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CLM crops
A process based crop growth model

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UCAR

Motivation for crop modeling

- Crop yields => Food supply
- Biofuel crop yields => Biofuel supply
- Land atmosphere interactions
  - Biogeophysical
    - Albedo, energy flux partitioning
  - Biogeochemical
    - Carbon uptake and release

CLM4

Temp. corn

Temp. cereals

Temp. soybean

effects on atm. ⤵

Levis et al. (2012)

Based on Agro-IBIS
(Kucharik & Brye, 2003)
crop code

CLM4

Temp. corn

Temp. cereals

Temp. soybean

effects on atm.

Levis et al. (2012)

CLM4.5

w/ options to fertilize & irrigate

Oleson et al. (2013)

enhanced soil C decomposition

Soy N fixation

Levis et al. (2013)

Drewniak et al. (2013)

CLM4

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Soy N fixation

Levis et al. (2013)

Drewniak et al. (2013)

CLM5

Trop. corn

Trop. soybean

Sugarcane

Rice

Cotton

Winter wheat

Grain CN product pool

78 plant function types if turned on crop model in CLM5

! 0 => not_vegetated
! 1 => needleleaf_evergreen_temperate_tree
! 2 => needleleaf_evergreen_boreal_tree
! 3 => needleleaf_deciduous_boreal_tree
! 4 => broadleaf_evergreen_tropical_tree
! 5 => broadleaf_evergreen_temperate_tree
! 6 => broadleaf_deciduous_tropical_tree
! 7 => broadleaf_deciduous_temperate_tree
! 8 => broadleaf_deciduous_boreal_tree
! 9 => broadleaf_evergreen_shrub
! 10 => broadleaf_deciduous_temperate_shrub
! 11 => broadleaf_deciduous_boreal_shrub
! 12 => c3_arctic_grass
! 13 => c3_non-arctic_grass
! 14 => c4_grass
! 15 => c3_crop
! 16 => c3_irrigated
! 17 => temperate_corn
! 18 => irrigated_temperate_corn
! 19 => spring_wheat
! 20 => irrigated_spring_wheat
! 21 => winter_wheat
! 22 => irrigated_winter_wheat
! 23 => temperate_soybean
! 24 => irrigated_temperate_soybean
! 25 => barley
! 26 => irrigated_barley
! 27 => winter_barley
! 28 => irrigated_winter_barley
! 29 => rye
! 30 => irrigated_rye
! 31 => winter_rye
! 32 => irrigated_winter_rye
! 33 => cassava
! 34 => irrigated_cassava
! 35 => citrus
! 36 => irrigated_citrus
! 37 => cocoa
! 38 => irrigated_cocoa
! 39 => coffee
! 40 => irrigated_coffee
! 41 => cotton
! 42 => irrigated_cotton
! 43 => datepalm
! 44 => irrigated_datepalm
! 45 => foddergrass
! 46 => irrigated_foddergrass
! 47 => grapes
! 48 => irrigated_grapes
! 49 => groundnuts
! 50 => irrigated_groundnuts
! 51 => millet
! 52 => irrigated_millet
! 53 => oilpalm
! 54 => irrigated_oilpalm
! 55 => potatoes
! 56 => irrigated_potatoes
! 57 => pulses
! 58 => irrigated_pulses
! 59 => rapeseed
! 60 => irrigated_rapeseed
! 61 => rice
! 62 => irrigated_rice
! 63 => sorghum
! 64 => irrigated_sorghum
! 65 => sugarbeet
! 66 => irrigated_sugarbeet
! 67 => sugarcane
! 68 => irrigated_sugarcane
! 69 => sunflower
! 70 => irrigated_sunflower
! 71 => miscanthus
! 72 => irrigated_miscanthus
! 73 => switchgrass
! 74 => irrigated_switchgrass
! 75 => tropical_corn
! 76 => irrigated_tropical_corn
! 77 => tropical_soybean
! 78 => irrigated_tropical_soybean

How we simulate crop growth?

