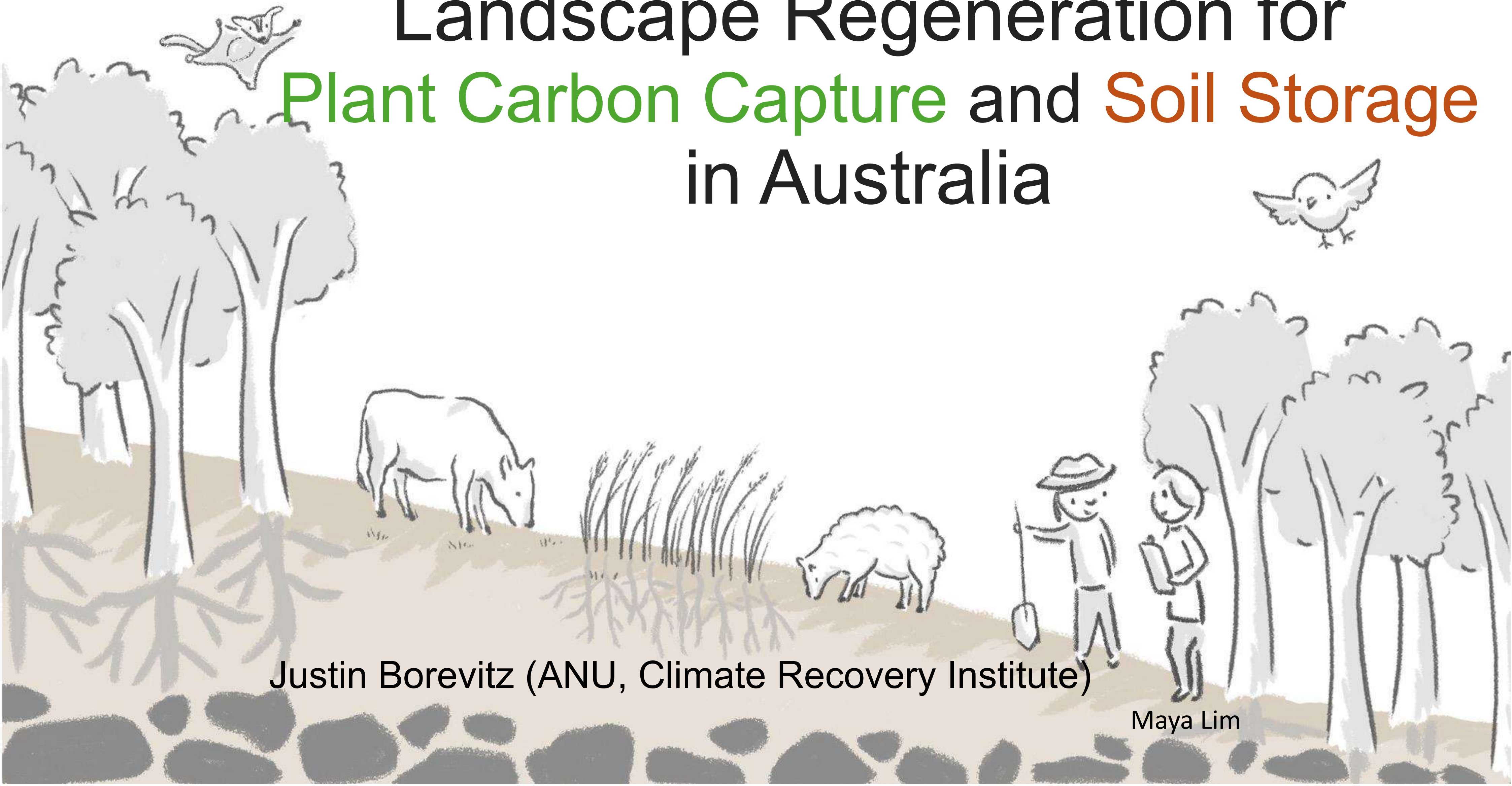
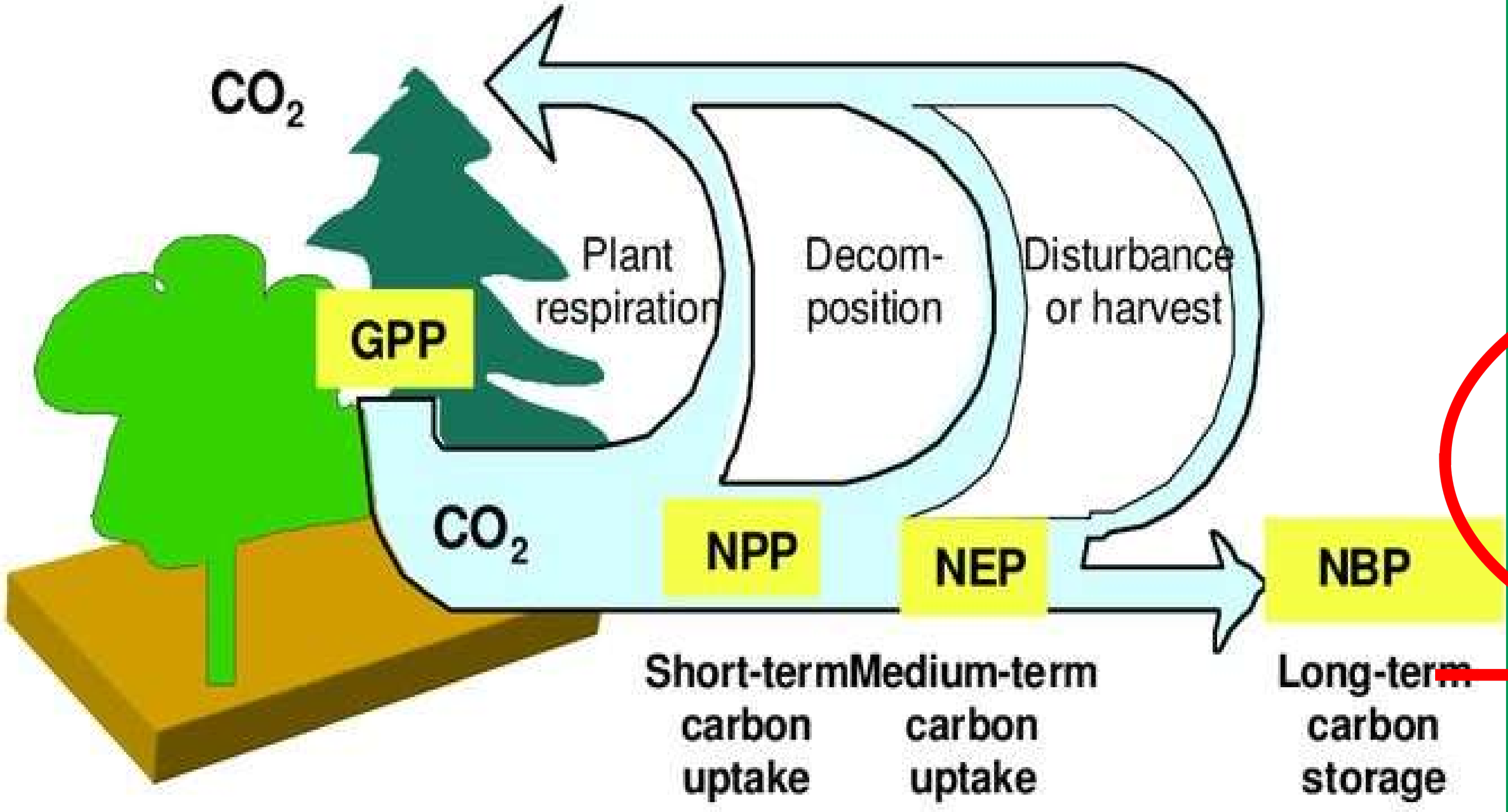
Landscape Regeneration for Plant Carbon Capture and Soil Storage in Australia

