Appendix B estimates that roughly 30 percent of croplands could consistently attain yields of at least 4 tons with 4 inches of irrigation, and 72 percent could do so with 8 inches of irrigation. The comparable shares for consistently attaining at least 5-ton yields are 15 and 41 percent of crop acreage, respectively.
### TABLE A3

Sensitivity of net operating returns on hay to hay prices and yields with 4–8 inches of irrigation

#### A. Net operating returns under base case production costs

<table>
<thead>
<tr>
<th>Hay yield (ton/acre)</th>
<th>4 in. irrigation Hay price ($/ton)</th>
<th>8 in. irrigation Hay price ($/ton)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>100 120 160 200 240</td>
<td>100 120 160 200 240</td>
</tr>
<tr>
<td>2</td>
<td>(284) (264) (224) (184) (144)</td>
<td>(432) (412) (372) (332) (292)</td>
</tr>
<tr>
<td>2.5</td>
<td>(209) (194) (114) (34) 46</td>
<td>(357) (307) (207) (107) (7)</td>
</tr>
<tr>
<td>3</td>
<td>(184) (124) (4) 116 236</td>
<td>(332) (272) (152) (32) (88)</td>
</tr>
<tr>
<td>4</td>
<td>(134) (54) 106 266 426</td>
<td>(282) (202) (42) 118 278</td>
</tr>
<tr>
<td>5</td>
<td>(84) 16 216 416 616</td>
<td>(232) (132) 68 268 468</td>
</tr>
<tr>
<td>6</td>
<td>(34) 86 326 566 806</td>
<td>(182) (62) 178 418 658</td>
</tr>
<tr>
<td>7</td>
<td>16 156 436 716 996</td>
<td>(132) 8 288 568 848</td>
</tr>
</tbody>
</table>

#### B. Net operating returns with higher production costs

<table>
<thead>
<tr>
<th>Hay yield (ton/acre)</th>
<th>4 in. irrigation Hay price ($/ton)</th>
<th>8 in. irrigation Hay price ($/ton)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>100 120 160 200 240</td>
<td>100 120 160 200 240</td>
</tr>
<tr>
<td>1</td>
<td>(388) (368) (328) (288) (248)</td>
<td>(618) (598) (558) (518) (478)</td>
</tr>
<tr>
<td>2</td>
<td>(338) (298) (218) (138) (58)</td>
<td>(568) (528) (448) (368) (288)</td>
</tr>
<tr>
<td>2.5</td>
<td>(313) (263) (163) (63) 37</td>
<td>(543) (493) (393) (293) (193)</td>
</tr>
<tr>
<td>3</td>
<td>(288) (228) (108) 12 132</td>
<td>(518) (458) (338) (218) (98)</td>
</tr>
<tr>
<td>4</td>
<td>(238) (158) 2 162 322</td>
<td>(468) (388) (228) (68) 92</td>
</tr>
<tr>
<td>5</td>
<td>(188) (88) 112 312 512</td>
<td>(418) (318) (118) 82 282</td>
</tr>
<tr>
<td>6</td>
<td>(138) (18) 222 462 702</td>
<td>(368) (248) (8) 232 472</td>
</tr>
<tr>
<td>7</td>
<td>(88) 52 332 612 892</td>
<td>(318) (178) 102 382 662</td>
</tr>
</tbody>
</table>