Temperature

Photosynthesis

Water

Evapotranspiration

Soil

Nutrient uptake

CO_2

Carbon allocation

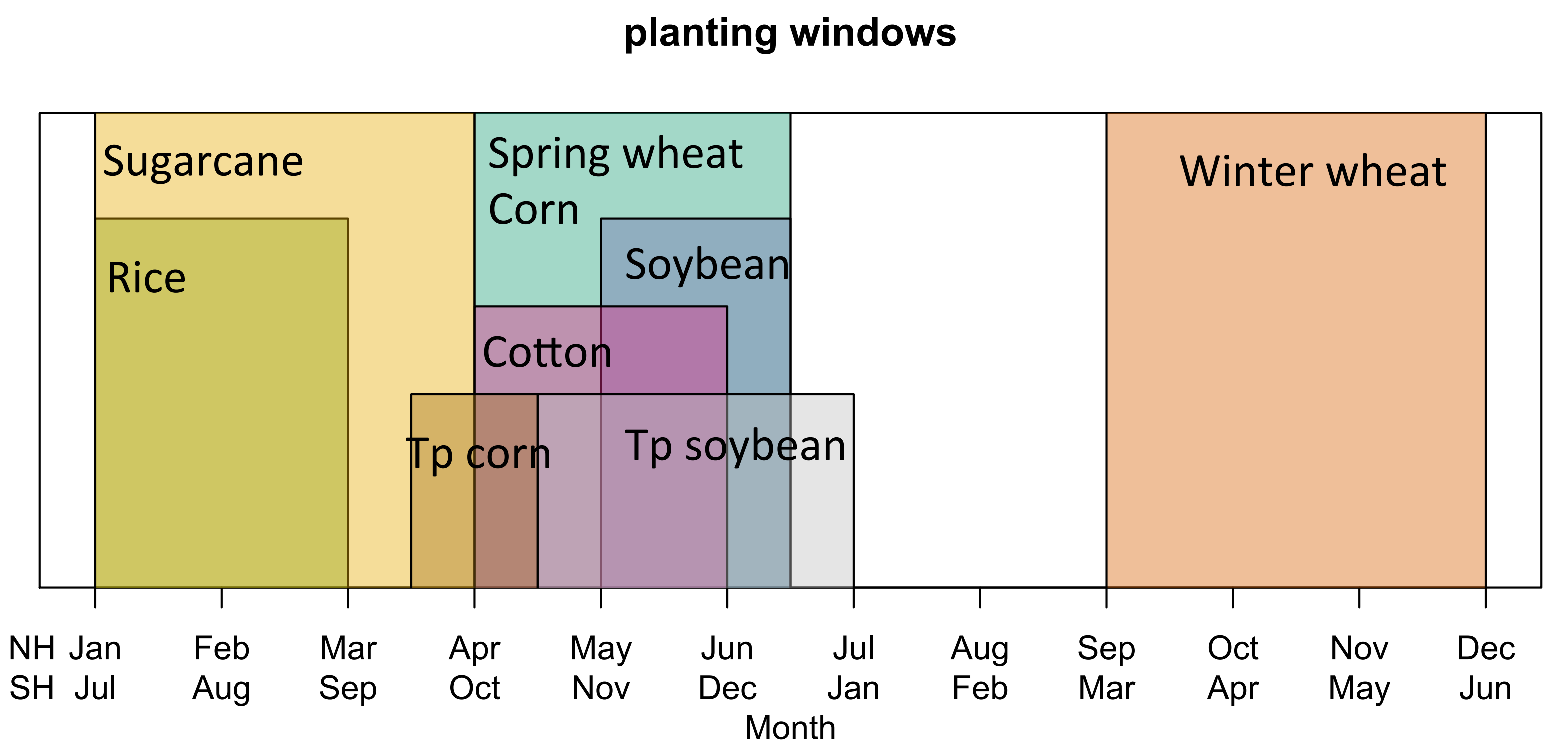
Crop phenology

Phase 1: Planting

- Within planting windows: meet temperature thresholds

e.g., for corn: min T10>6 °C and T10>10 °C

- Still allows planting if not meet the threshold and past planting windows



Crop phenology

Phase 2: Leaf emergence:

- Based on heat accumulated in the top soil layers

e.g., for winter wheat GDD_{tsoi}>3%GDDmat=51 ^{o}days

- Leaf, stem, root carbon increasing

Phase 3: Grain fill:

- Based on heat accumulated since leaf emerge

e.g., for winter wheat GDD_{plant}>40%GDD_{mat}=680

- Leaf carbon decreasing
- Grain carbon increasing

Phase 4: Harvest:

- Exceed the growing degree days for maturity
- or, exceed the maximum days for crop growth

e.g., for winter wheat GDD_{plant}>GDD_{mat}=1700,
or days since planting > 330 days

Crop carbon allocation

f1=aroot:aleaf
f3=astem:aleaf
f5=agrain:aleaf

Phase2:

$$a_{\text{repr}} = 0,$$

$$a_{froot} = a^i_{froot} - (a^i_{froot} - a^f_{froot})\frac{\text{GDD}_{T_{2m}}}{\text{GDD}_{\text{mat}}} \quad \text{where} \quad \frac{\text{GDD}_{T_{2m}}}{\text{GDD}_{\text{mat}}} \le 1,$$

$$a_{\text{leaf}} = (1 - a_{froot})\frac{a^i_{\text{leaf}}(e^{-b} - e^{[-b(\text{GDD}_{T_{2m}}/h)]})}{e^{-b} - 1} \quad \text{where} \quad b = 0.1,$$

$$a_{\text{livestem}} = 1 - a_{\text{repr}} - a_{froot} - a_{\text{leaf}},$$

Phase3:

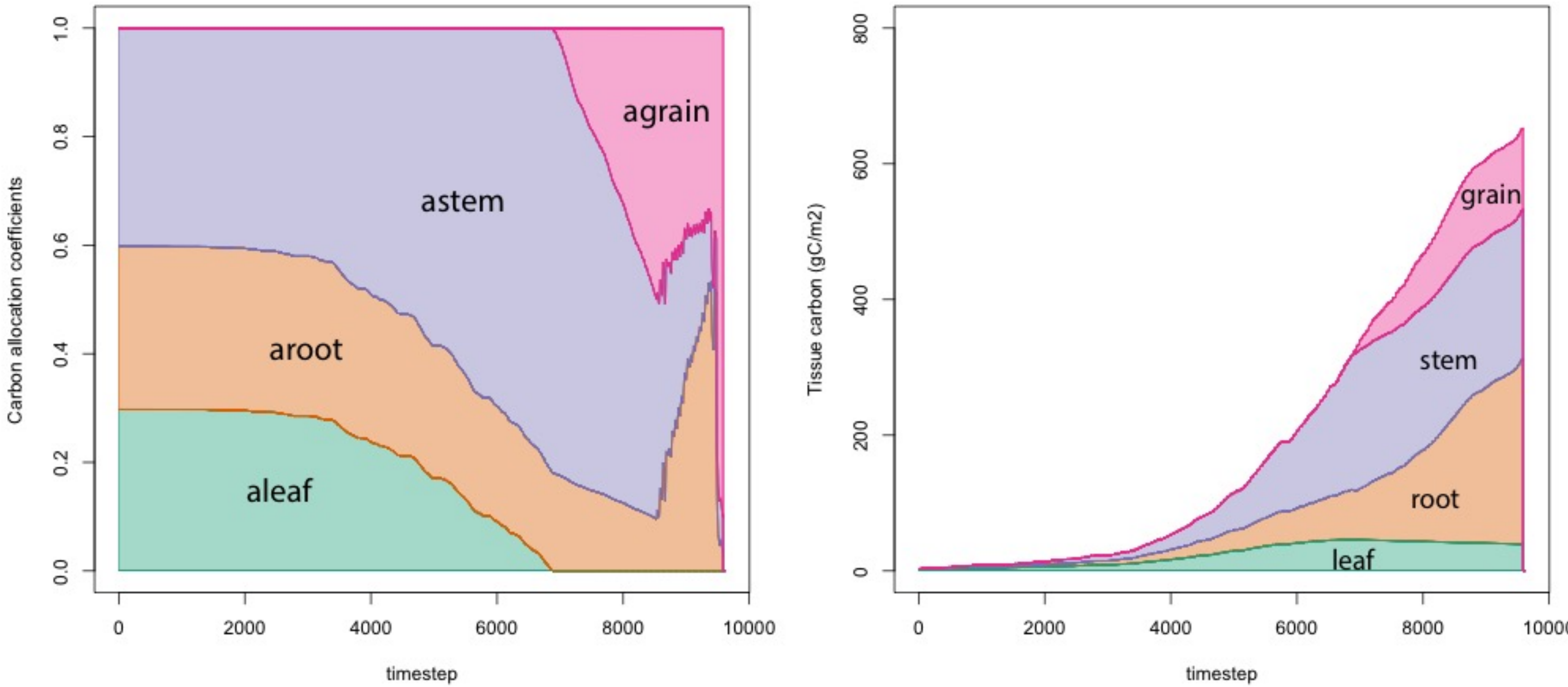
$$a_{\text{leaf}} = a_{\text{leaf}}\left(1 - \frac{\text{GDD}_{T_{2m}} - h}{\text{GDD}_{\text{mat}} d_L - h}\right)^{d^{\text{leaf}}_{\text{alloc}}} \ge a^f_{\text{leaf}} \quad \text{where} \quad \frac{\text{GDD}_{T_{2m}} - h}{\text{GDD}_{\text{mat}} d_L - h} \le 1,$$

