Crops, albedo and climate impact from a life cycle perspective

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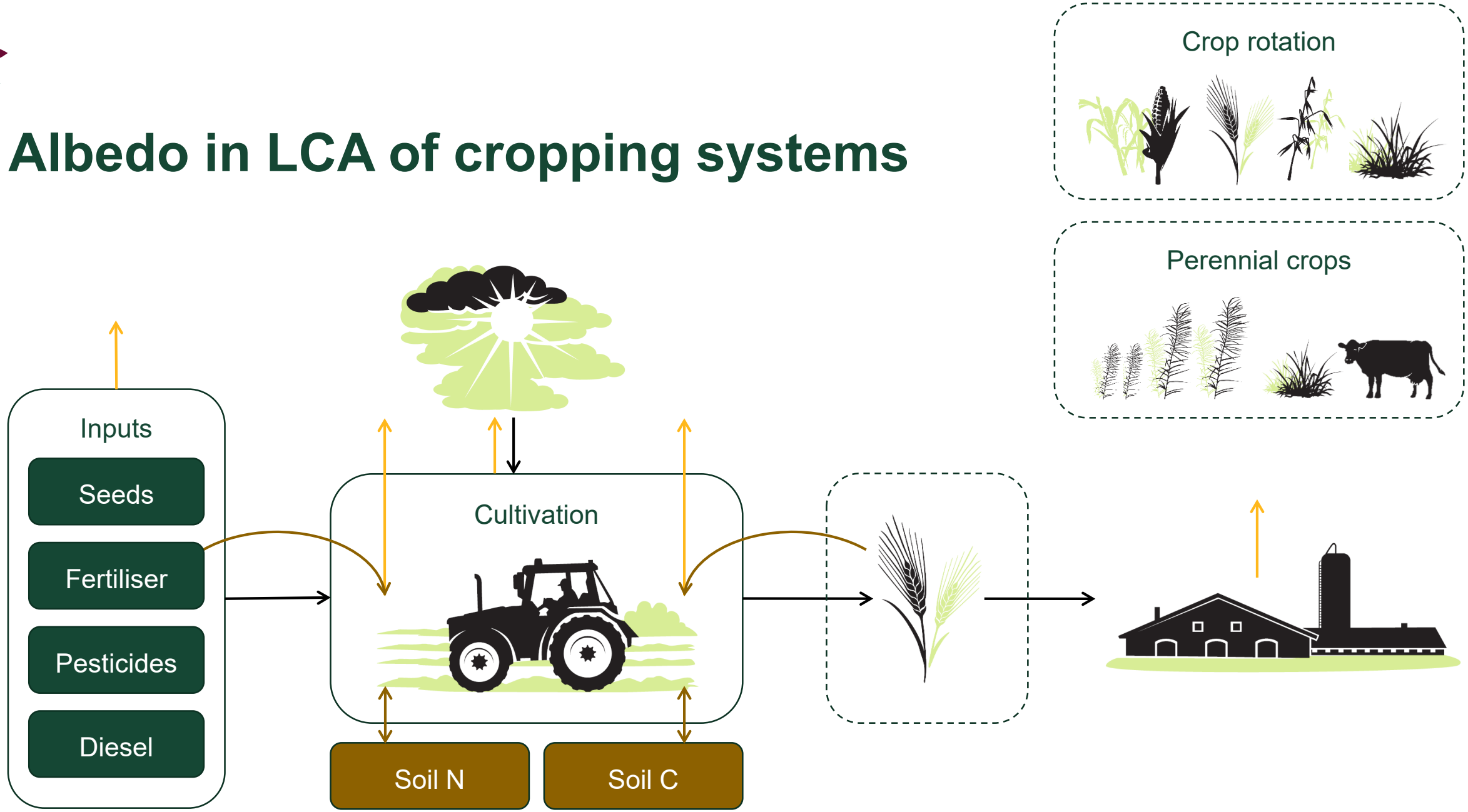
- Albedo in agriculture
  - Land use decision
  - Management choices
- LCA perspective on albedo, soil C and GHG emissions
  - System modelling
  - Climate impact assessment
- Crop-specific albedo
  - Stationary tower
  - Mobile mast
  - Remote sensing

Albedo in LCA of cropping systems



Pictures: Fredrik Saarkoppel, SLU

How LCA is useful?

Process-based modelling?
Usually not done

Decision support?
Less than expected

System understanding

Big and small impacts
Within a system

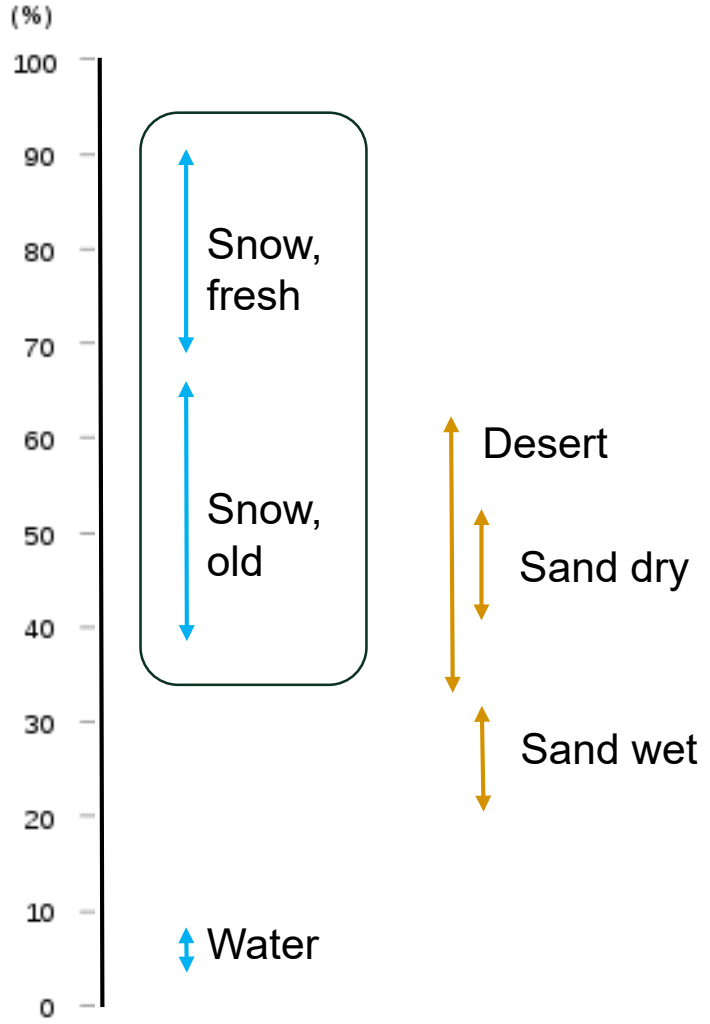
System comparison
Based on a common function