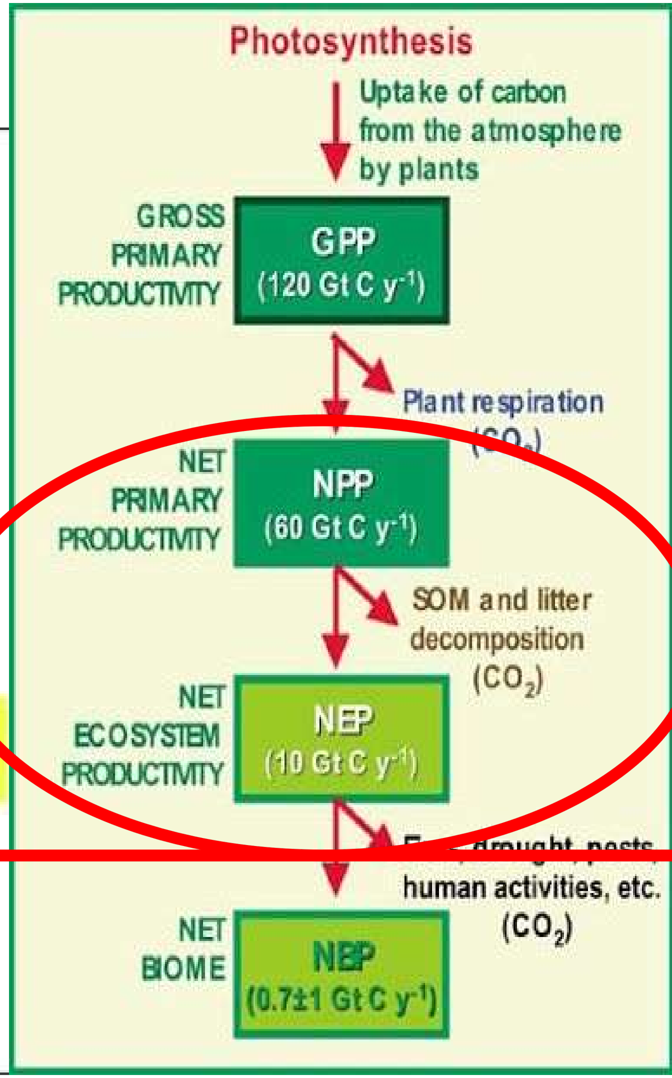


Justin Borevitz (ANU, Climate Recovery Institute)

Maya Lim

Land based Carbon Cycle





GLOBAL CARBON project

Fate of anthropogenic CO_2 emissions (2014–2023)

Sources = Sinks

35.6 $GtCO_2$/yr

90%

10%

4.1 $GtCO_2$/yr

19.2 $GtCO_2$/yr

48%

29%

11.7 $GtCO_2$/yr

26%

10.5 $GtCO_2$/yr

Budget Imbalance:
(the difference between estimated sources & sinks)