$$a_{\text{livestem}} = a^{i,3}_{\text{livestem}} \quad \text{when} \quad a^{i,3}_{\text{livestem}} \le a^f_{\text{livestem}} \quad \text{else} \ldots,$$

$$a_{\text{livestem}} = a_{\text{livestem}}\left(1 - \frac{\text{GDD}_{T_{2m}} - h}{\text{GDD}_{\text{mat}} d_L - h}\right)^{d^{\text{stem}}_{\text{alloc}}} \ge a^f_{\text{livestem}} \quad \text{where} \quad \frac{\text{GDD}_{T_{2m}} - h}{\text{GDD}_{\text{mat}} d_L - h} \le 1,$$

$$a_{\text{repr}} = 1 - a_{froot} - a_{\text{livestem}} - a_{\text{leaf}}$$

Crop Carbon allocation



Leaf carbon => leaf area index, canopy height
Grain carbon => yield

Adding crop specific processes

Additional processes for winter wheat:

- Vernalization process

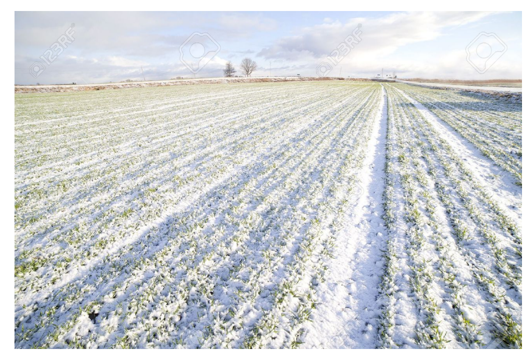
winter crops must expose to low, nonfreezing temperatures(optimum temperature=4.9^{o}C) to enter the reproductive stage

A generalized vernalization function for winter wheat (Streck et al., 2003), effective vernalization days and vernalization factor