Impact comparison
Based on a common indicator

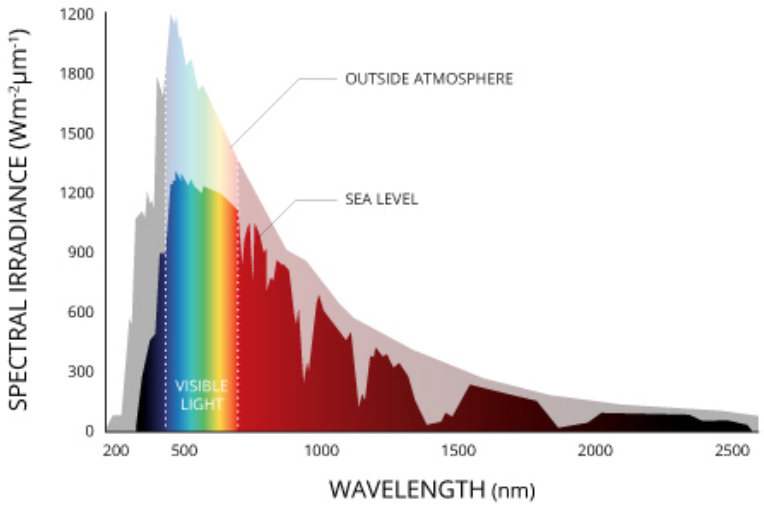
Land use:
Crop, varieties, sequence in rotation, fallow, perennials

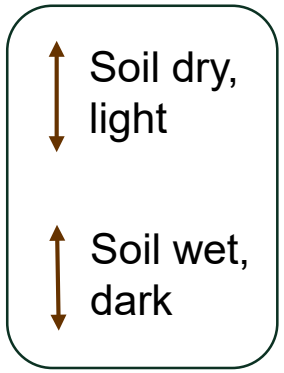
Land management:
Timing, residue retention, cover crop, fertilisation

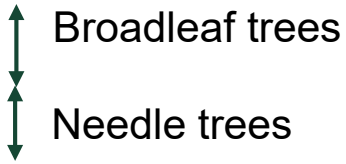
Albedo of cropland: small operating space?

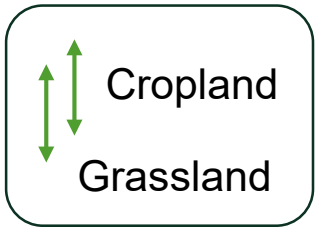


- When?
- How long?
- Can we influence?
- How big?
- How robust?