#### C. Net operating returns with lower production costs

<table>
<thead>
<tr>
<th>Hay yield (ton/acre)</th>
<th>4 in. irrigation Hay price ($/ton)</th>
<th>8 in. irrigation Hay price ($/ton)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>100 120 160 200 240</td>
<td>100 120 160 200 240</td>
</tr>
<tr>
<td>1</td>
<td>(218) (198) (158) (118) (78)</td>
<td>(299) (279) (239) (199) (159)</td>
</tr>
<tr>
<td>2</td>
<td>(168) (128) (48) 32 112</td>
<td>(249) (209) (129) (49) 31</td>
</tr>
<tr>
<td>2.5</td>
<td>(143) (93) 7 107 207</td>
<td>(224) (174) (74) 26 126</td>
</tr>
<tr>
<td>3</td>
<td>(118) (58) 62 182 302</td>
<td>(199) (139) (19) 101 221</td>
</tr>
<tr>
<td>4</td>
<td>(68) 12 172 332 492</td>
<td>(149) (69) 91 251 411</td>
</tr>
<tr>
<td>5</td>
<td>(18) 82 282 482 682</td>
<td>(99) 1 201 401 601</td>
</tr>
<tr>
<td>6</td>
<td>32 152 392 632 872</td>
<td>(49) 71 311 551 791</td>
</tr>
<tr>
<td>7</td>
<td>82 222 502 782 1,062</td>
<td>1 141 421 701 981</td>
</tr>
</tbody>
</table>

**SOURCES:** Author estimates based on information in Table A1 and text.

**NOTES:** Net operating returns shown are for dryland-plus wheat hay with 4 or 8 inches of irrigation. Panel A uses base case cost assumptions (shown in Table A1). Panel B uses the higher cost assumptions, with increased water costs from $300 to $500/af, N fertilizer costs from $0.43 to $0.75/lb, and diesel from $4.16 to $5/gal. Panel C assumes lower water costs relative to the base case ($100/af). Costs do not include overhead. See text for discussion.
References


CDFA. 2016. *California Cost of Milk Production 2016 Annual*. California Department of Food and Agriculture.


Mathesius, Konrad, Michelle Leinfelder-Miles, Mark Lundy, Daniel A. Sumner, and Donald Stewart. 2016. *Sample Costs to Produce Wheat: Sacramento Valley – Irrigated*. University of California Agriculture and Natural Resources, Cooperative Extension, Agricultural Issues Center, and University of California, Davis Department of Agricultural and Resource Economics.


Appendix B. Modeling Water-Limited Wheat Forage Yields Across the San Joaquin Valley

Introduction
How much of the San Joaquin Valley could theoretically support water-limited crops? An area’s suitability for water-limited farming will depend on many factors. These include average rainfall amount and distribution, soil type, susceptibility to salt accumulation, proximity to other dryland farming areas, and availability of and ability to deliver small amounts of supplemental irrigation—as well as the assumption that this water could not be used or sold more profitably elsewhere. Here we explore the primary agronomic limitation—water—and how precipitation variability across space and time can interact with early season irrigation events to influence the probability of achieving agronomically and economically viable yields.

In some areas of the San Joaquin Valley, especially those that receive less than 10 inches of annual rainfall on average, growing winter crops without irrigation may be infeasible. However, wetter areas of the valley could see some success under the right conditions. Critically, it is not just the overall quantity of water received that influences the success or failure of a water-limited crop, but also its variability within seasons. Especially when no supplemental irrigation is available, poorly timed or low-volume storms can lead to crop establishment failure early in the season, and when seasonal water supply is less than crop demand, yield reductions will occur. Using the modeling tools described below, we illustrate some of these possible outcomes for water-limited crops with varying levels of supplemental irrigation.

Note that this analysis depends on model-generated estimates for water-limited wheat yield, and must therefore be treated as exploratory. More work is needed to test the practical feasibility of these systems, validate model results in the field, and understand other factors that could constrain or otherwise influence water-limited yield. For instance, interactions with diverse crop rotations, tillage and crop establishment approaches, the effects of soil salinization, and the potential for interactions with weeds are not captured in this analysis.

Methods
We used winter wheat as a model crop to explore preliminary questions surrounding the agronomic feasibility of water-limited crops in the valley. Winter wheat has the advantage of being a well-studied crop with existing crop models that have been evaluated for many climates and soils globally. This gives us more confidence in deploying modeled crop growth and yield for wheat than we might have for a crop with less-developed modeling platforms. In addition, wheat and similar winter cereals (e.g., triticale, barley), can be harvested at various growth stages to create different products, a feature that enables growers to adapt their management plan to in-season weather and market conditions.