Vernalization begin after germination and end before flowering

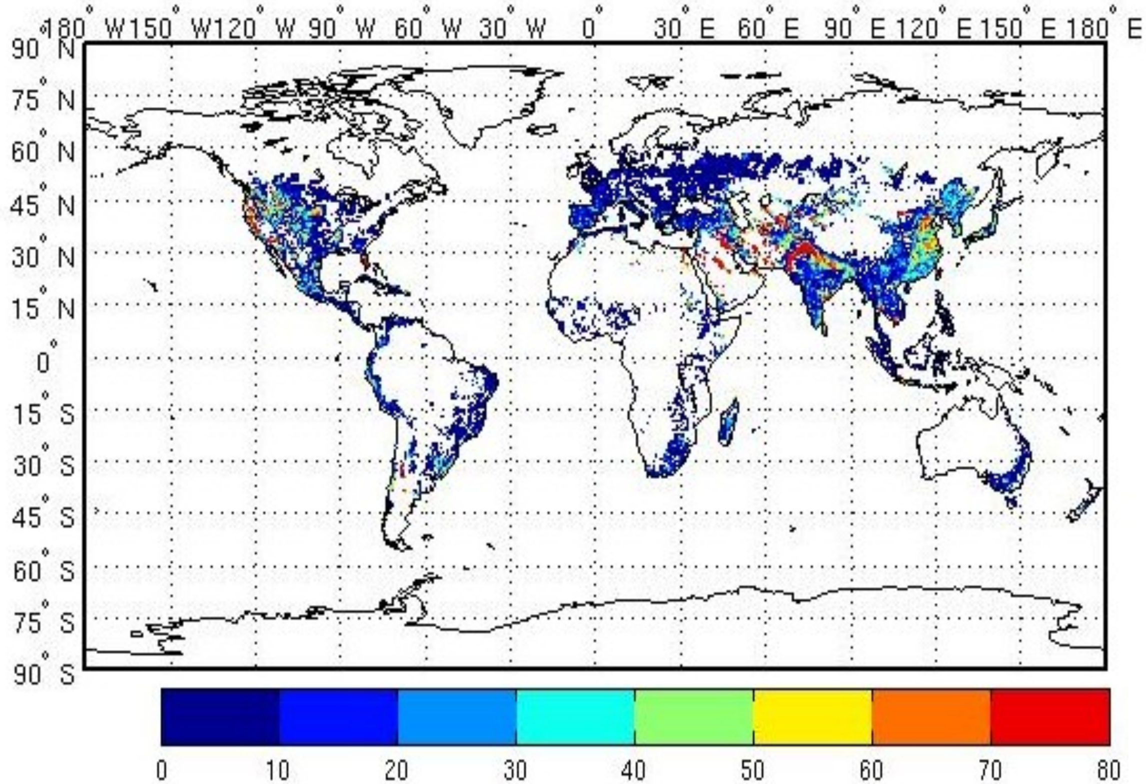
- Cold tolerance and damage

Survival rate and winter killing degree days



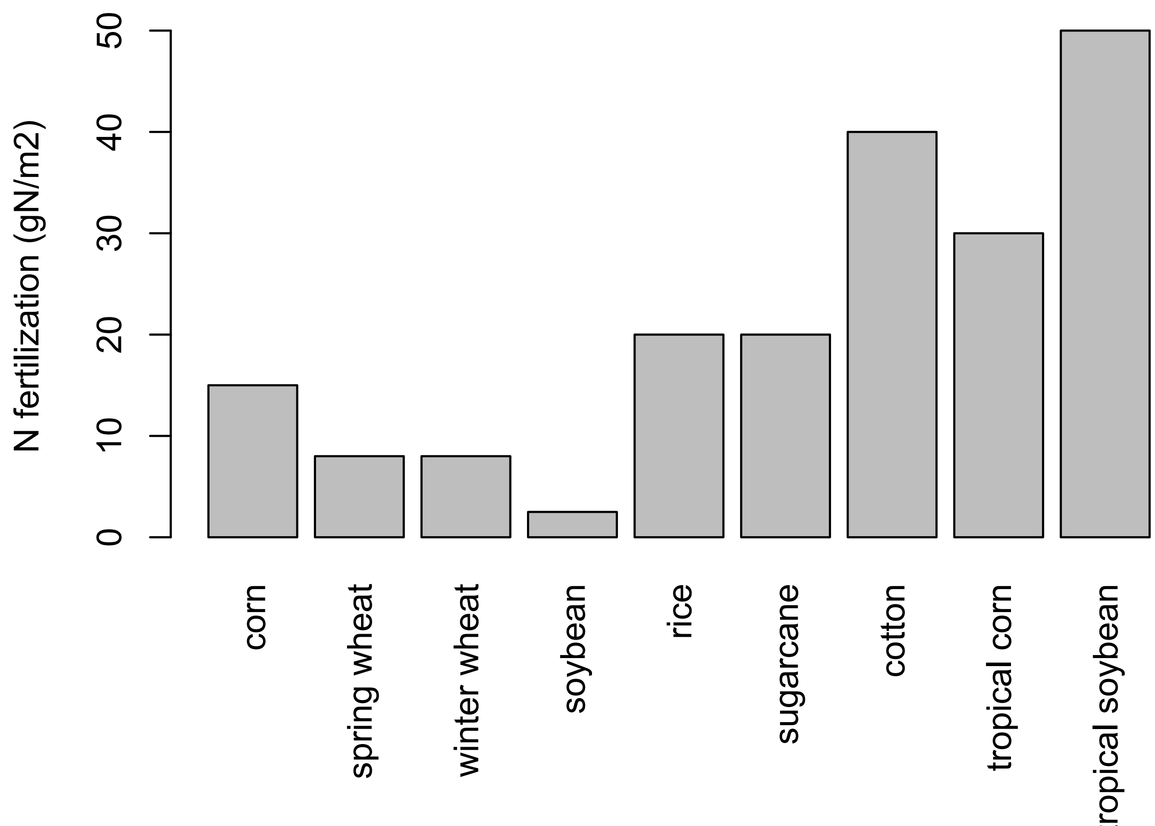
Irrigation

% of crops equipped for irrigation (Portmann et al. 2010)



Nitrogen fertilization

20 days windows for N fertilization since leaf emerge



Run CLM crop and coding

CLM crop model run with BGC, need spin up
Use crop compset: ICRUCLM50BGCCROP

Global simulation:

```
./create_newcase -compset ICRUCLM50BGCCROP -mach
yellowstone -res f19_g16 -case ~/
test_f19_g16_ICRUCLM50BGCCROP
```

Single point/regional simulation:

```
./create_newcase -compset ICRUCLM50BGCCROP -
mach yellowstone -res CLM_USRDAT -case test_usrdat_
ICRUCLM50BGCCROP
```

Code:

- Define crop variables: src/biogeochem/CropType.F90
- Phenology and growth processes: src/biogeochem/CNPhenologyMod.F90

Subroutine: CropPhenology, CropPhenologyInit, vernalization, coldtolerance

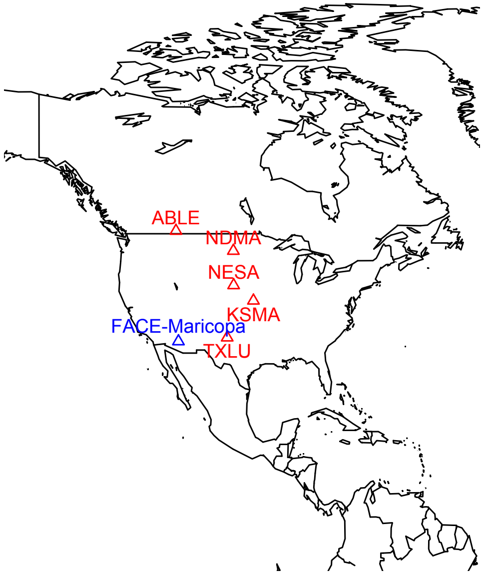
- Carbon allocation: src/biogeochem/NutrientCompetitionFlexibleCNMod.F90