Methods to quantify albedo

Stationary tower

Single site, continuous

30 min, several years

Interannual change of perennials

Variability between years

No height limit ☺

Mobile mast

Point sampling, discontinuous

2-5 min, one year

Choice of crop and management

Comparable sites, same year

MODIS albedo product

Global, discontinuous

Daily, 2000 to present

Variability between sites and years

Trends: land cover, time, region

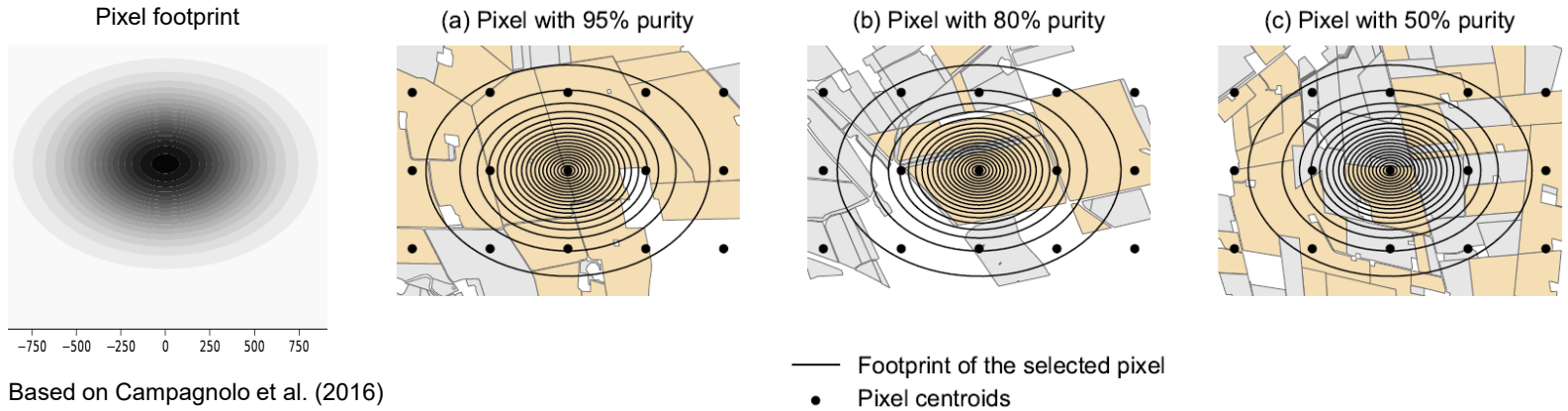
Readily available

Crop-specific albedo from MODIS

Trends due to crop (type), region, season, year

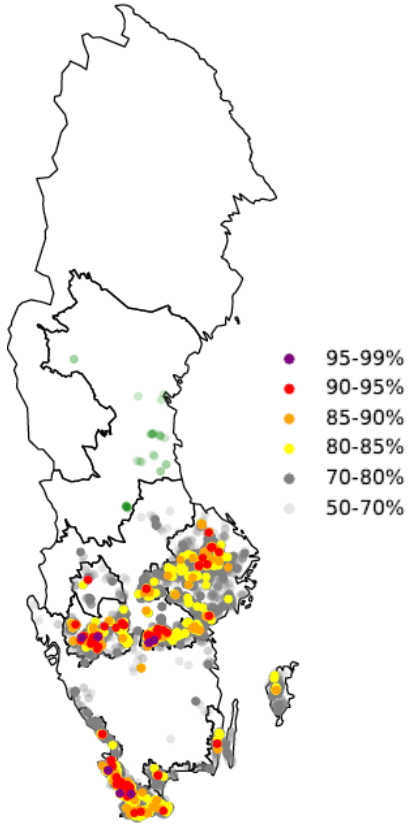
- MODIS albedo product MCD43 is a gridded composite product
- Geospatial analysis to find ”pure” pixels: >80% of MODIS signal from a single crop
- Field polygons from geospatial aid application (GSAA) data:
  crops or crop groups with equal payment eligibility under EU CAP
- Suitable for major crops/ production regions

INSPIRE Directive



Based on Campagnolo et al. (2016)

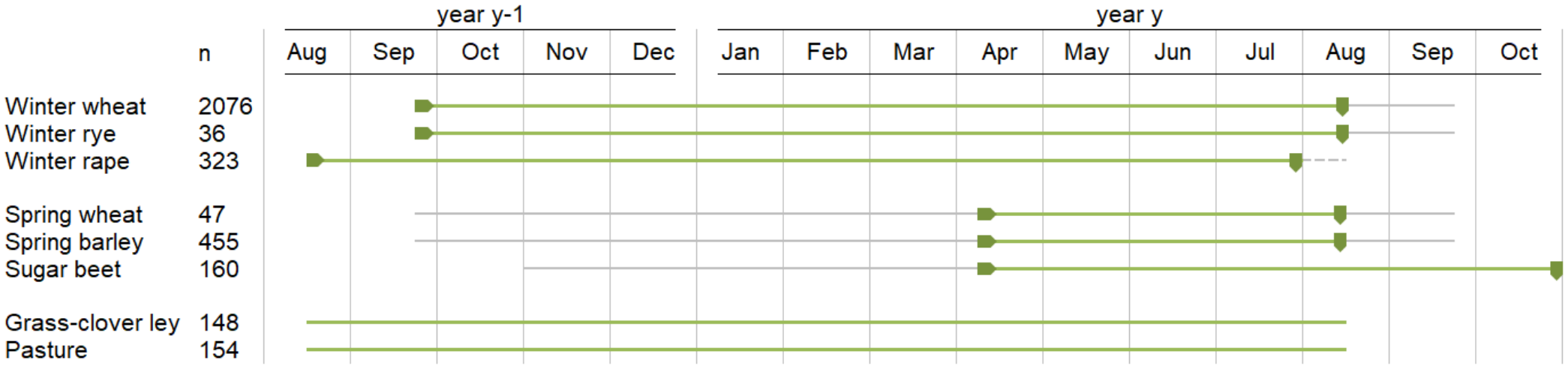
Purity of MODIS pixels with winter wheat