To better understand the possible scope for water-limited wheat cropping across the valley, we first estimated yields for late-stage (soft dough) wheat forage at four key sites and three irrigation scenarios—0 inches (“dryland”), 4 inches, or 8 inches of irrigation (“dryland-plus”)—using the Agricultural Production Systems Simulator (APSIM; Holzworth et al. 2014). The four sites—Turlock, Visalia, West Side, and Shafter—represented a range of average annual rainfall amounts and soil types. The drier Shafter and West Side sites receive an average of 6–7 inches annually, while the wetter Visalia and Turlock sites receive 9–12 inches annually. Irrigation events...
in the simulations were triggered by soil moisture depletion beyond a specified threshold, with the 4-inch scenario comprising a single irrigation application and the 8-inch scenario comprising two separate 4-inch applications. We focused on forage production for crops harvested at the soft dough stage of growth because we estimated that these products were more likely to provide net positive returns on operating costs under a range of yield levels, commodity prices, and operating costs than grain products or early-season (boot) forage products (see Appendix A).

Soft dough forage yields were simulated across 20 years for all four sites in APSIM. We then fit a quadratic plateau model to the estimated forage yields using total rainfall as the predictor under each of the three irrigation scenarios. Based on the modeled relationship between forage yields and total precipitation, we identified minimum precipitation amounts necessary to achieve certain yield levels. Using precipitation data across a 2.5 km² grid of irrigated cropland in the San Joaquin Valley, we applied the resulting precipitation thresholds to determine whether a given location within the valley received sufficient precipitation to achieve a given yield level in a given year across 10 years. Based on these annual estimates at each location, we calculated the percentage and total acreage receiving sufficient precipitation to achieve a yield level in 100 percent of simulated years.

We performed this process for several target yield levels: 1) 5-ton (US) dry matter yields, or the yield level that is likely to provide net positive returns on operating costs under a wide range of commodity prices and production costs (see Appendix A); 2) 4-ton yields, or the yield level that is likely provide net positive operating returns as long as prices are high and/or costs are relatively low; and 3) maximum yields, which represent the point at which yields stopped increasing even with increasing precipitation amounts. Details on price/cost assumptions for calculating net operating returns from water-limited wheat outputs are presented in Appendix A.

Note that maximum yields in these simulations did not necessarily represent the maximum yield potential of the crop under ideal growing conditions. For example, a typical irrigated winter wheat crop will achieve higher grain or forage yields with 10 to 15 inches of irrigation applied in a season, depending on climate, soil type, and efficiency of the irrigation system. Also, maximum yields varied slightly across the irrigation scenarios and ranged from 6.1 tons/acre in the no-irrigation scenario to 7.5 tons/acre in the 8-inch scenario. This difference primarily represents the effects of improved coincidence of water supply and demand in the irrigated scenarios and the addition of 50 pounds/acre of nitrogen fertilizer during simulated irrigation events.

Given inherent variability in forage yield at a given level of water input, the spatial distribution of precipitation requirements for achieving target yield levels across the valley were sensitive to the uncertainty of the statistical model used to determine precipitation thresholds. We therefore present both the average area that could achieve the three yield levels, as well as the upper and lower 95% confidence intervals to demonstrate the possible range of outcomes while accounting for statistical uncertainty.

A companion article with complete details of the methodology is available from the authors upon request, and is in preparation for submission to a peer-reviewed journal (Peterson, Pittelkow, and Lundy, forthcoming).