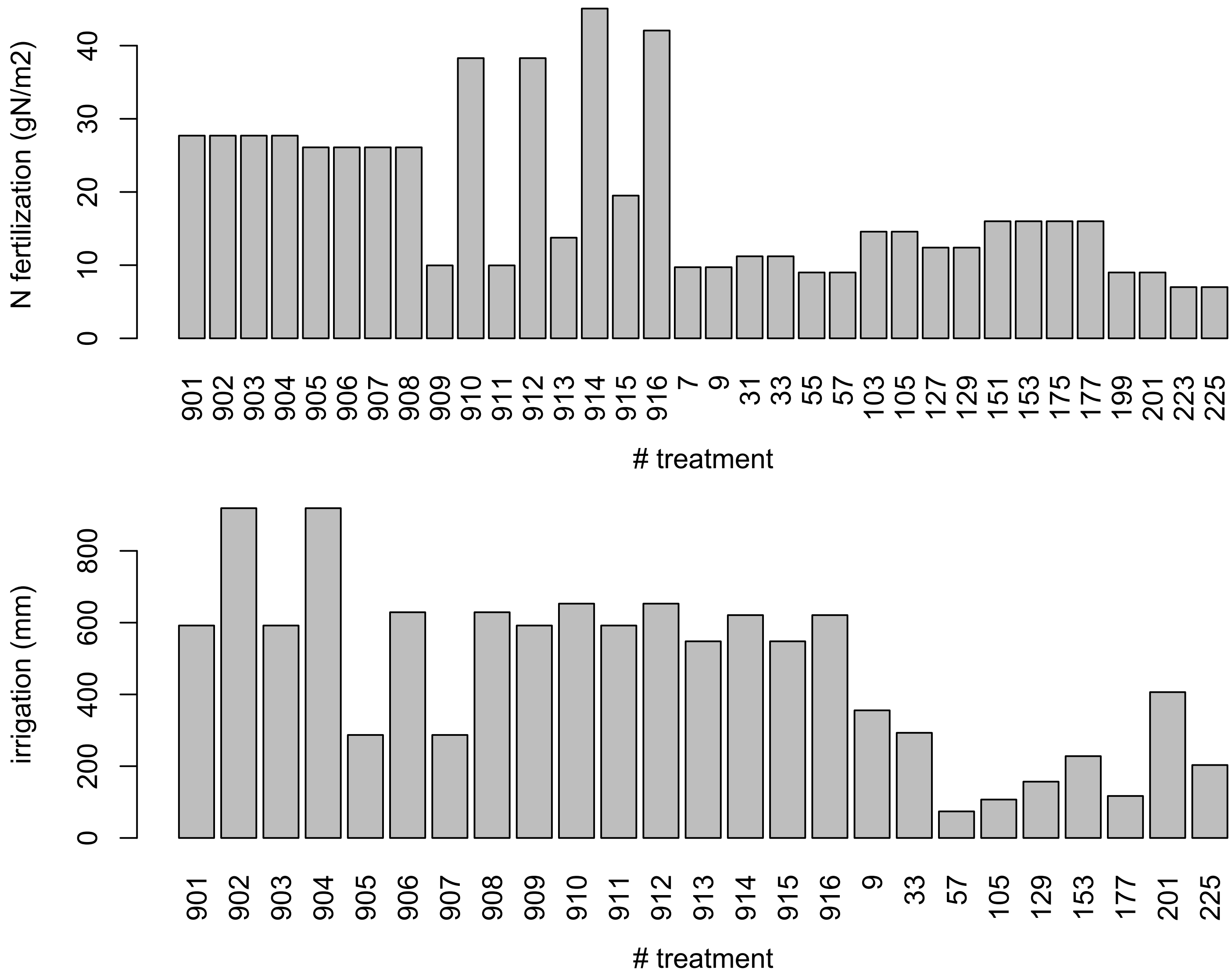
subroutine calc_plant_nitrogen_demand

AgMIP-wheat project (post-CLM4.5)

- Activities: site simulations across 34 nitrogen, irrigation, and CO2 treatments at FACE-Maricopa spring wheat site and five other winter wheat sites.
- 17 crop models inter-comparison
- Goal: understanding whether CLM wheat appropriately response to different levels of nitrogen fertilization, irrigation, CO2.

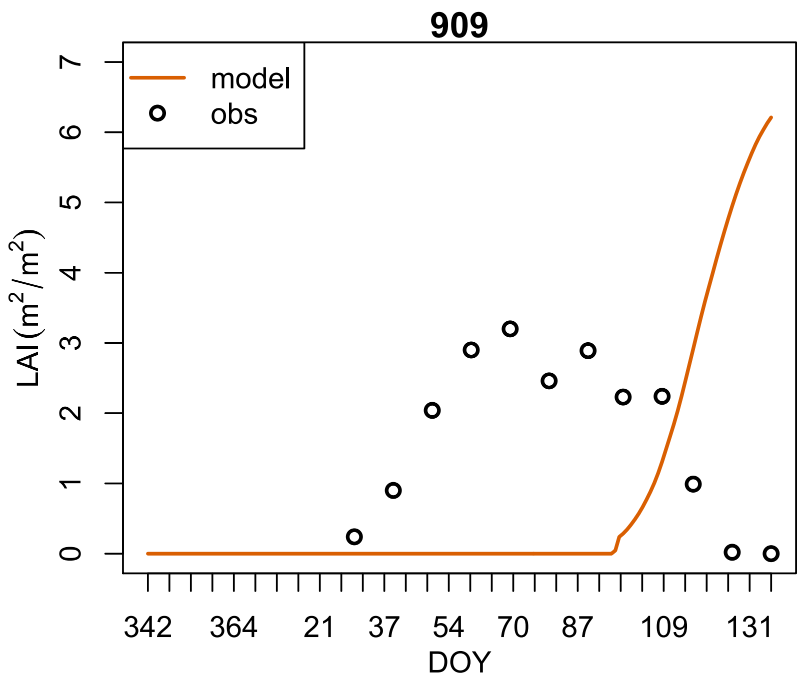
Site	Latitude	Longitude	Elevation (m)	Temperature (°C)	Year	CO2 (ppm)
TXLU	33.63	-101.83	1090	8.2	1984-1986	346
KSMA	39.09	-96.37	122	11.7	1984-1986	346
NESA	41.37	-100.49	975	11.5	1984-1986	346
NDMA	46.46	-100.55	588	14.2	1984-1986	346
ABLE	49.42	-112.5	920	12.2	1984-1986	346
Maricopa-MARA	33.0628	-111.9826	361	11.1	1993-1994	370
Maricopa-MARB	33.0628	-111.9826	361	11.1	1996-1997	370 +1.2TMIN
Maricopa-MARC	33.0628	-111.9826	361	11.1	1993-1997	550+1.2TMIN