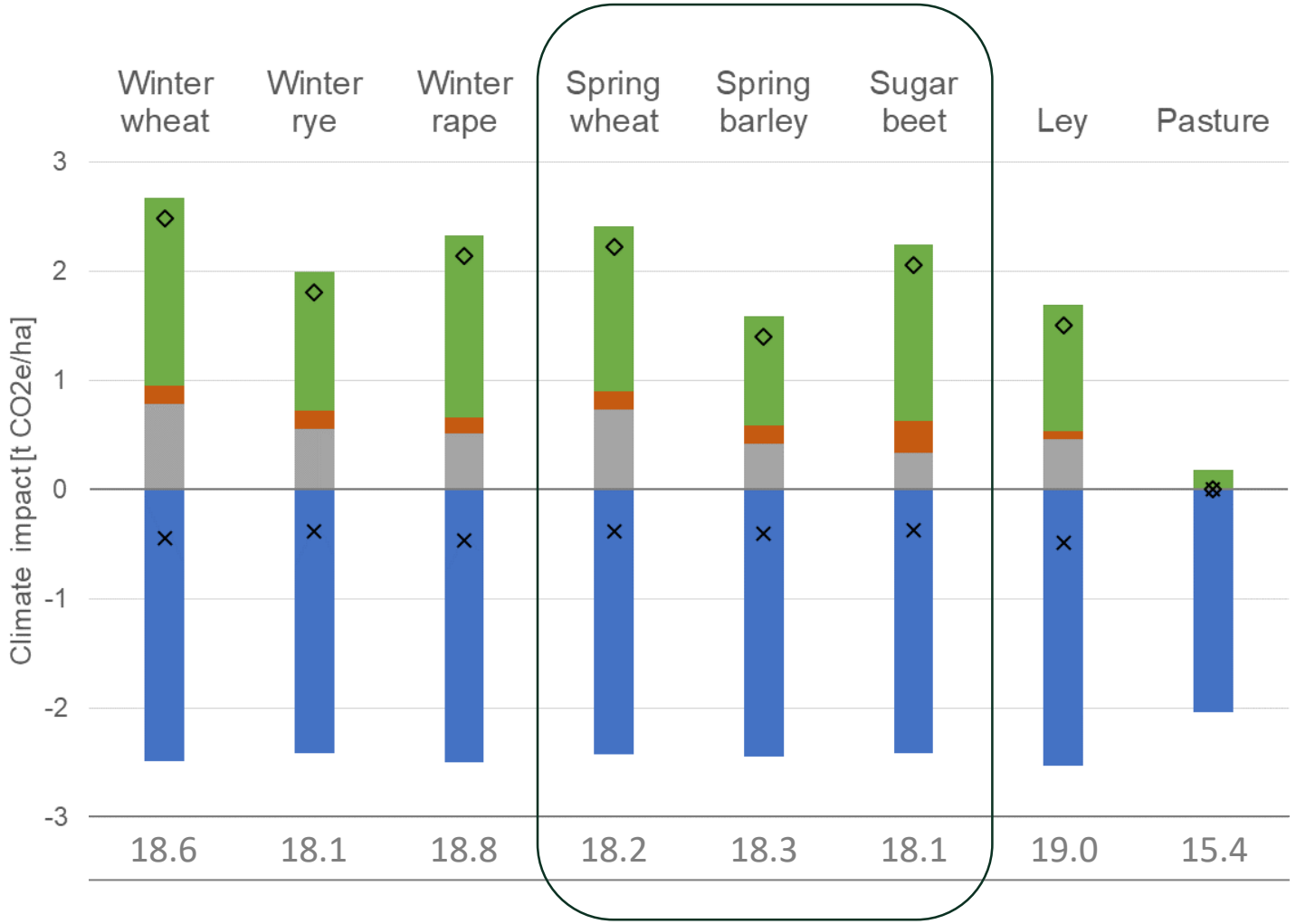
Results for production region 1

8 land use types, 10 years (harvest 2011-2020) → 3400 pixels

- Sufficient number of pixels to fill data gaps (winter)
- Long periods outside the growing season
- Large differences between years but mostly consistent across crops



LCA result: climate impact (GWP)



Albedo change offsets
20-30% of the net GHG impact
if pasture is the reference land use

„Reference problem“ in LCA of land use:
no „zero“ emission/albedo scenario
(soil C, soil N, albedo)

- Soil N2O: direct, leaching, volatilisation
- Field operations: diesel production and use)
- Inputs: mineral fertiliser (90%), seeds, pesticides
- Albedo
- ◇ Net GHG
- × Net albedo

10-year mean albedo [%]

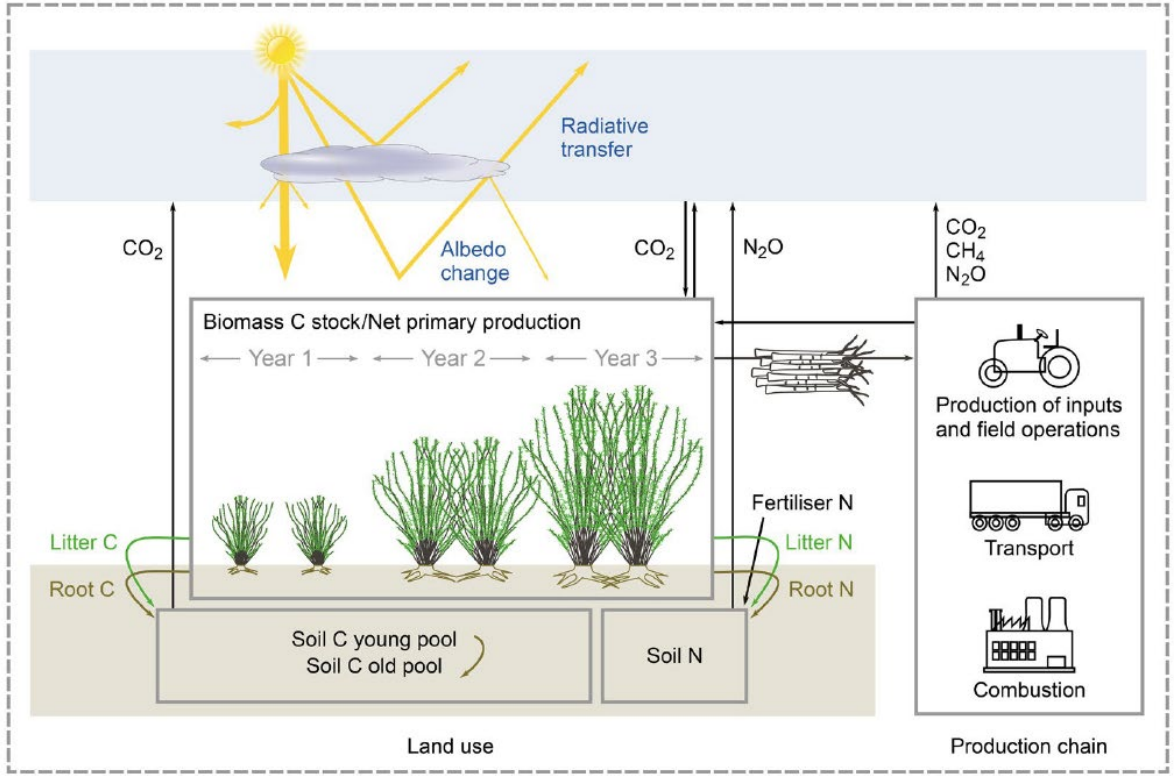
Tower-measured albedo in time-dependent LCA

