# Introduction

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# Materials and Methods

## Production scenarios

The Department of Agricultural and Resource Economics at University of California periodically releases regional estimates for costs of production for select commodities, which are based on county-based representative management schedules which are determined through iterative discussions between extension employees and producers. Based on availability of these cost-estimates and alfalfa production patterns in California, three regions were chosen: Intermountain region Siskiyou County 2020 (Northern CA); Southern San Joaquin Valley Tulare County 2016 (Central CA); Imperial County 2023 (Southern CA). These counties represent a range of Californian irrigated alfalfa production systems (Figure 1 – add labels to counties if we want to keep this figure).

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| A map of the state of california  Description automatically generated |
| Figure 1 California USA counties with more than 10,000 hectares (dark blue) of irrigated alfalfa production, with Siskiyou representing Northern CA, Tulare representing Central CA, and Imperial County representing Southern CA, respectively (highlighted in red) |

For each county a baseline scenario was constructed using information provided from the cost of production reports. When data necessary for the analyses were not provided, publicly available data and expert knowledge were used as supplemental data sources (see supplemental material for details).

## Impact quantification

Two impact categories (energy use, net greenhouse gas emissions) were used in this study on both a per yield basis (one metric ton of baled alfalfa dry matter adjusted to 0% moisture) and on a per area basis (one hectare of alfalfa cultivation). The analysis included establishment, production, and stand termination with all activities amortized over the stand life of the alfalfa crop. Therefore, the four functional units of analysis were:

1. Energy used per unit land per year (MJ ha-1 year-1)
2. Energy used per unit of dry matter production per year (MJ Mg-1 year-1)
3. Carbon dioxide equivalents (CO2e) released (positive) or sequestered (negative) per unit land area per year (CO2e ha-1 year-1)
4. CO2e released/sequestered per unit of dry matter produced per year (CO2e Mg-1 year-1)

A model was built in R (CITE) for each functional unit using the contributing components listed in Table 1. The primary data sources used in this study include University of California Davis (UC Davis) extension cost and return studies (CITE), XX Details about each component (including exact data sources and calculations) are described in detail in supplemental material and the calculations are available as R code in a Github repository supporting this publication (to be made public upon acceptance).

##### Table X. Summary of components contributing to energy and GHG impacts from irrigated alfalfa production in California

|  |  |  |
| --- | --- | --- |
| **Impact category** | **Direct** | **Indirect** |
| Energy | Consumption of energy on the farm in the form of fuel used to run tractors and irrigation pumps | Energy used to manufacture products consumed during alfalfa production, including fertilizers, pesticides, and seed. Manufacturing of durable products such as machinery and pumps was not included. |
| Greenhouse gas (GHG) emissions | GHG released from combustion of fuel, CO2 sequestered in the soil and reduction in N2O resulting from a given intervention based on California Healthy Soils models, N2O derived from the application of fertilizers and plant material to the soil | GHG released during the manufacturing of products consumed during alfalfa production, N2O produced from volatilization and leaching of N from the soil, reduction in fertilizer use in subsequent crop attributed to alfalfa stand (CITE). |

## Uncertainty and sensitivity analyses

The impacts of technical and methodological assumptions were tested into order to assess the uncertainty in the estimates by varying continuous parameters from 50% to 150% of the assumed baseline values, and by varying categorical values by each of their possible values. Additionally, the sensitivity of results to variation in contextual assumptions was tested by varying inputs from a theoretical minimum to a theoretical maximum. Supplementary material includes more details on these tests.

## Scenario analyses

In order to explore future scenarios or interventions, we changed model parameters to achieve the following scenarios within the three production contexts:

1. Electric harvesting equipment
2. Electric tractor for spraying and fertilizer applications
3. Electric irrigation equipment
4. Deficit irrigation production
5. Drip irrigation installation

# Results

Table 2. Characteristics of the three representative counties under baseline conditions

|  |  |  |  |
| --- | --- | --- | --- |
|  | **Siskiyou County (North)** | **Tulare County (Central)** | **Imperial County (South)** |
| Location and Koppen climate type | Northern California (CA), warm summer Mediterranean | Central CA, cold semi-arid | Southern CA, hot desert |
| Planting rate | 22.4 kg ha-1 | 28 kg ha-1 | 22.4 kg ha-1 |
| Number of harvests | 3 | 9 (2 haylage1, 7 hay2) | 12 (3 green chop3, 9 hay) |
| Average number of field passes per year (for reference only) | 6.8 | 11 | 16 |
| Fertility | 336 kg ha-1 monoammonium phosphate (MAP) at establishment, 94.6 L ha-1 liquid ammoniated phosphate (10-34-0) each production year | 336 kg ha-1 MAP at establishment | 336 kg ha-1 MAP and 280 kg ha-1 potash at establishment, 84 kg ha-1 MAP and 280 kg ha-1 potash each production year |
| Total dry matter yields | 3 Mg ha-1 | 8 Mg ha-1 | 8 Mg ha-1 |
| Irrigation source from ground/surface water | 50/50 | 50/50 | 0/100 |
| Well depth4 | 46 meters | 152 feet | NA |
| Water requirements | 47 ha-mm establishment,  249 ha-mm each year of production | 83 ha-mm establishment,  249 ha-mm each year of production | 187 ha-mm establishment,  872 ha-mm each year of production |
| Irrigation water delivery method(s) | Irrigation pivots for establishment and production | Sprinkler for establishment, flood for production | Sprinkler for establishment, flood for production |
| Irrigation pump energy source | Diesel | Diesel | Diesel |
| Subsequent crop, fertilizer credit from alfalfa | Wheat, 89.6 kg N ha-1 credit | Tomatoes, 190.4 kg N ha-1 credit | Wheat, 89.6 kg N ha-1 credit |

1 Haylage is alfalfa that is cut and left to wilt in the field before being chopped and transported to a dairy, where it is stored in a bag, pile, or bunker for the ensiling process (CITE)

2 Hay is xxxx

3 Green chop is XXXX

4Based on county-level averages reported by the NRCS Energy Estimator Tool (<https://ipat.sc.egov.usda.gov/Default.aspx>)