4%
-1.6 $GtCO_2$/yr

Source: Friedlingstein et al 2024; Global Carbon Project 2024

GLOBAL CARBON project

Carbon Dioxide Removal

Equivalent to ~5% of annual Fossil CO_2 emissions

Equivalent to ~1 millionth of annual Fossil CO_2 emissions

1.9 $GtCO_2$ per year

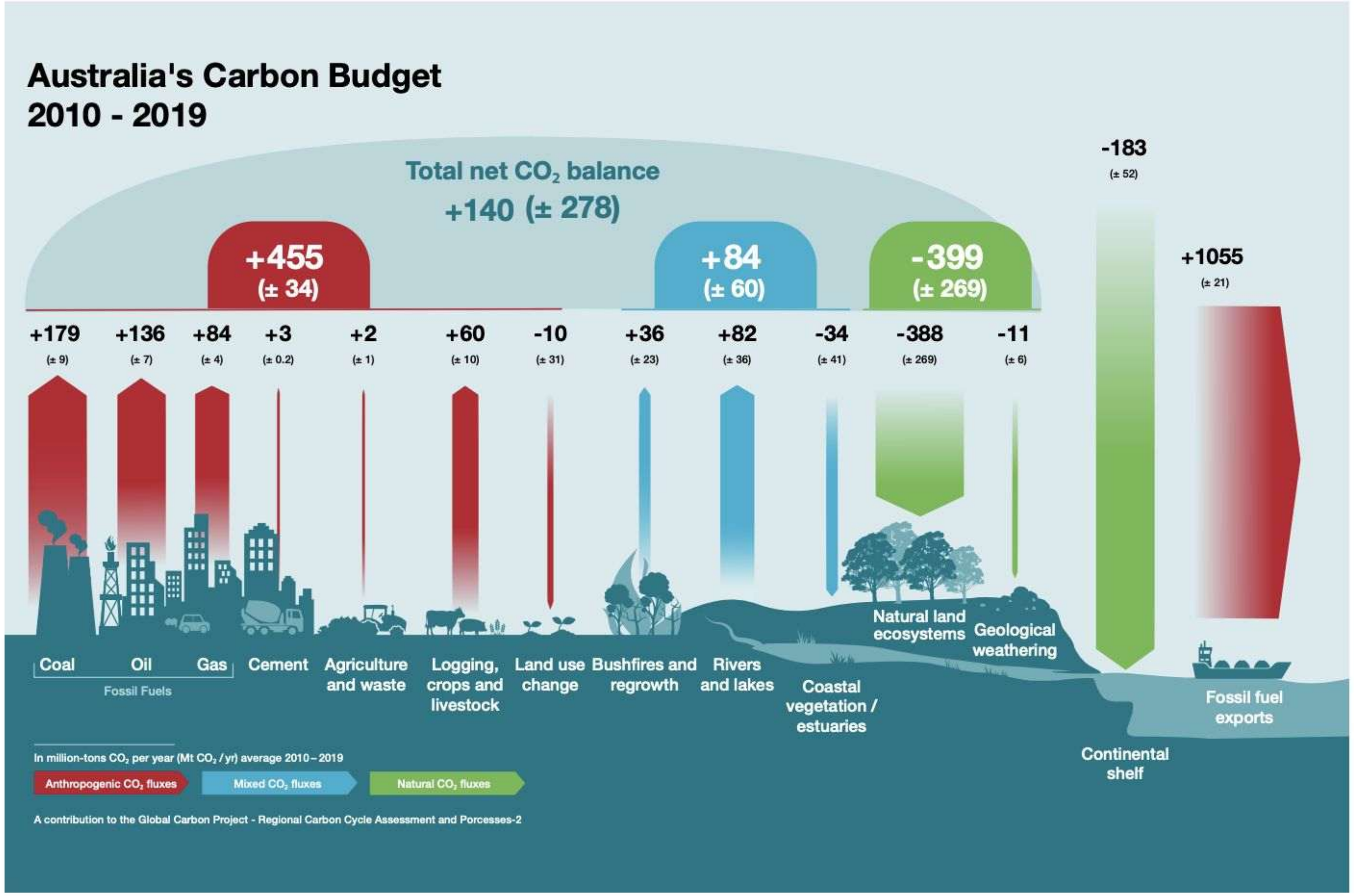
0.004 $MtCO_2$ per year

0.03 $MtCO_2$ per year

Vegetation-based CDR estimates from GCB2024

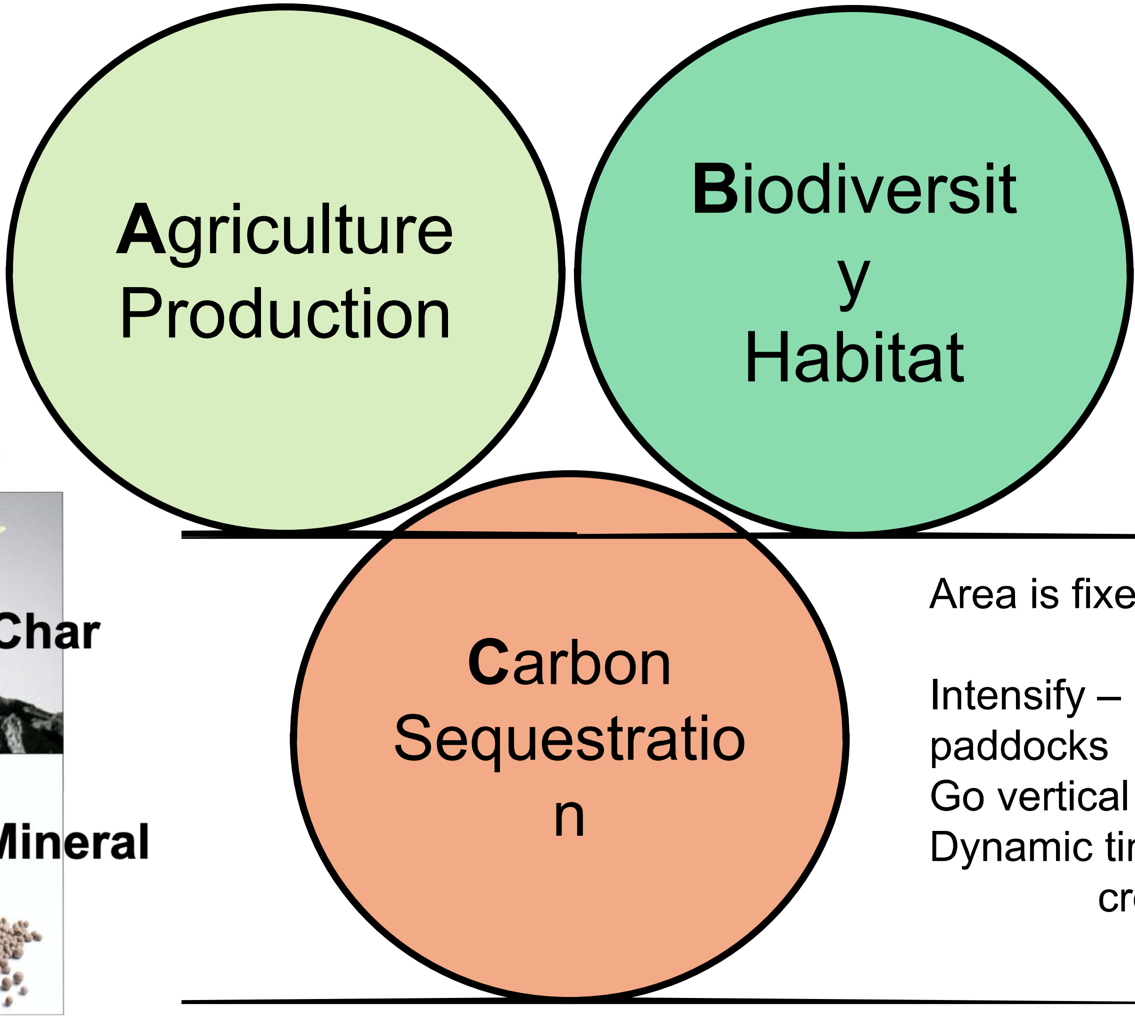
CDR not based on vegetation from the State of CDR report (2024)

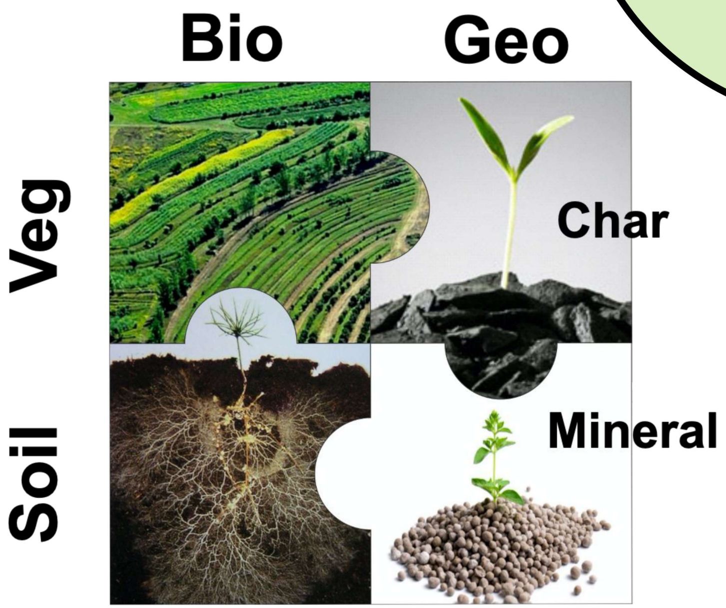
Australia close to Net Zero?
Exports?



Australia's Carbon Budget 2010-2019. A product of the Climate Systems Hub; and a contribution to the Global Carbon Project – Regional Carbon Cycle Assessment and Processes-2 a global assessment of GHG budgets for all continents and ocean basins.

Land use Integration

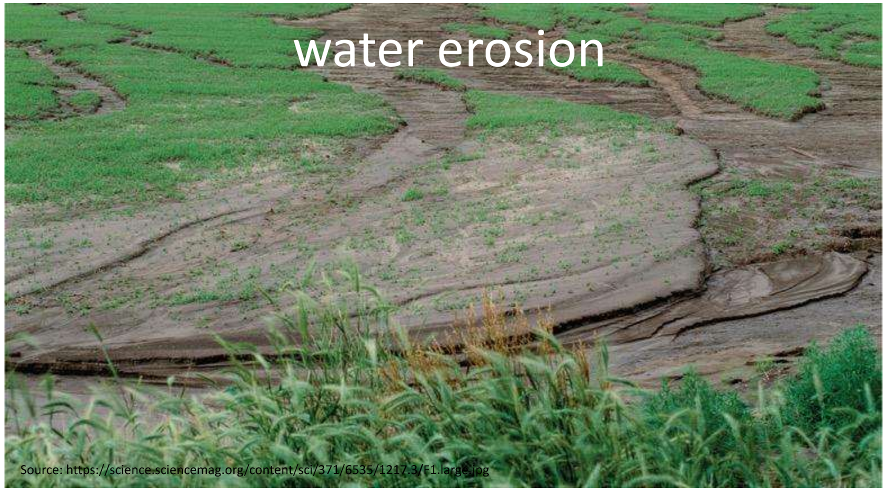




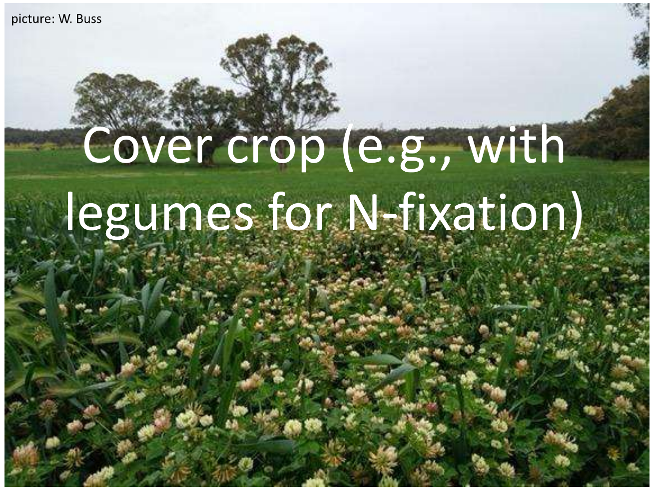
Area is fixed

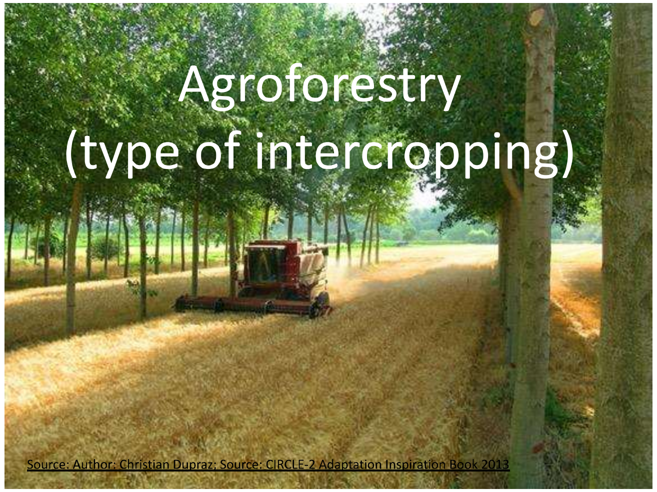
Intensify – more precision paddocks
Go vertical - deep roots, tall shoots
Dynamic time – rotations grazing, cropping, thinning