Single-site case study on a perennial energy crop

- Short-rotation willow plantation: 3-year cutting cycles, replanted after ~25 years, 50 years land use
- Low inputs, high biomass production, high inputs and low losses from soil C pool
- Reference land use: green fallow
- Soil C: ICBMregion model with annual inputs, 2 pools, decomposition increases with rain, temp, cultivation
- Biomass C

Time-dependent LCA

- Inputs, emissions and albedo are recorded per year
- Global annual mean surface temp change over time



Sieber et al. (2020): Including albedo in time-dependent LCA of bioenergy

Why time-dependent methods?

- Account for the timing of emissions and removals, e.g. temporary C storage in biomass or soil
- The same amount of GWP implies different timing of temperature change when caused by different climate forcers

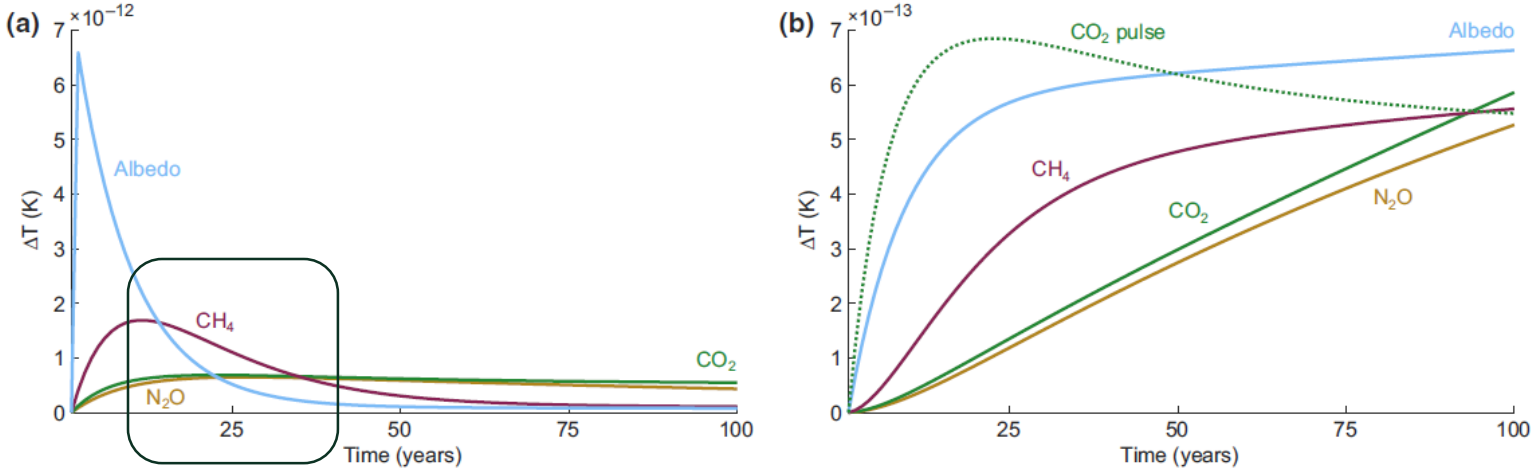


FIGURE 7 Annual temperature response to GWP_{100} of 1 Mg CO_2e resulting from (a) emission pulses of 1 Mg CO_2, 27.8 kg N_2O or 3.4 kg fossil CH_4, or from annual mean albedo RF of 9.2×10^{-11} W/m^2 during 1 year; and (b) from sustained emissions or albedo RF at constant rate over 100 years; the response to the CO_2 pulse is reproduced from (a) for comparison. GWP, global warming potential; RF, radiative forcing. Metric values taken from Myhre et al. (2013)

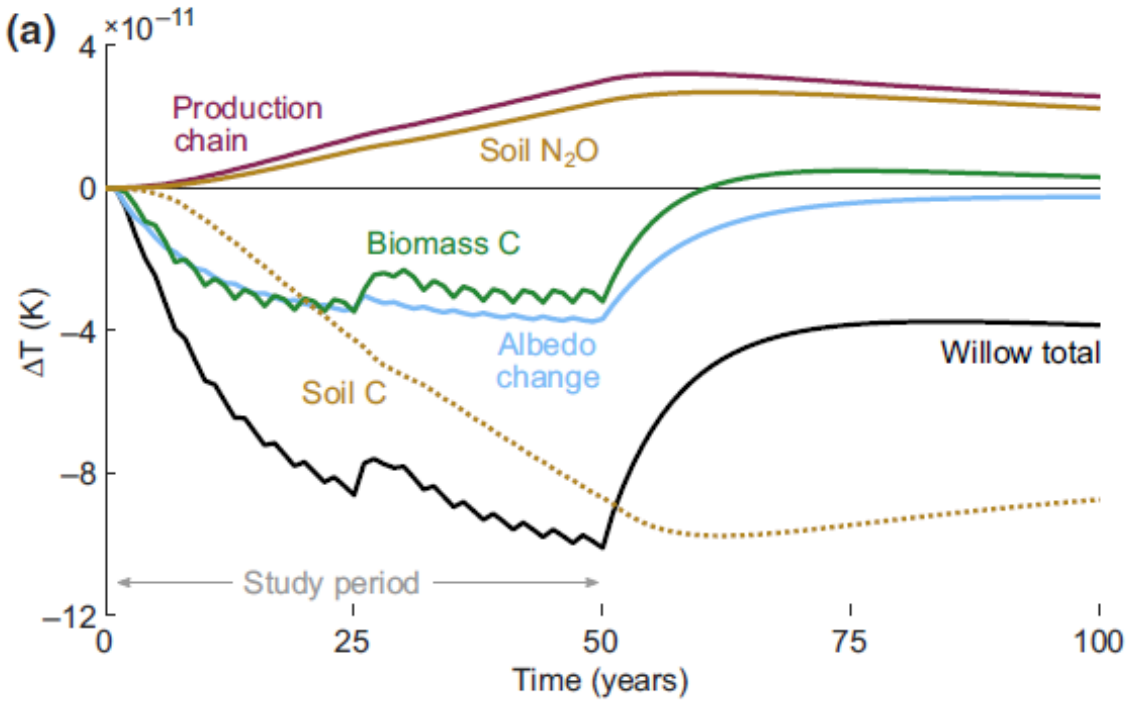
GWP100 measures the relative impact of long-lived and short-lived pollutants on temperature 20-40 years after emission

