# Goal(s)

Determine the potential for irrigated Californian alfalfa to be climate-neutral

# End user target

Producers (energy + carbon payments)

Policy makers (GHG emissions)

# Functional unit(s):

One hectare of land

One Mg of dry matter

# System boundaries:

Cradle to roadside (defend with percent that is sold)

# Notes:

Lots of warnings about picking one impact category and calling it an LCA

A need to distinguish between uncertainty and variability

Energy is pretty easy. GHG start to require lots of assumptions (what fuel are you using, etc.)

# Components of alfalfa production needing GHG estimates

1. Fuel combustion for field operations **30 kg co2e/ha per pass**
2. Fuel manufacturing **30 kg co2e/ha per pass**
3. Insecticide/herbicide manufacturing
4. Seed production
5. Fertilizer manufacturing **200 kg CO2e/ha (combustion only?)**
6. Irrigation energy **2,000 kg CO2e/ha**
7. Nitrous oxide emissions **100 kg co2e/ha from fertilizer**, **5-500 from roots**
8. Avoided emissions from reduced fertilizer needs in next crop **10 kg CO2e avoided per kg N avoided/ha; (could be 100!) 200 kg co2e/ha**
9. Carbon sequestered **500 kg co2e/ha/year**

**Tulare back-of-envelope example**

|  |  |  |
| --- | --- | --- |
|  | **Flow** | **kg co2e per ha per year** |
| 1 | Fuel combustion for field operations | 1,000 |
| 2 | Fuel manufacturing | 1,000 |
| 3 | Insecticide/herbicide manufacturing | 100 |
| 4 | Seed production | 10 |
| 5 | Fertilizer manufacturing | 200 |
| 6 | Irrigation energy | 2,000 |
| 7 | Nitrous oxide emissions | 200 |
| 8 | Avoided emissions from reduced fertilizer in next crop | 200 |
| 9 | Carbon sequestered | 500 |

# Fuel used in field operations

***~30 kg CO2eq/ha per pass (not including manufacturing of the fuel)***

The USDA (I actually don’t know who developed these fuel estimates) has a dataset they use for running erosion models. The dataset includes different types of field operations, with each operation assigned a fuel consumption value (in liters of diesel consumed per acre). These estimates were created in the 1980s.

For non-soil disturbing operations, the range in fuel consumption is quite low, and general categories are as follows:

|  |  |  |
| --- | --- | --- |
| Operation | Erosion model fuel use (gallons of diesel per acre) | Gallons diesel per hectare |
| Sprayer | 0.133 | 0.33 |
| Planting, double disk opener | 0.655 | 1.62 |
| Plant material handling (chop, flail, shred) | 0.747 | 1.85 |
| Harvesting hay/silage | 1.61 | 4.06 |

For Tulare, there are 28 non-harvest passes over 3 years and 32x3 passes for harvests. This is an average of roughly 40 passes per year. There is roughly 10 kg co2e released per gallon of fuel, and say it takes 3 gallons of fuel per hectare. That means a pass releases ~ 30 kg co2 from fuel combustion.

*FTM assumes ~60 lbs CO2eq/acre for harvesting (Table 20). This equates to about 53 kg CO2eq/ha. If I use the 1.61 gal diesel per acre above and the 10.21 kg CO2eq per gallon of diesel, I get ~50 kg CO2eq/ha. This means the FTM estimates are only accounting for the actual baling component (and not all the operations that lead up to it, which is reasonable), and it doesn’t include the energy/GHG used/emitted in the manufacture of the fuel used.*

For tillage operations, there is some variability between similar operations.

Converting from fuel used to CO2 emissions should have two components: the CO2 released from the actual burning of the fuel, and the CO2 released during the manufacturing of the fuel. The following reference includes the amount released from combustion (which I confirmed in the Alfalfa notes R project – the 10.21 kg CO2 is literally just the amount of carbon contained in a gallon of diesel).

https://www.epa.gov/climateleadership/ghg-emission-factors-hub

Table

Description automatically generated

I don’t know where to get information on the GHG associated with the manufacture of fuels. Probably GREET?

# Fuel manufacturing

From a paper, it said ethanol’s carbon intensity is 50 gco2e per MJ ethanol. Conversions (45 MJ/kg ethanol) comes out to 6.6 kg co2e/gal. The paper says this is 40% lower than other fuels. So let’s say 10 kg co2e/gal. This is roughly equivalent to the amount released upon combustion.