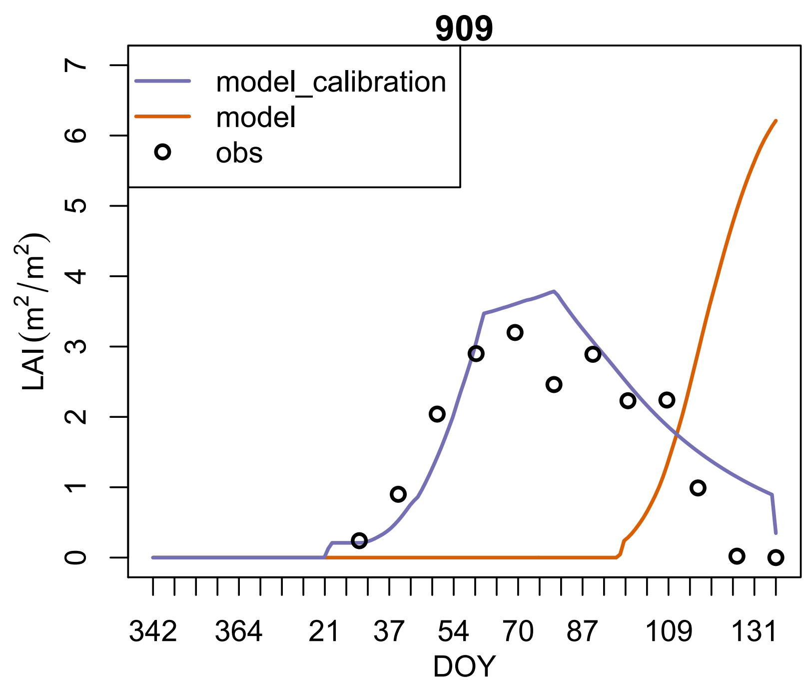



N fertilization (gN/m2)
0
10
20
30
40
901 902 903 904 905 906 907 908 909 910 911 912 913 914 915 916 7 9 31 33 55 57 103 105 127 129 151 153 175 177 199 201 223 225
treatment
irrigation (mm)
0
200
400
600
800
901 902 903 904 905 906 907 908 909 910 911 912 913 914 915 916 9 33 57 105 129 153 177 201 225
treatment

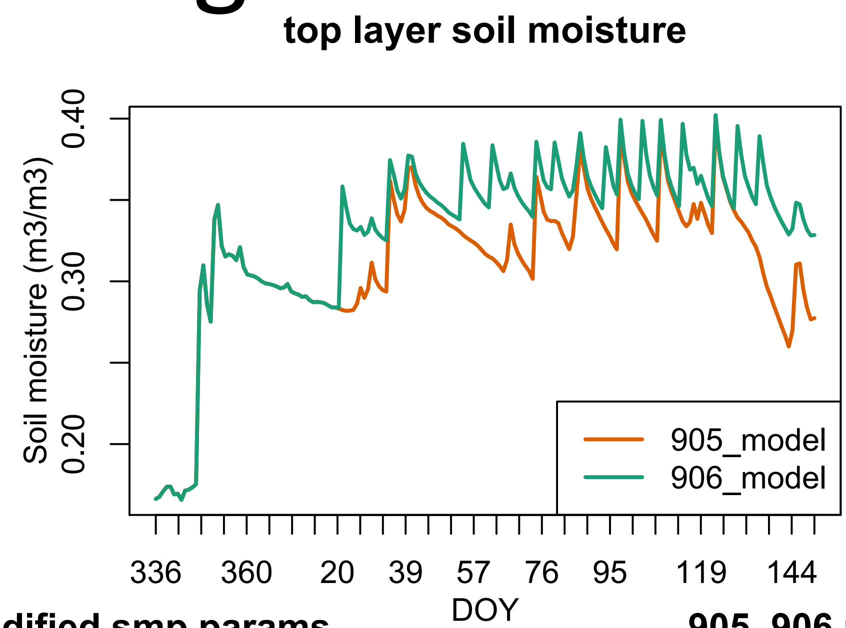
Calibrations

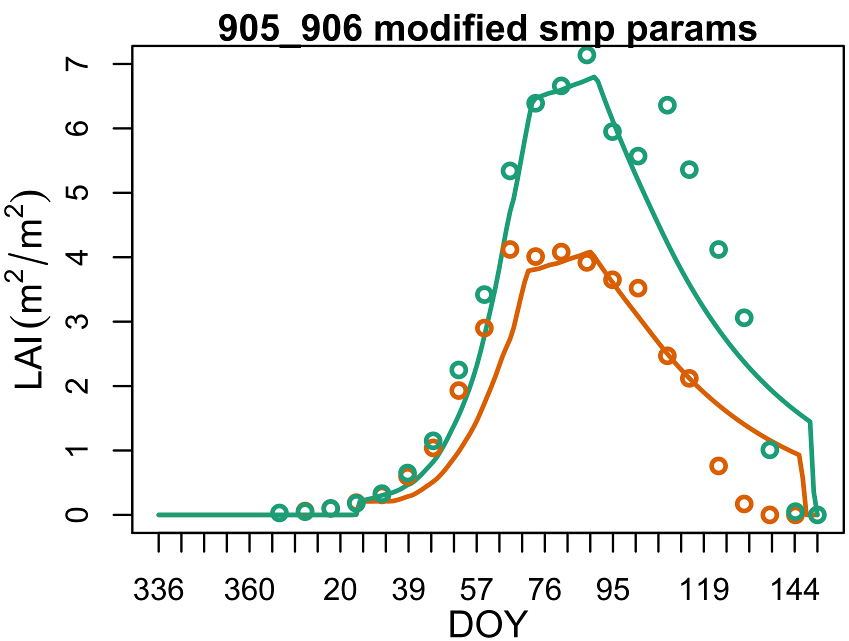
- Minimum planting date: April 1
- Maximum planting date: June 15
- Growing degree days for maturity (GDDm): 1700
- Leaf emerge: 5% GDDm
- Grain fill: 60% GDDm
- Leaf longevity: 1 year