Sieber et al. (2020): Including albedo in time-dependent LCA of bioenergy

LCA result: climate impact (ΔT)

Albedo change: 34% of GWP_{100}, 36% of ΔT[50] and 6% of ΔT[100] when willow is cultivated on former green fallow

Net climate cooling effect of willow-based bioenergy



Differences in timing of temperature response to change in albedo and C stock:

- Response time
- Response duration
- Stabilising (albedo) vs declining (carbon) response to sustained change
- Overshoot

Annual average changes:

- Albedo 16.5% fallow to 21.5% willow, -0.6 t CO2e/ha
- 0.8 t C in soil (growing stock), -3 t CO2e/ha
- 11 t C in biomass (temporary stock)

Management-specific albedo from mobile mast

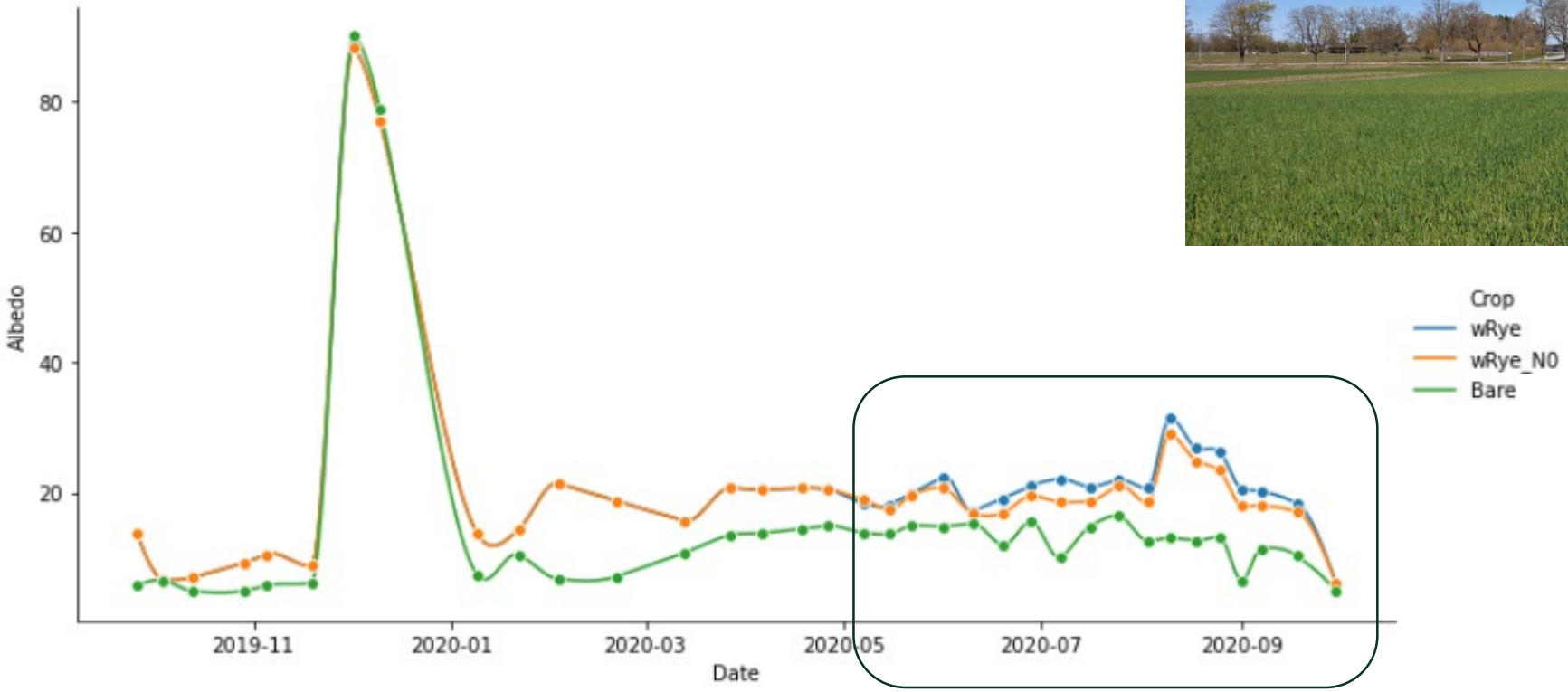
Crop and management choices

- 12 fields: 6 cereals, pea, rapeseed, 3 types of ley, bare soil
- Winter and spring varieties
- 3 N fertilisation levels (zero, regular, high) on 3 cereal crops
- 2 intensity levels and different compositions for ley
- Cover crop: only undersowing for ley, ploughing in spring not an option on heavy clay soils in Uppsala
- Ploughing after harvest vs residue retention or shallow incorporation

→ Effect of crop rotation!