**Minimum and maximum water-limited wheat forage yields**

Figure B1 presents the valley-wide likelihood of achieving 4-ton, 5-ton, and maximum wheat forage yields on currently irrigated cropland (2016 estimates) in the San Joaquin Valley under the three irrigation scenarios. As water is the primary limitation to crop establishment and growth in these simulations, the probability of achieving 4-ton and 5-ton forage yields increases greatly with 4–8 inches of irrigation, but the likelihood of achieving

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11 Forage yields are reported at 12 percent moisture content.
maximum yields remains low. Even with 8 inches of irrigation, maximum wheat forage yields (6.1 tons/acre for the 0-inch irrigation scenario, 7.4 tons/acre for the 4-inch irrigation scenario, and 7.5 tons/acre for the 8-inch irrigation scenario) are largely unattainable across much of the valley, with the exception of the wetter northeastern corner. In contrast, 4 inches of irrigation is enough to attain at least 4 tons—and occasionally 5 tons—of dry matter across a much larger area, primarily in the northern half and eastern edge of the valley.

**FIGURE B1**
Probability of achieving 4-ton, 5-ton, and maximum wheat forage yields

**SOURCES:** Historical precipitation data are from PRISM gridded climate data (PRISM Climate Group 2014). Irrigated cropland extent is from the California Department of Water Resources 2016 land use layer.

**NOTES:** The spatial extent represents irrigated cropland in the San Joaquin Valley in 2016. Dots indicate the location of the four sites used in simulations to determine productivity levels under a range of rainfall totals. See text for details.
Confidence intervals for 5-ton forage yields

As with any extrapolation exercise, these results are sensitive to the assumptions underlying our statistical models, including uncertainty around the thresholds for the amount of rainfall required to reach a given yield level. Given this, we also present the range of possible outcomes from our modeled data. Figure A2 presents the upper and lower 95 percent confidence intervals for the 5-ton yield level. From this, we can see that on the more optimistic end of the range (where less water is required to achieve the yield target, or the lower confidence interval), 5-ton yields were likely across a larger area of the valley. On the more pessimistic end of the range (where more water is required to achieve the yield target, or the upper confidence interval), 5-ton yields were less likely under any irrigation scenario.

These ranges are important to consider given the exploratory nature of this analysis. The results presented here are an illustration of only one set of possible outcomes, acknowledging the full set of limitations described above. More on-the-ground work is required to understand how reasonable our assumptions and results are, and to improve our confidence in these estimates.
FIGURE B2
Confidence intervals for five-ton forage yields across the San Joaquin Valley

*SOURCES:* Historical precipitation data are from PRISM gridded climate data (PRISM Climate Group 2014). Irrigated cropland extent is from the California Department of Water Resources 2016 land use layer.

*NOTES:* The spatial extent represents irrigated cropland in the San Joaquin Valley in 2016. Dots indicate the location of the four sites used in simulations to determine productivity levels under a range of rainfall totals. See text for details.

*Sensitivity of spatial outputs to model assumptions*

As noted above, the size of the area with potential suitability for water-limited wheat was sensitive to our assumptions regarding model fit and water input requirements. Table B1 presents the range of possible outcomes for the amount of currently irrigated cropland area that could achieve a given forage yield level in 100 percent of simulated years with 0, 4 inches (single application), and 8 inches of irrigation (two applications). It also presents the model estimate for the average amount of rainfall required to achieve the given yield level. The range of
outcomes is represented by the 95 percent confidence interval (CI), or the range of values that are likely to contain the mean rainfall requirement if samples of the same size were repeatedly drawn from the population. The upper confidence limit reflects the more pessimistic possibility—more rainfall is required to reach the yield level—while the lower confidence limit reflects the more optimistic possibility—less rainfall is required to reach the yield level.

TABLE B1

Percent of cropped area likely to achieve yield level, with 95 percent confidence intervals

