# Introduction

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# Materials and Methods

## Alfalfa production scenarios

The Department of Agricultural and Resource Economics at the University of California (UC) periodically releases regional estimates for costs of production for select commodities, including alfalfa. The cost-estimates are based on county-level representative management schedules 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 for the present analysis: (1) Intermountain region Siskiyou County 2020 (Northern CA); (2) Southern San Joaquin Valley Tulare County 2016 (Central CA); (3) Imperial County 2023 (Southern CA). These counties represent a range of Californian irrigated alfalfa production systems (Figure 1 – map). For each county, a baseline production scenario was constructed using information provided from the cost of production reports. Yields were estimated using the United States Department of Agriculture (USDA) National Agricultural Statistics Service (NASS) California County Agricultural Commissioners annual Crop Reports for 2018-2022 for each county (CITE). 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

Impacts (energy use, net greenhouse gas emissions) were calculated on an annual, per land area basis. The analysis included establishment, production, and stand termination with all activities amortized over the stand life of the alfalfa crop (which was assigned based on UC extension cost and return studies).

1. Energy used per unit land per year (MJ ha-1 year-1)
2. Carbon dioxide equivalents (CO2e) released (positive) or sequestered (negative) per unit land area per year (CO2e ha-1 year-1)

Impacts were also converted to a per yield basis (one metric ton of baled alfalfa dry matter adjusted to 0% moisture) using the total dry matter yields produced over the stand life of the alfalfa.

## Model

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 included UC cost of production reports, USDA NASS, the US Department of Energy (DOE) Greenhouse gases, Regulated Emissions, and Energy use in Technologies (GREET®) model version CA-GREET4.0 (CITE), National Resources Conservation Service (NRSC) resources, and California’s Healthy Soils Program data which is driven by the COMET-Farm™ tool (CITE). 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 1. 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 to move and distribute water for irrigation with 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 | GHGs released from combustion of fuel; N2O derived from the application of fertilizers and plant material to the soil; CO2 sequestered in the soil and reduction in N2O resulting from a given intervention | GHGs 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, sensitivity, and scenario analyses

The impacts of technical and methodological assumptions (e.g., conversion factors) on estimated impacts were tested by varying continuous parameters from approximately 50% to 150% of the assumed baseline values, and by varying categorical assumptions by each of their possible values. Additionally, the sensitivity of results to variation in contextual assumptions (e.g., fuel type, irrigation pump efficiency) was tested by varying inputs from a theoretical minimum to a theoretical maximum. For both of these tests, single parameters were changed at a time (supplementary material includes more details on these tests). In order to avoid parameter change combinations that did not represent realistic production conditions, we limited our multi-parameter changes to scenarios identified by stakeholders as meaningful and interesting:

1. Electrifying
   1. harvesting equipment
   2. tractor for spraying and fertilizer applications
   3. irrigation equipment
2. Deficit irrigation production
3. Drip irrigation for production
4. Stand life extension

# Results

Table 2. Baseline characteristics of the three California (CA) alfalfa production regions selected for this study

|  |  |  |  |
| --- | --- | --- | --- |
|  | **Northern CA** | **Central CA** | **Southern CA** |
| Location | Siskiyou County | Tulare County | Imperial County |
| Koppen climate type | Warm summer Mediterranean | Cold semi-arid | 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 | 14.1 Mg ha-1 year-1 | 20.2 Mg ha-1 year-1 | 16.6 Mg ha-1 year-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>)