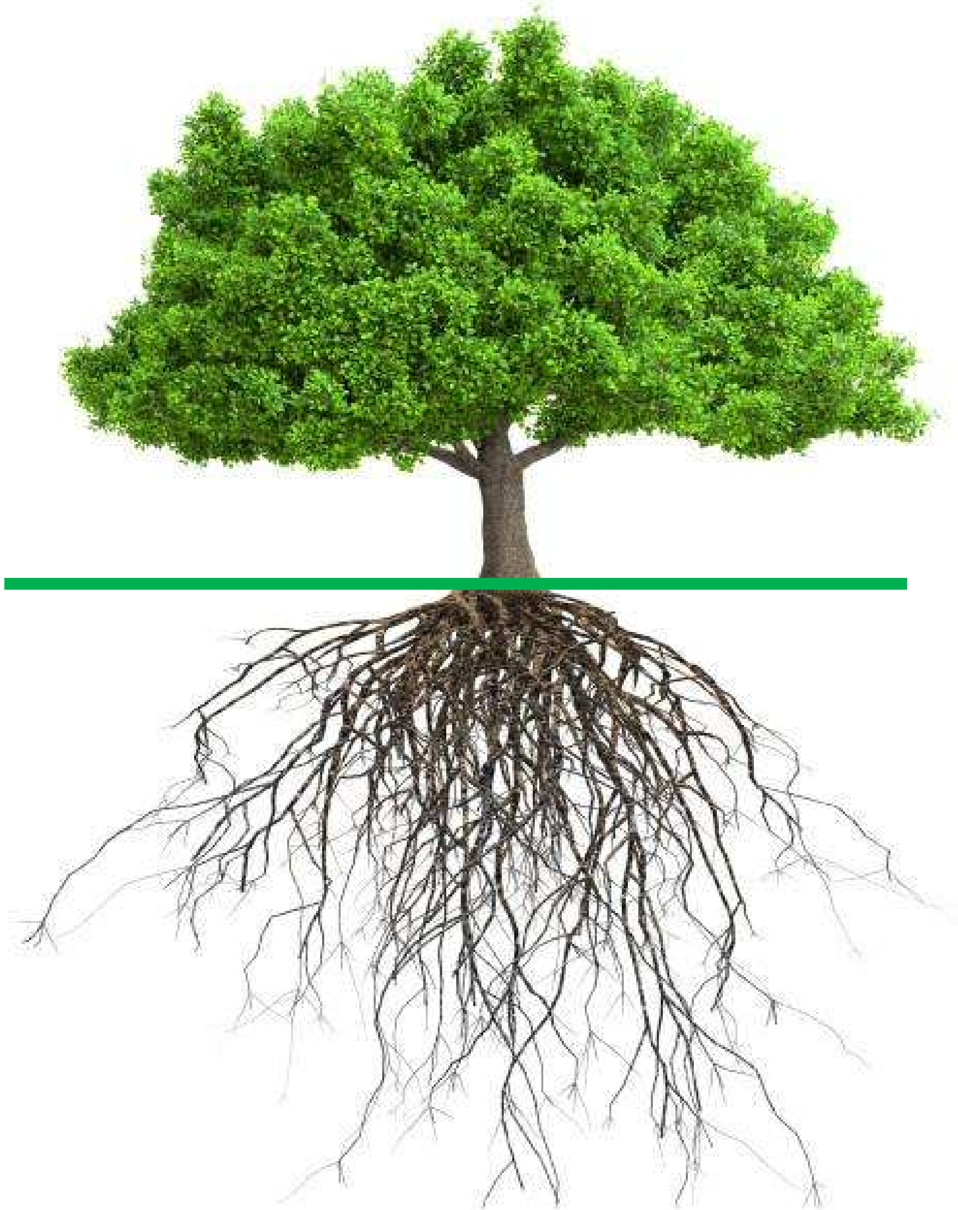
Farm degradation and soil carbon loss



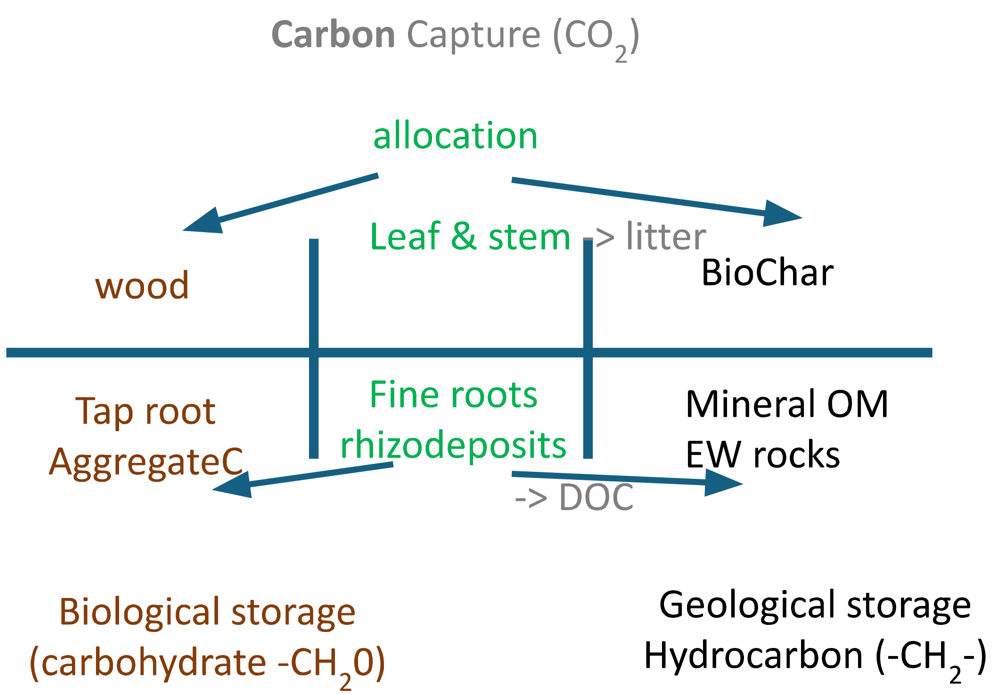
Sustainable and Regenerative





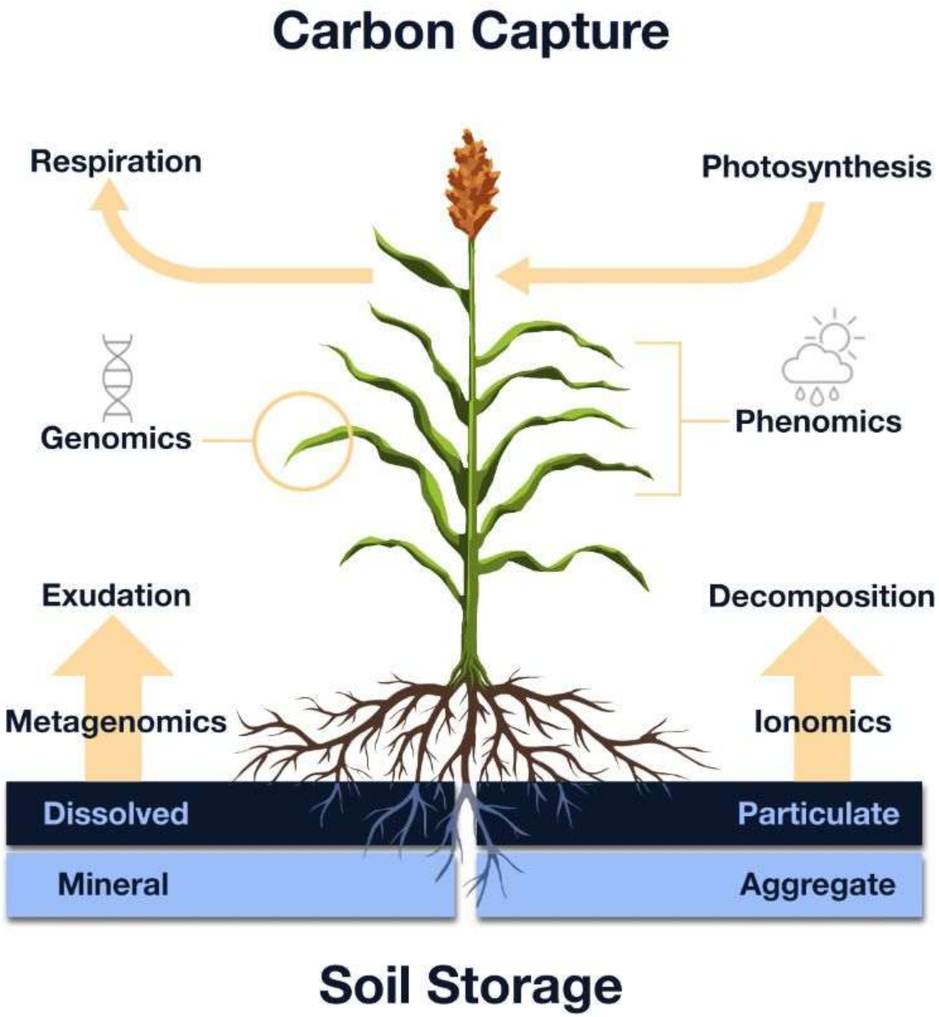


Land Carbon Cycle



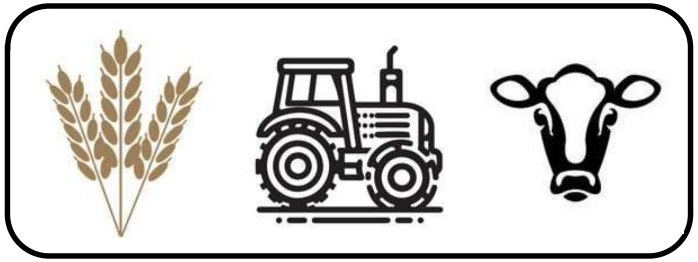
Plant Carbon Cycle

- *Leaves* — *Carbon Flow*
  - *Photosynthesis, respiration*
  - *Translocation, decomposition*
- Stems — Carbon Stock
  - Annual, perennial, woody
  - Shoot and tuber
- *Roots + microbes* — *Carbon Flow*
  - *Exudates, respiration, decomposition*
- Soil — Carbon Stock
  - Particulate, Aggregate, Mineral