<table>
<thead>
<tr>
<th>Rainfall requirement (in.)</th>
<th>No irrigation</th>
<th>4 inches irrigation (single application)</th>
<th>8 inches irrigation (two 4-inch applications)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soft dough forage yield (tons/acre)</td>
<td>mean</td>
<td>95% CI</td>
<td>mean</td>
</tr>
<tr>
<td>4</td>
<td>8.5</td>
<td>6.0</td>
<td>11.1</td>
</tr>
<tr>
<td>5</td>
<td>10.9</td>
<td>8.3</td>
<td>13.5</td>
</tr>
<tr>
<td>Max (6.1 tons/acre)</td>
<td>17.1</td>
<td>14.5</td>
<td>19.6</td>
</tr>
<tr>
<td>Soft dough forage yield (tons/acre)</td>
<td>mean</td>
<td>95% CI</td>
<td>Mean</td>
</tr>
<tr>
<td>4</td>
<td>5.1</td>
<td>3.5</td>
<td>6.7</td>
</tr>
<tr>
<td>5</td>
<td>6.7</td>
<td>5.1</td>
<td>8.3</td>
</tr>
<tr>
<td>Max (7.4 tons/acre)</td>
<td>15.4</td>
<td>13.7</td>
<td>17.0</td>
</tr>
<tr>
<td>Soft dough forage yield (tons/acre)</td>
<td>mean</td>
<td>95% CI</td>
<td>mean</td>
</tr>
<tr>
<td>4</td>
<td>3.3</td>
<td>1.9</td>
<td>4.8</td>
</tr>
<tr>
<td>5</td>
<td>4.6</td>
<td>3.1</td>
<td>6.1</td>
</tr>
<tr>
<td>Max (7.5 tons/acre)</td>
<td>11.3</td>
<td>9.8</td>
<td>12.8</td>
</tr>
</tbody>
</table>

SOURCES: Author estimates based on information in Figures B1 and B2.

NOTES: *Rainfall requirement* represents the threshold of precipitation needed to achieve a given yield level. The upper confidence interval (CI; right hand column under 95 percent CI) represents the upper range of the rainfall requirement, where more water is required to reach the same yield level. The lower CI (left hand column under 95 percent CI) represents the lower range of the rainfall requirement, where less water is required to reach the same yield level. Numbers in parentheses represent total number of acres within irrigated cropland in the San Joaquin Valley (2016 data) that could achieve the given outcome. See text for methodological details.

These results demonstrate the range of possible outcomes under different irrigation scenarios taking into account the uncertainty inherent in the model. With no irrigation, the model estimated that around five percent of valley cropland can hit 4-ton yields on average, but this ranges from 19 percent (887,300 acres) to <1 percent (13,300 acres) depending on a rainfall requirement of 6 and 11.1 inches, respectively. The mean area drops to 0 percent for 5-ton yields, but with more optimistic rainfall requirements it expands to up to 7 percent of the valley (328,300 acres). Nowhere in the valley could achieve the maximum yield of 6.1 tons/acre of dry matter in 100 percent of years. With 4 inches of irrigation, the likelihood of achieving 4-ton yields increases to 30 percent of cropland (ranging from 15–67 percent or 701,000–3.2 million acres), and the likelihood of achieving 5-ton yields increases to 15 percent of cropland (ranging from 7–30 percent or 328,300–1.4 million acres). Still, nowhere in the valley could achieve the maximum yield of 7.4 tons/acre. With 8 inches of irrigation, a much larger area in the valley could potentially attain 4-ton yields—72 percent of cropland (ranging from 34–99 percent or 1.6–4.6 million
acres). Moreover, around 41 percent of cropland (19–79 percent or 878,000–3.7 million acres) could hit 5-ton yields, whereas less than 1 percent (22,200 acres) could achieve maximum 7.5 ton/acre yields, even under optimistic rainfall requirements.

Achieving 4–5 ton yields in 100 percent of years may be a somewhat arbitrary expectation, so the values presented here may underestimate the potential area for which these yields could be achieved with reasonable frequency—e.g., in 80 or 90 percent of years. Nevertheless, this analysis provides a starting point for understanding where dryland and dryland-plus crops stand a better chance of success given rainfall patterns that have prevailed in the past 10 years. We can also see that 8 inches of irrigation, when applied in two, targeted 4-inch irrigation events, is enough to expand the possible area that could grow harvestable quantities of wheat forage—and presumably other dryland-appropriate crop types as well. Further work is needed to understand the other agronomic and practical factors that may constrain dryland and dryland-plus cropping across the valley and increase our certainty in modeled estimates.
References


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