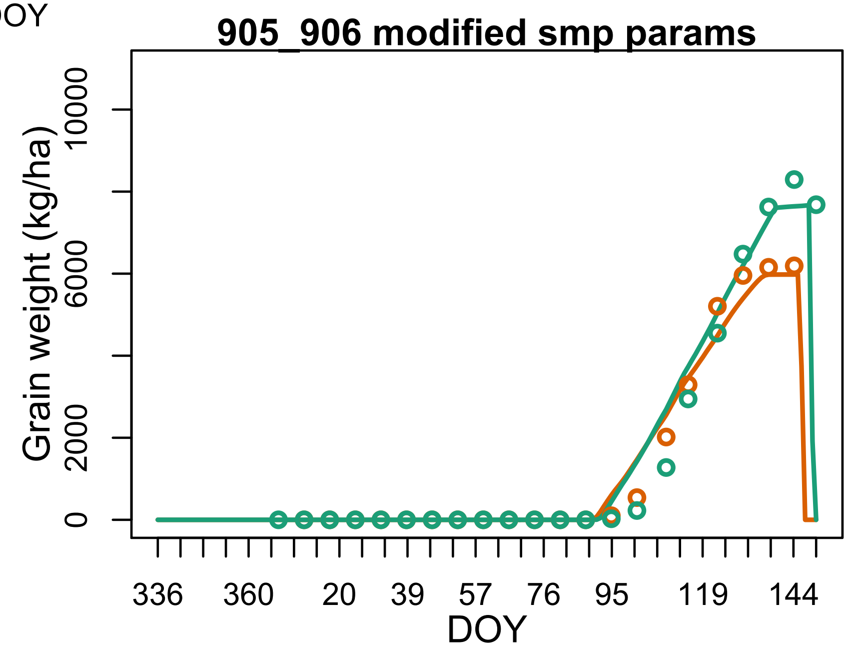




Irrigation effects

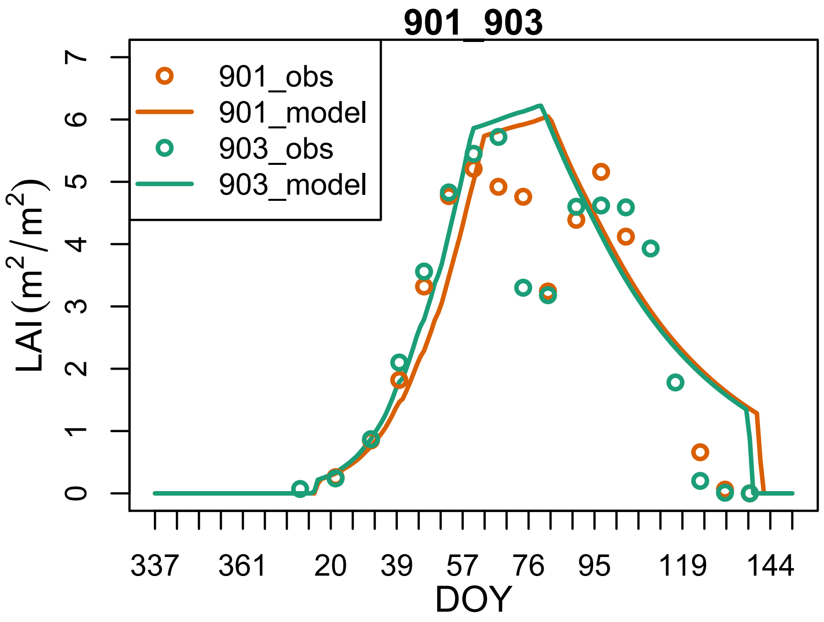


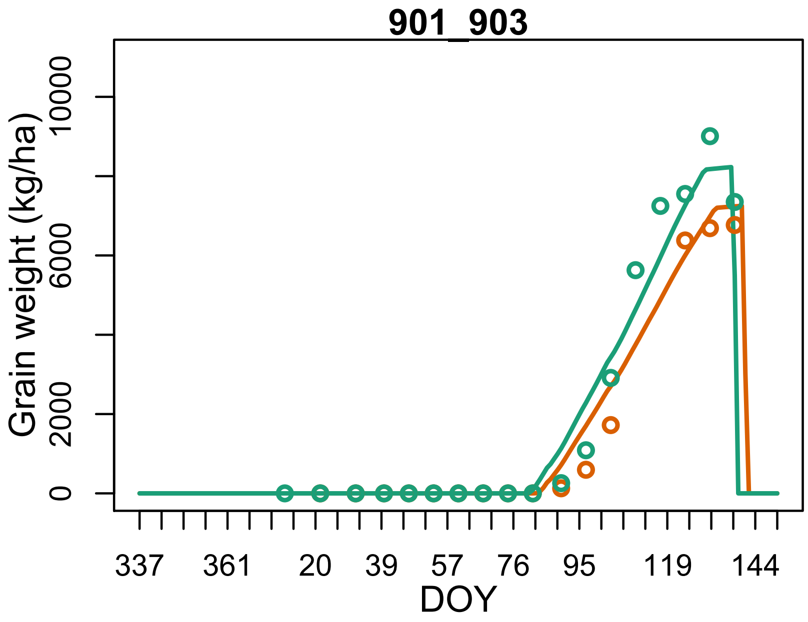




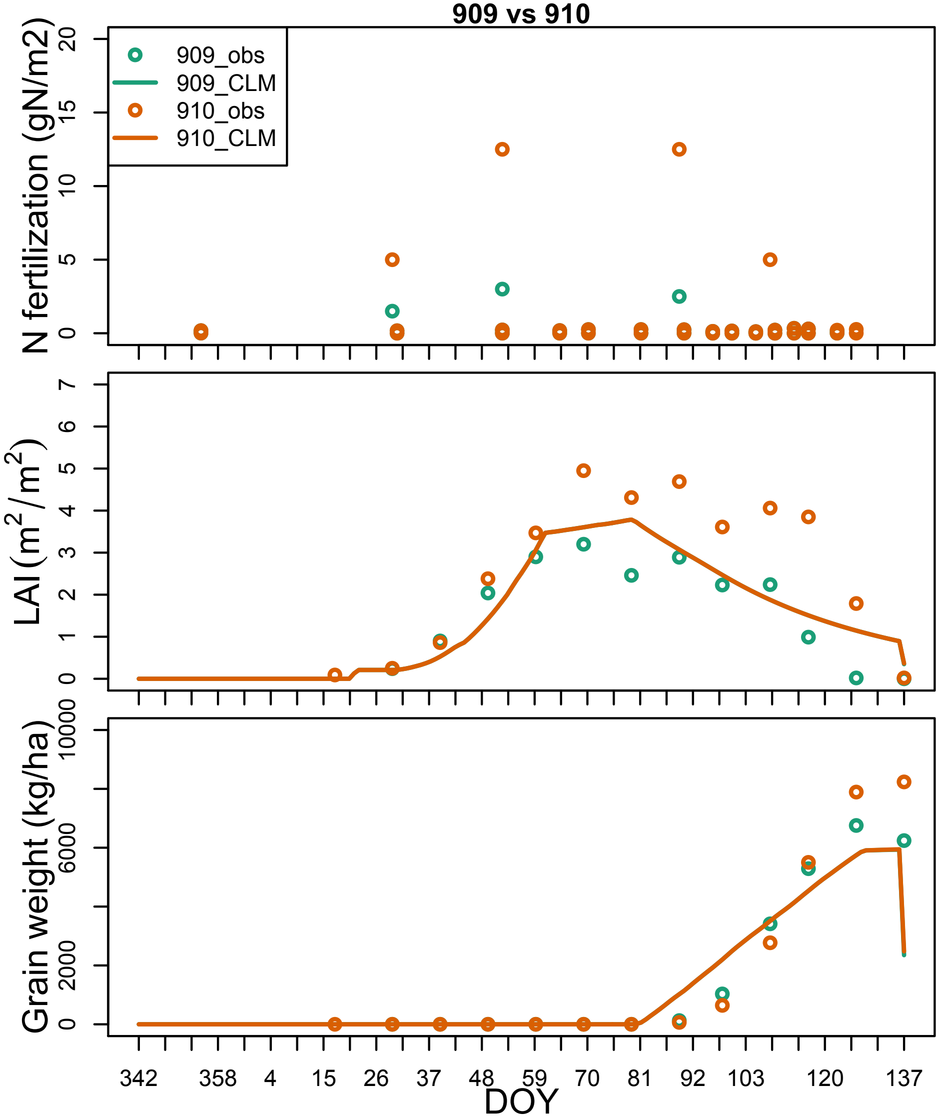
CO2 effects

901: 370ppm
903: 550ppm

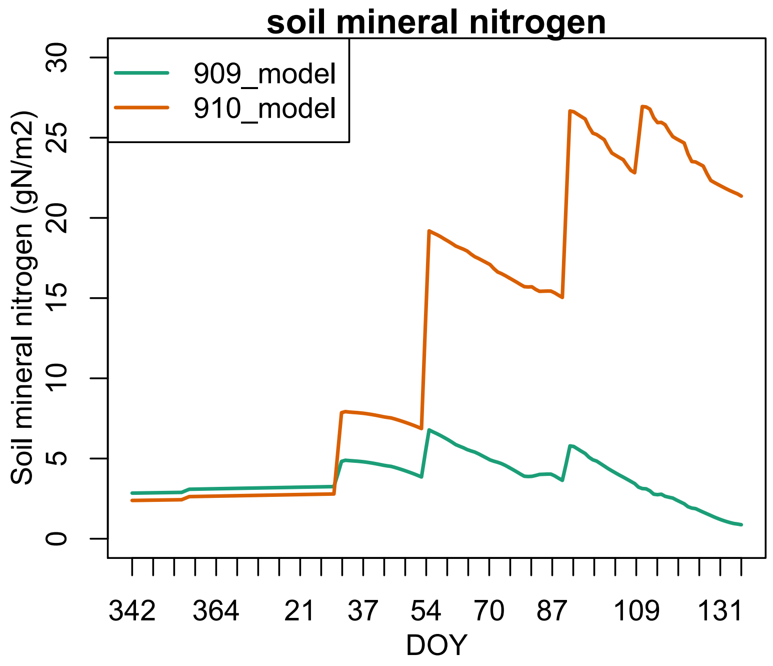




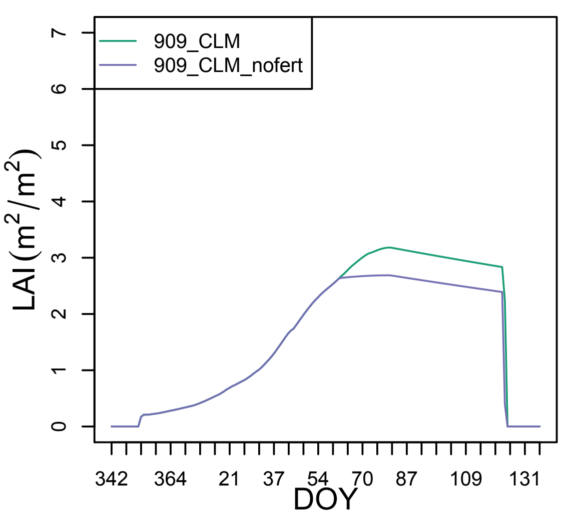
N fertilization effects

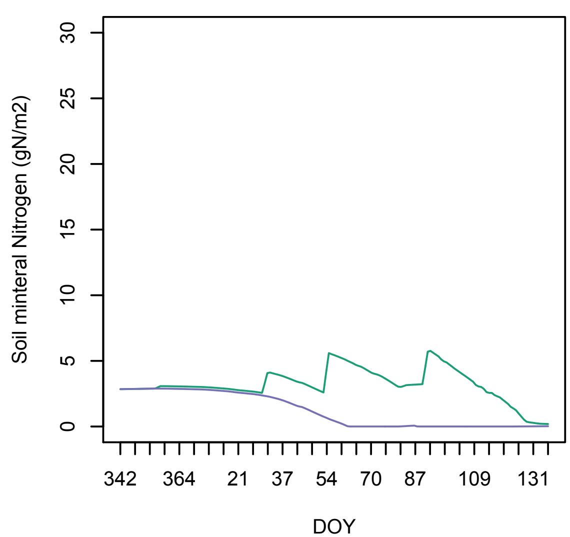


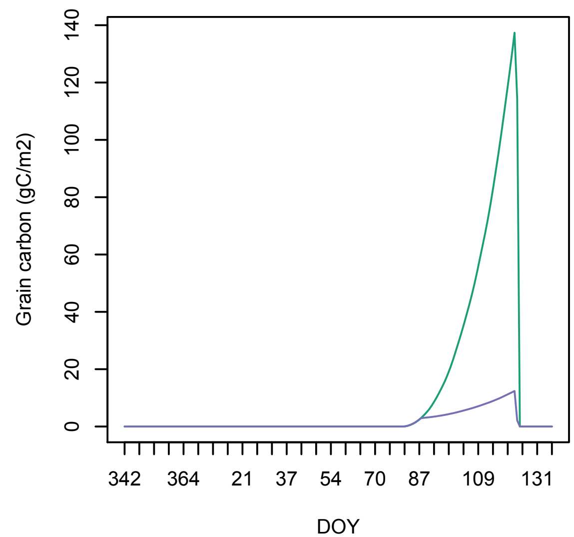
CLM has no response to different levels of N fertilization because the lower level of N fertilization is sufficient for crop growth in CLM



How about if not apply N fertilization in CLM?







TODO list

- Validate CLM5 crop response to elevated CO2, N fertilization, irrigation.
- Develop more crop specific growth processes (response to drought, flood, extreme events)
- Develop the user friendly calibration procedures
- Develop the gridded crop parameters
- Adding more crops (limited by observations)

Questions?