Results from mobile mast measurements

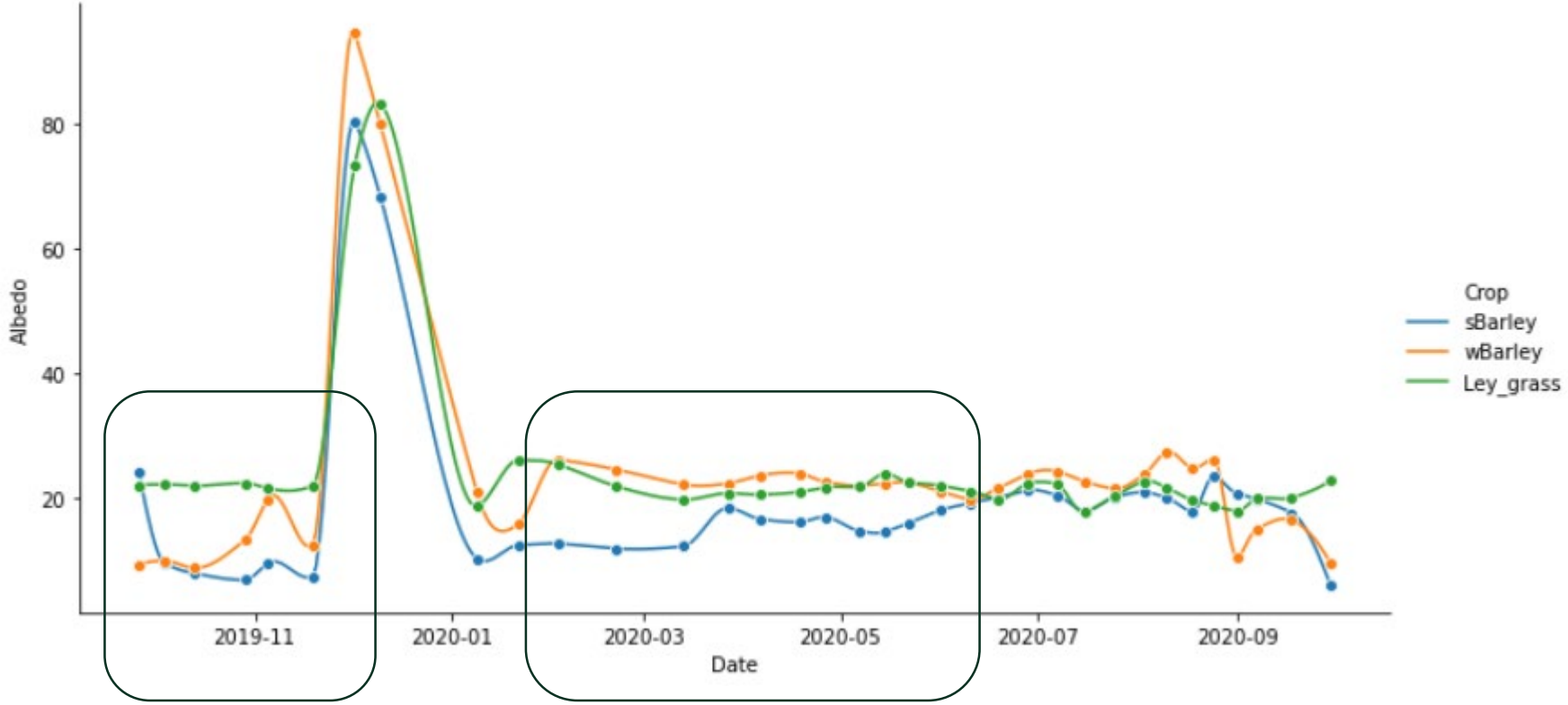
Effect of N fertilisation: higher albedo