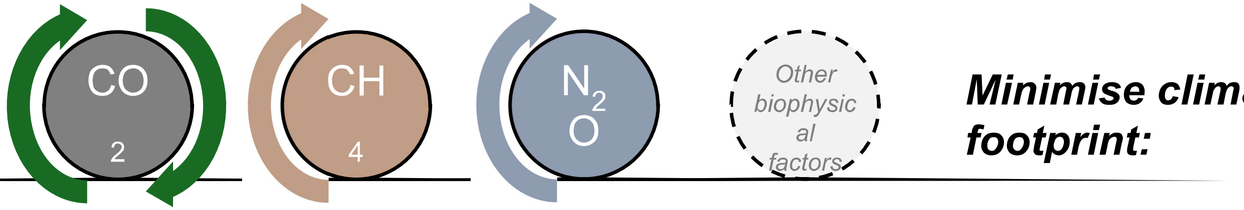


Dynamic Agro-Ecosystem Simulator
Project Context: The Agricultural Sector

Our managed landscapes face multiple challenges:



Increase food and fibre production to support a growing population



Minimise climate footprint:

- ***Reduce emissions***
- ***Enhance carbon storage***

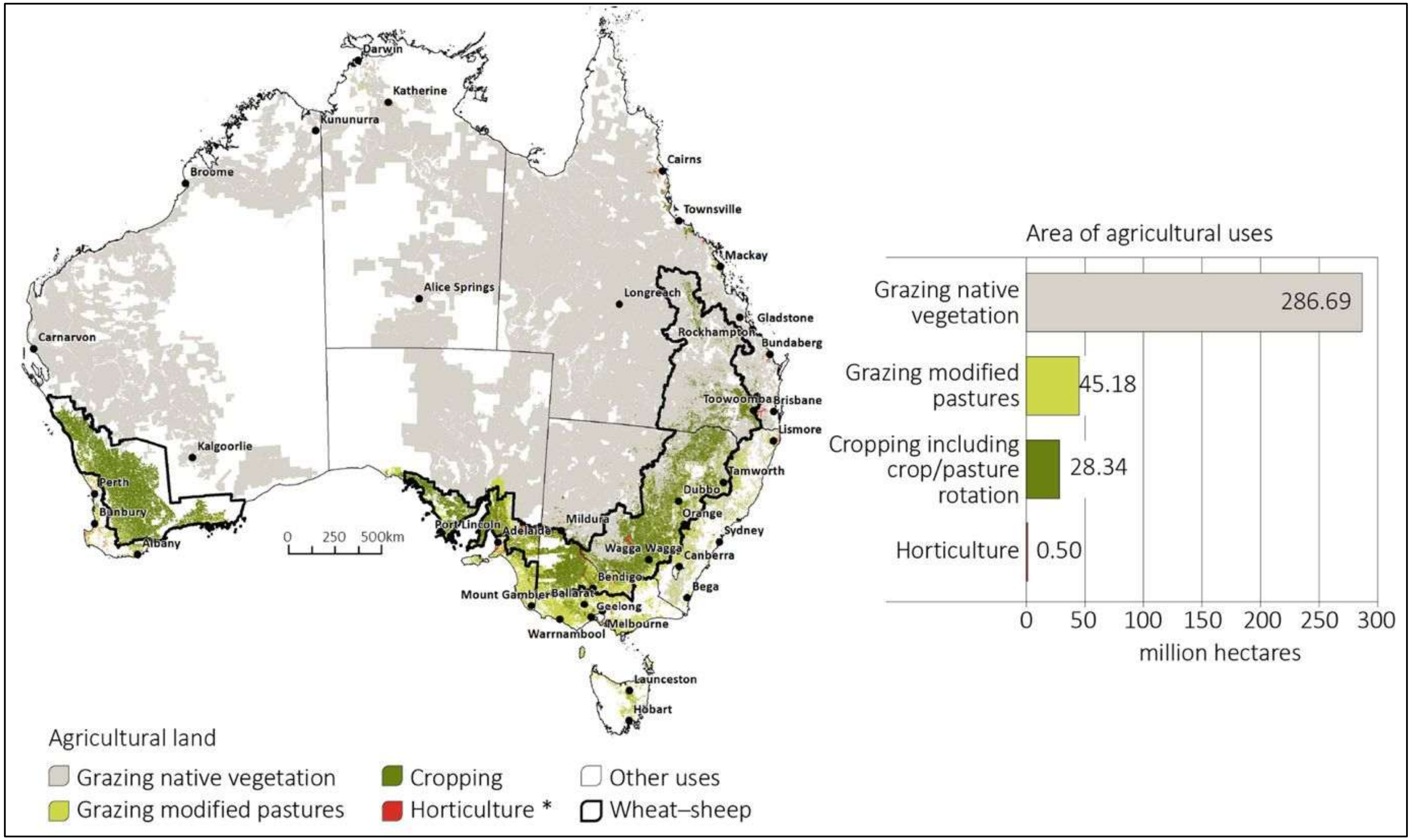
Preserve and regenerate ecological assets

Project Context: The Agricultural Sector

Agriculture:

- Covers ~55% of the continent* (2023)
- 74% of water consumption (2021-22)
- 13.6% of goods and services exports (2022–23)
- 2.7% of value added (GDP) and 2.2% of employment (2022-23)

Sector growth has slowed in recent decades



Source: ABARES

* Excluding timber production

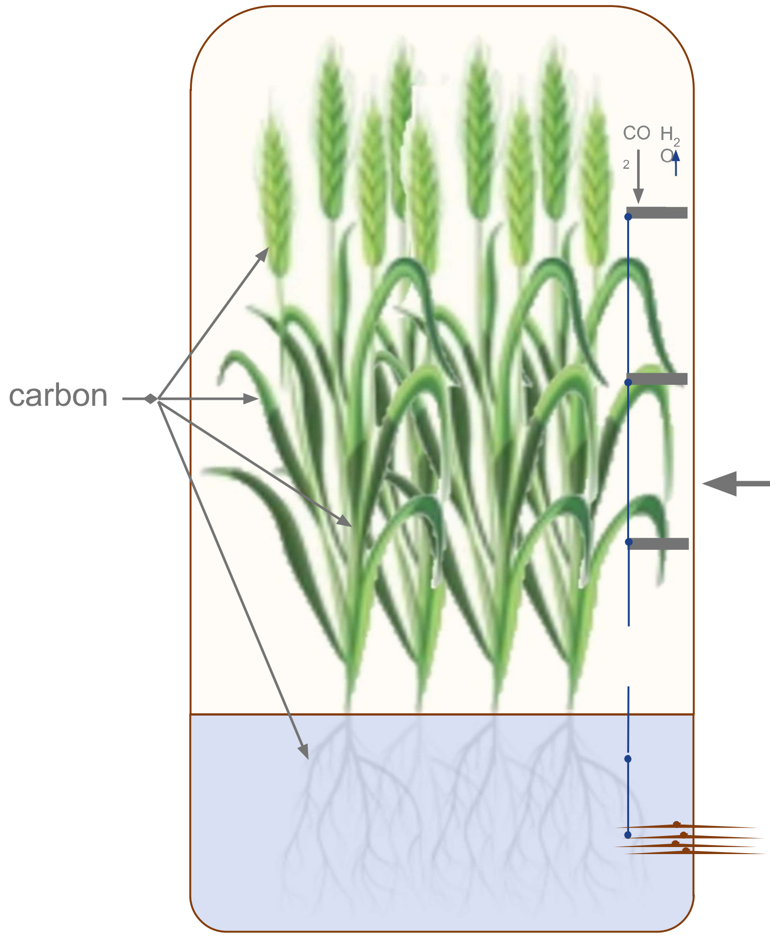
Agro-ecosystem modelling

The Dynamic Agro-Ecosystem Model II

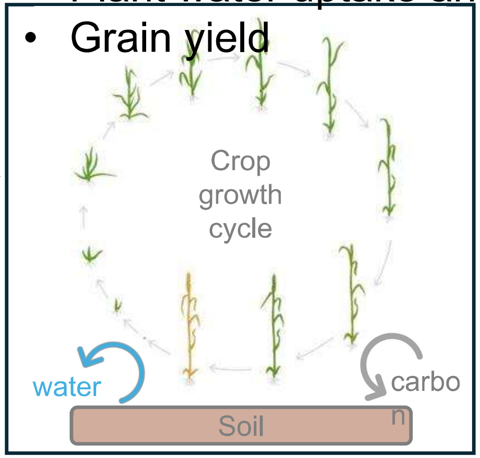
Represents plants, soil, carbon, water, erosion, cropping management.