# Pesticide manufacture

Look at that Audsley paper.

They say:

214 MJ/kg ai for insecticides

168 for fungicides

454 for preglone + glyphosate

264 for not preglone + glyphosate

Tulare applied 2 pints per acre of Roundup PowerMaxx which has 5.88 lbs glyphosate per gallon.

2 pints is 0.25 gallons, so that is 1.47 lbs of glyphosate per acre, or 1.65 kg/ha.

To get the maximum, let’s say it is 454 \* 1.65 = 750 MJ/ha.

Now it depends where the energy to create this chemical comes from. If it comes from a coal-fired power plant then 1MWh releases 850 kg co2e. 1 MJ is 0.0002777 MWh. This could mean 177 kg co2e/ha per Roundup application?

# Fertilizer manufacture

**~200 kg CO2e/ha**

From the FTM Table 2 (which I’m unsure how it was created, seems to be loosely taken from the Greet ag-chemicals info. Not sure how they converted BTUs to CO2e).

For MAP, they list 6,521 BTUs/lb product. In Tulare they applied 200 lbs per ac, so 1,304,200 btus/ac, or roughly 20 gallons of diesel used per hectare. FTM says ther are 22.7 lbs of co2 eq in a gal of diesel (again, only combustion?), so ~200 kg co2e/ha.

# Seed production

# Irrigation energy

The NRCS energy estimator tool (<https://ipat.sc.egov.usda.gov/Default.aspx>) gives gallons of diesel (or whatever fuel you choose), but uses state-wide estimates for the depth of well and amount of water applied. Those can be overwritten, we just need good data to support those over-writings. For this exercise I put in a zipcode in Tulare County, and it estimated a 200+ foot depth well and 50 ac-in of water application for alfalfa. Assuming flood irrigation, this produced an estimate of 67 gallons of diesel used per acre. Using FTM’s conversions, this equated to 1,700 kg co2e per hectare. I made a github repo comparing the FTM estimates to the NRCS estimates. FTM estimates are much, much lower but I think they have a units problem.

# Nitrous oxide emissions

Using IPCC dry-area estimates, the range in CO2eq from N2O emissions avoided per kg N applied is 0-0.005 Mg CO2eq/kgN. The kg N is supposed to include the N applied as fertilizer, the N contained in above ground biomass left in the field, and the N contained in below-ground biomass.

The Tulare example applied 200 lbs of 11-52-0, meaning there was 22 pounds of N applied per acre, roughly 22 kg/ha. This equates to 110 kg co2e/ha from the fertilizer.

A paper from Serbia estimated there was 150 kg root N per ha in an alfalfa field (Vasileva et al. 2015). Not the best source, but fine for estimating. It seems a bit high? They say there is 3 Mg of root material, which would mean the roots are 5% nitrogen.

Another method, if you are adding 500 kg of co2 (see carbon sequestered), that is 130 kg of C. If soil has a C:N ratio of 10, that would mean you are adding 13 kg of N per year to the soil. So root N could be anywhere from 10 to 100 kg N per ha per year. So anywhere from 50-500 kg co2e/ha.

# Avoided emissions

IPCC has direct and indirect emissions. Additionally, you could account for the reduced fertilizer manufacturing emissions.

Direct

Using IPCC dry-area estimates, the range in CO2eq from N2O emissions avoided per kg N applied is 0-0.005 Mg CO2eq/kgN avoided.

Indirect

Need to investigate. Not sure how big of a problem nitrate leaching is in dry areas?

Manufacturing

See fertilizer manufacture for details on that component. Assuming the farmer uses the most GHG-intensive N source of ammonium nitrate, for every kg N avoided they would get a credit of 0.007 Mg CO2eq/kgN.

Best case scenario: 0.012 Mg CO2eq avoided per kg N not applied. About 10 kg.

# Carbon sequestered

Using the ‘Healthy Soils’ estimates in Tulare county for adding a perennial crop to a basic rotation, they estimate 26 metric tons (Mg?) of co2e will be sequestered per 100 acres of implementation.

26000 kg co2 per 100 acres = 260 kg co2 per acre is roughly 500 kg co2e per ha per year.