Results from mobile mast measurements

Winter and permanent crop vs spring crop: cover in early spring and autumn

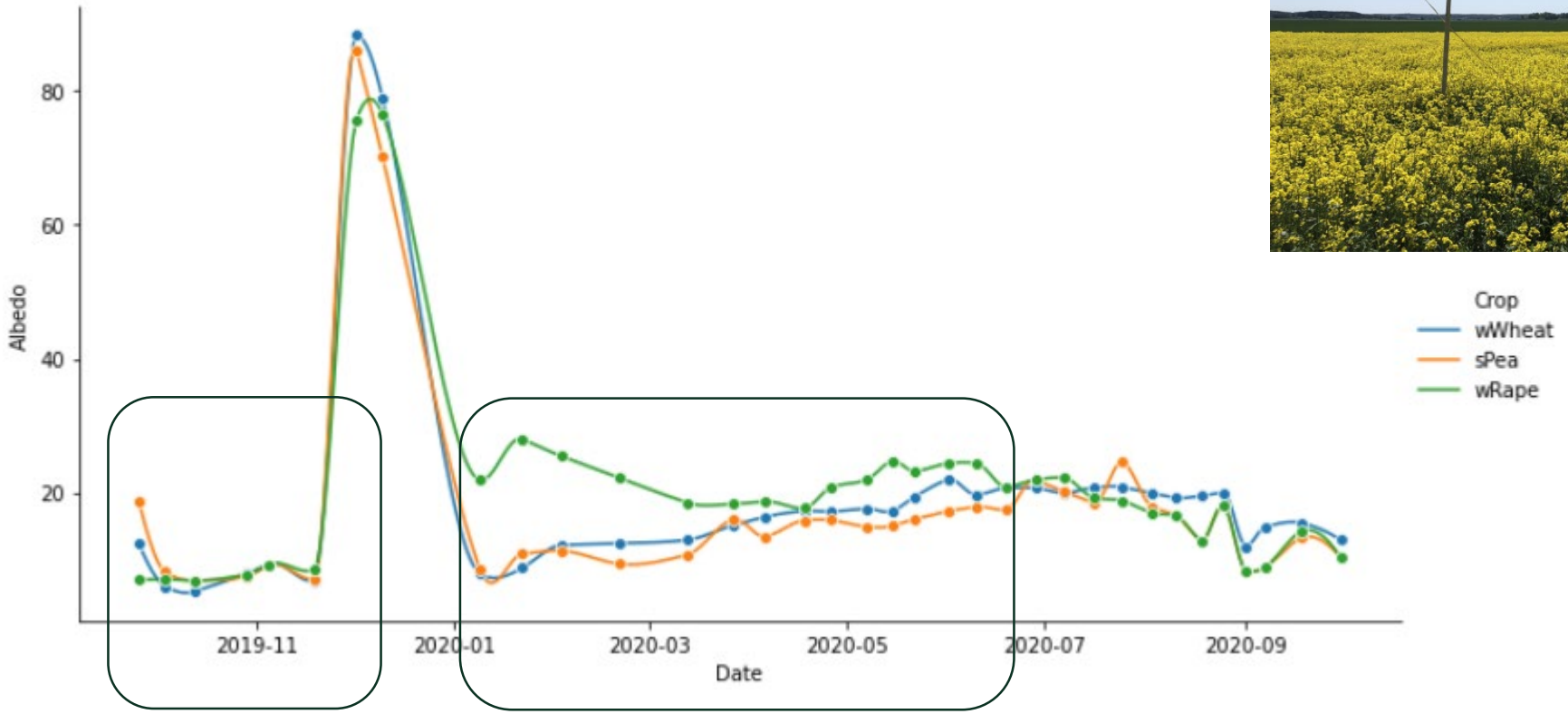
Here: residue retention on spring barley field



Results from mobile mast measurements

Broadleaf crops vs cereal: better spring cover when winter-sown

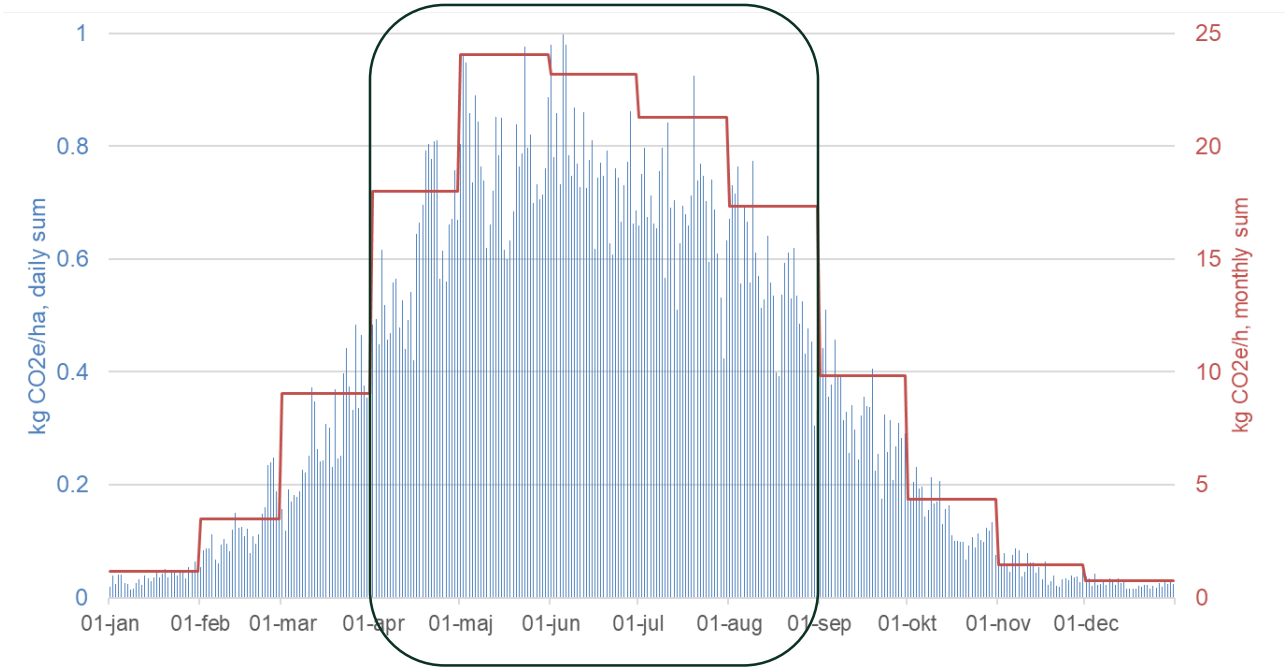
Here: residue retention on spring pea field



Timing and duration of „geoengineering“

GWP of 1% albedo change on 1 hectare during 1 day or 1 month

- Up to 1 kg CO2e per day
- 80% April to August, 3% November to February



Full year: 134 kg CO2e/ha

1-8% realistic on agricultural land, with seasonal variation

Up to ~1 t CO2e/ha in Sweden

Conclusions

- Life cycle perspective helpful to understand magnitude of impacts
- Assessment of land use effects (soil C, soil N, albedo) requires a reference
  → depending on research question
- Annual temperature change (ΔT_t) includes information on timing of impacts
  → GWP has the same shortcomings for albedo change as for short-lived GHG
- Combination of methods to measure albedo
  → field-scale to study management effects
  → field-scale to understand trends in remote sensing data
- Albedo geoengineering on croplands: some improvements possible
  → Timing and duration of albedo change is crucial
  → Practical limitations: crop rotation, workload distribution, cost, soil type, climate,…

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