Current versions: Wheat, canola and *generic crop/pasture*

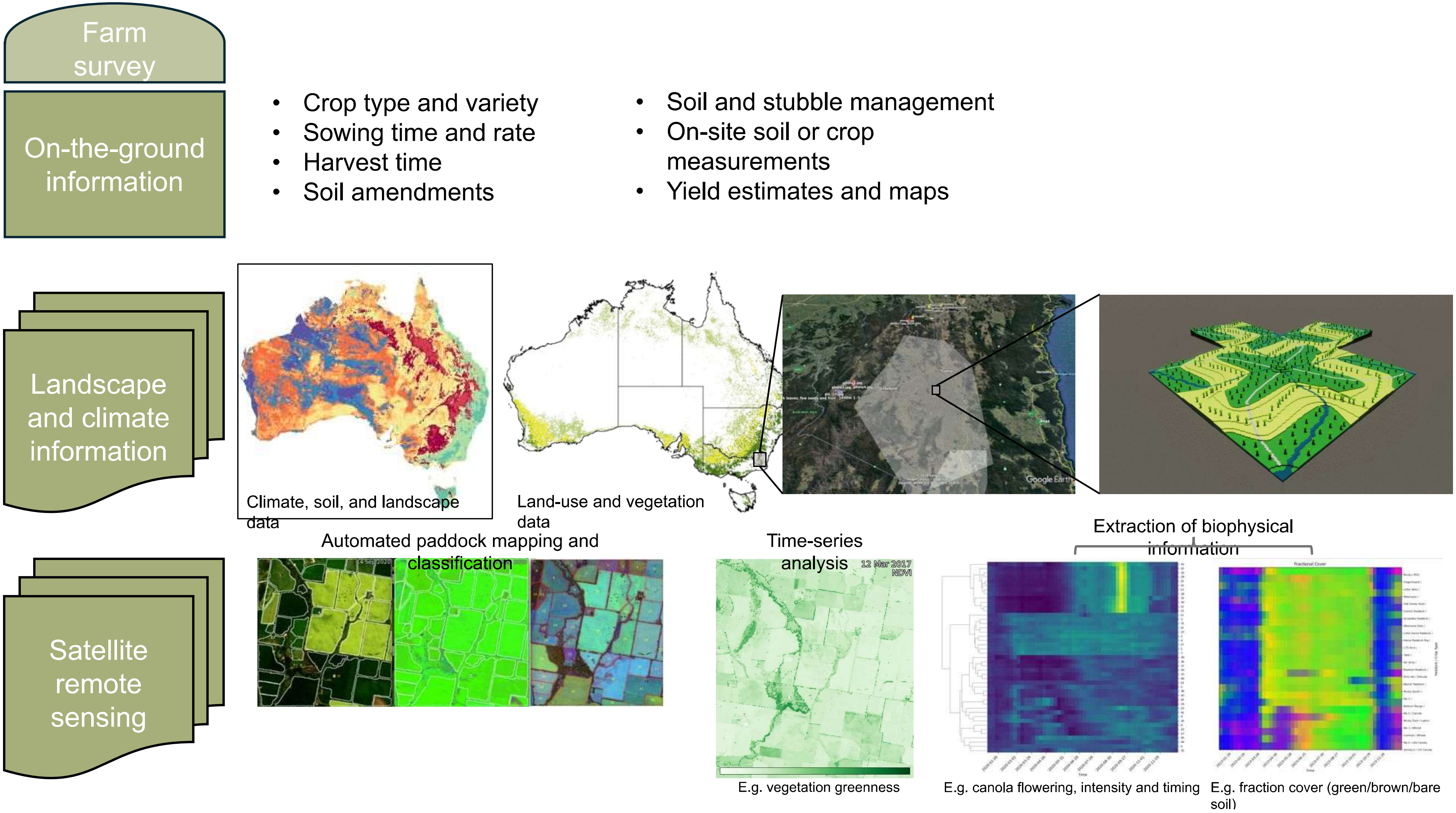
Model inputs: Radiation, temperature, humidity, carbon dioxide concentration, wind speed, sowing + harvest times, soil moisture, soil type and soil properties.



Predicts:
- Plant growth and development
- Plant carbon uptake and loss
- Plant water uptake and loss
- Grain yield



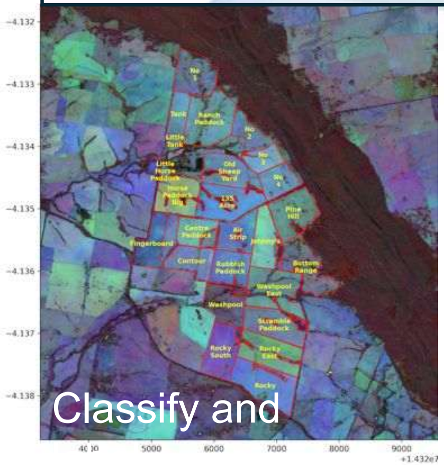
Includes an advanced representation of crop drought response – particularly important for Australia


Farm survey
On-the-ground information
Crop type and variety
Sowing time and rate
Harvest time
Soil amendments
Soil and stubble management
On-site soil or crop measurements
Yield estimates and maps
Landscape and climate information
Climate, soil, and landscape data
Land-use and vegetation data
Satellite remote sensing
Automated paddock mapping and classification
Time-series analysis
12 Mar 2017
NDVI
Extraction of biophysical information
E.g. vegetation greenness
E.g. canola flowering, intensity and timing
E.g. fraction cover (green/brown/bare soil)

A Drought Case Study in Wheat

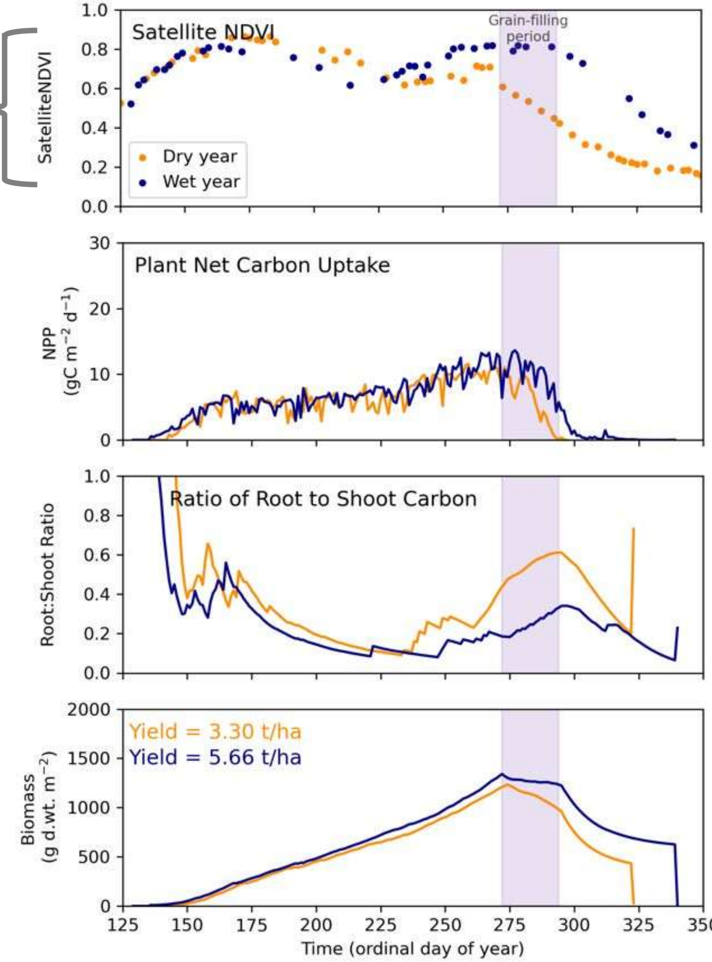
- Automatic separation of landscape heterogeneity into management units
- Satellite measurements including vegetation activity metrics (e.g., NDVI)

Mapping of land management units (e.g. paddocks)



Extract and analyse satellite data over time

2019 – Dry 2022 – Wet

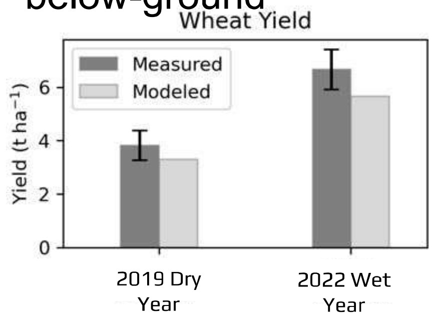


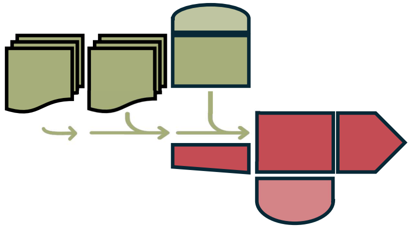
Key take-aways:

Satellite greenness during dry year is lower during critical grain-filling period

Our biophysical model predicts the drought effect on wheat yield

Wet-vs-dry has marked impact on paddock carbon dynamics above- and below-ground



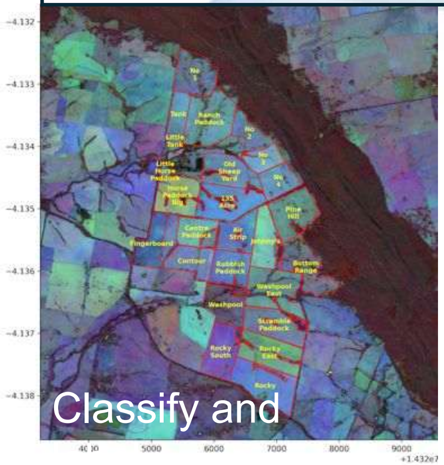


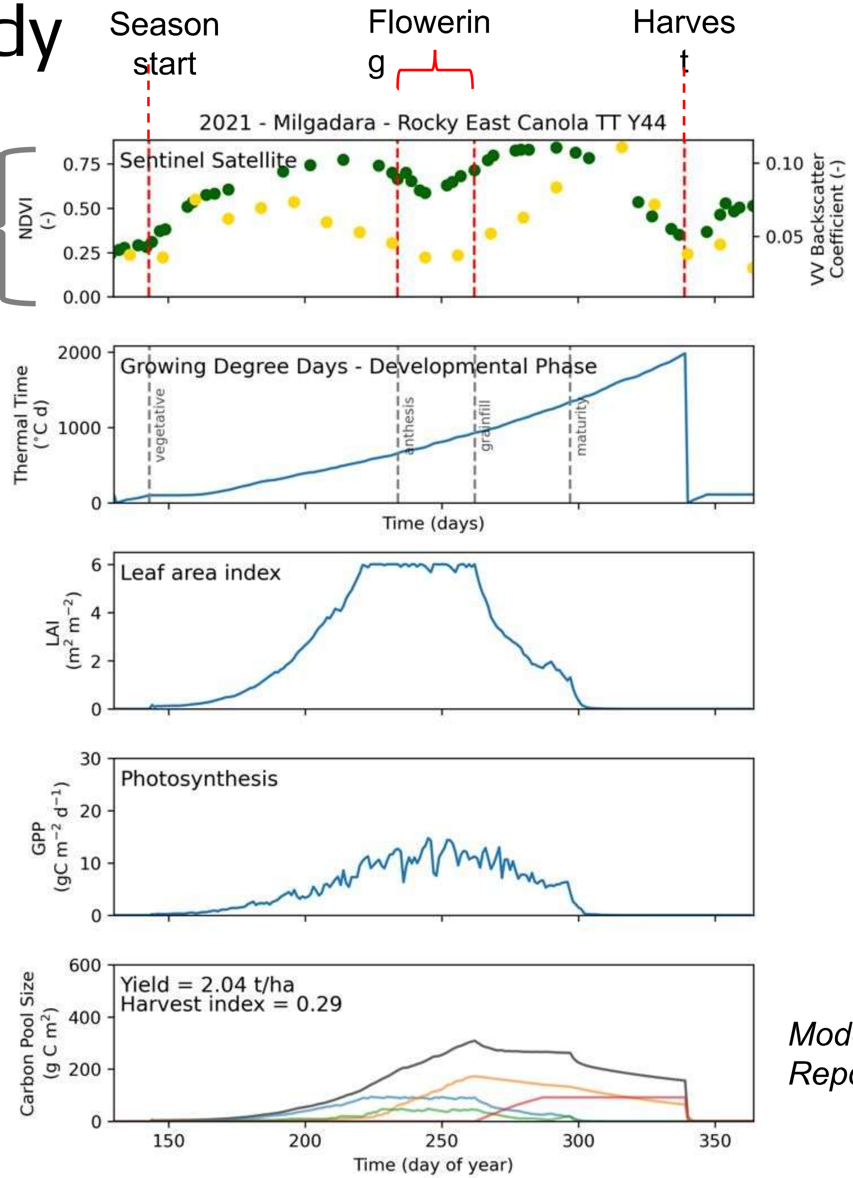
A Canola Case Study

Canola is easily observable from satellites. Flowering duration is closely linked to grain production.

- Extract key crop transition dates from satellite observations
- Calibrate model developmental rate to observed
- Run full biophysical model

Sentinel-1
Sentinel-2





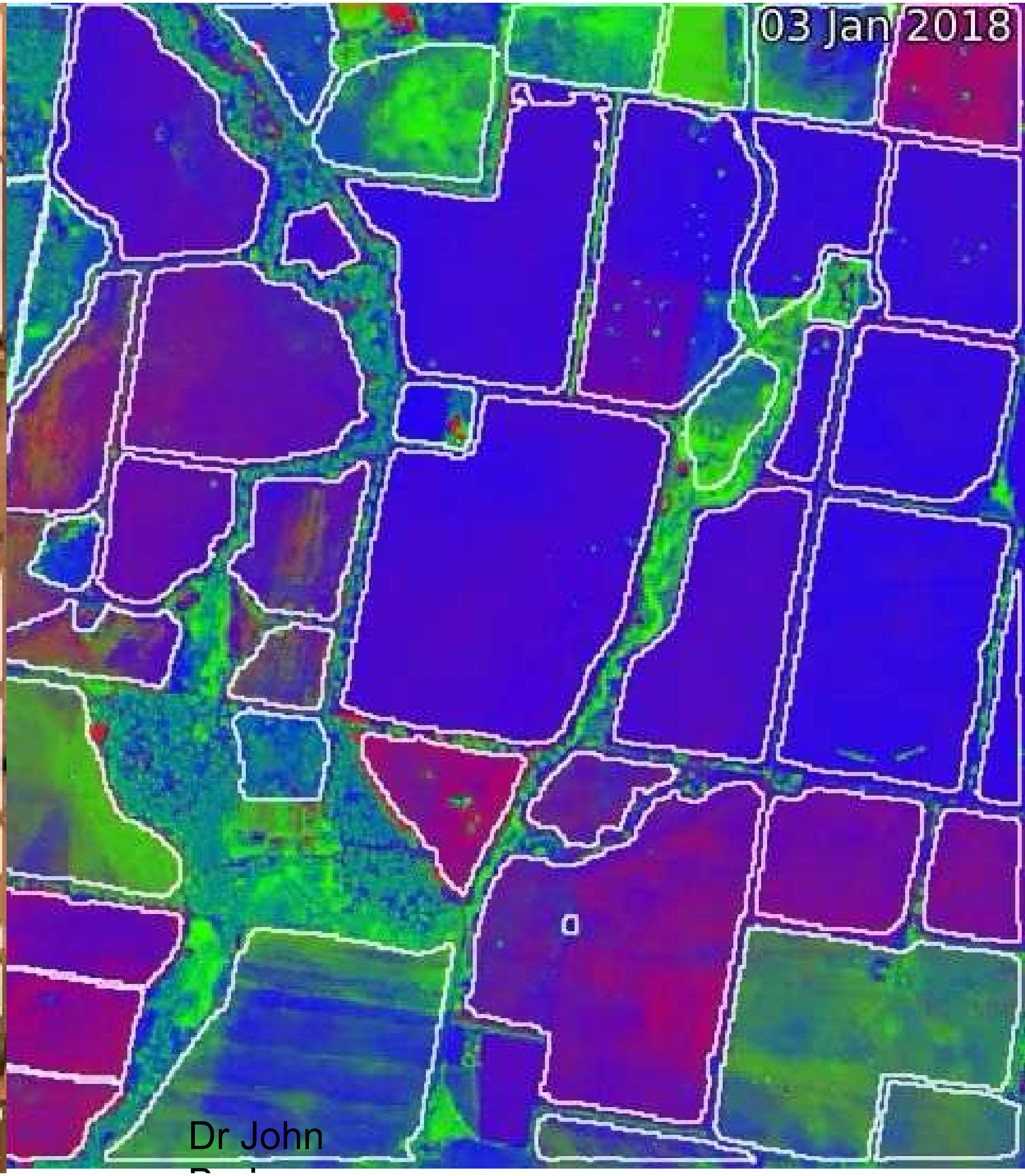
Key take-aways:

Satellite measurements show canola green up, flowering, and dry down

Our approach tunes the biophysical model to local conditions, improving realism

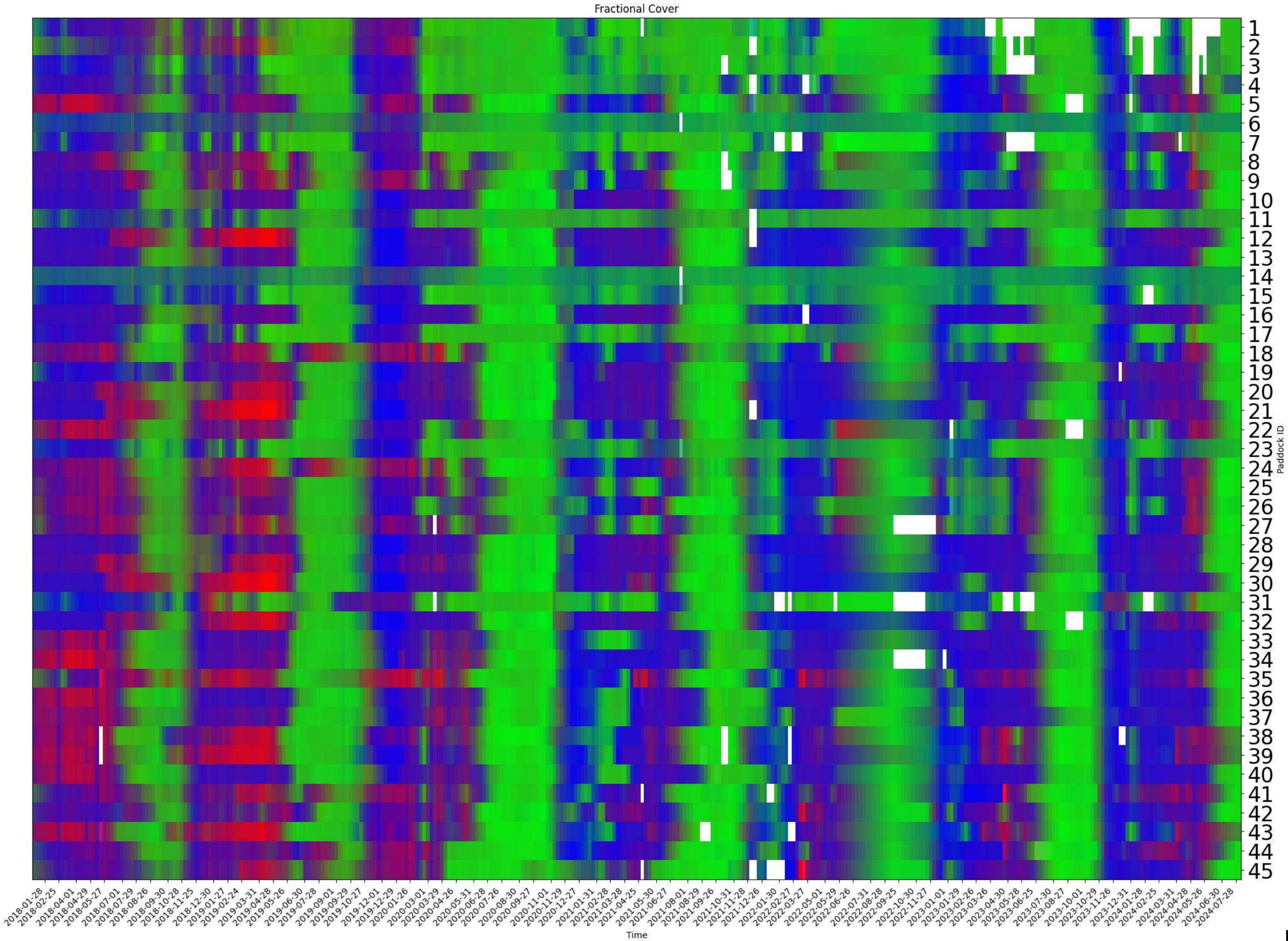
This enables monitoring and analysis of crop carbon-water

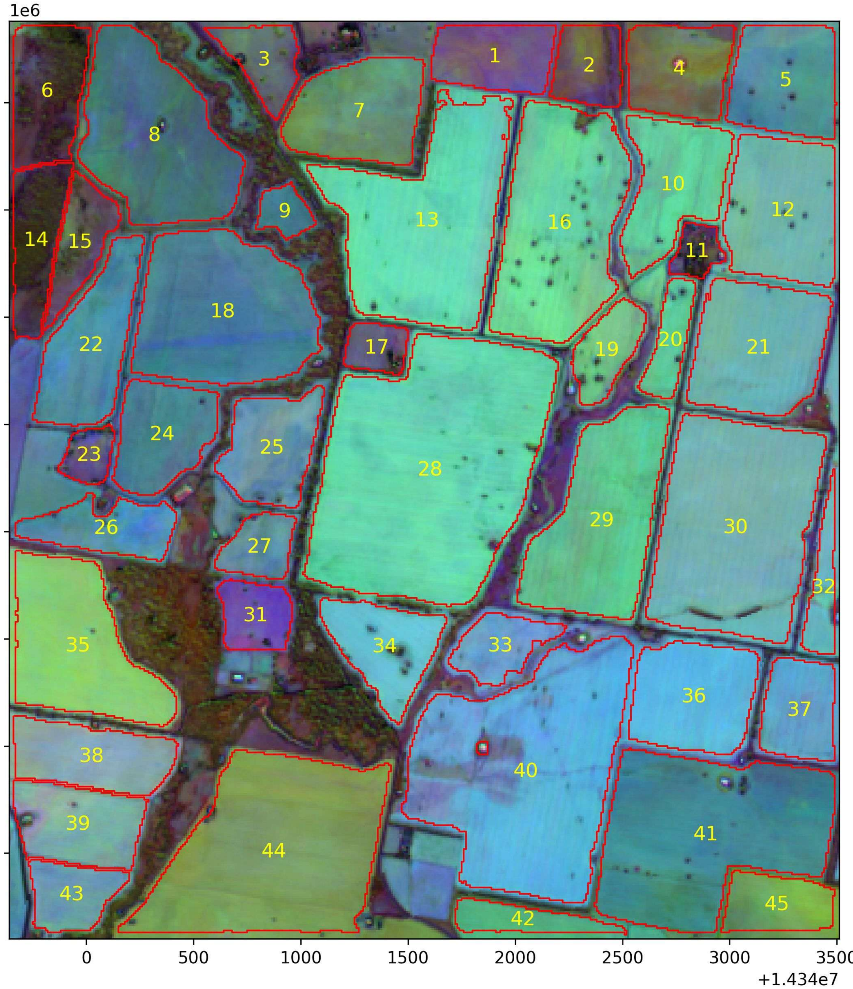
Modelled yield = 2.04 t/ha
Reported yield = 1.53 t/ha



Dr John

Bare – Brown – Green Dynamics

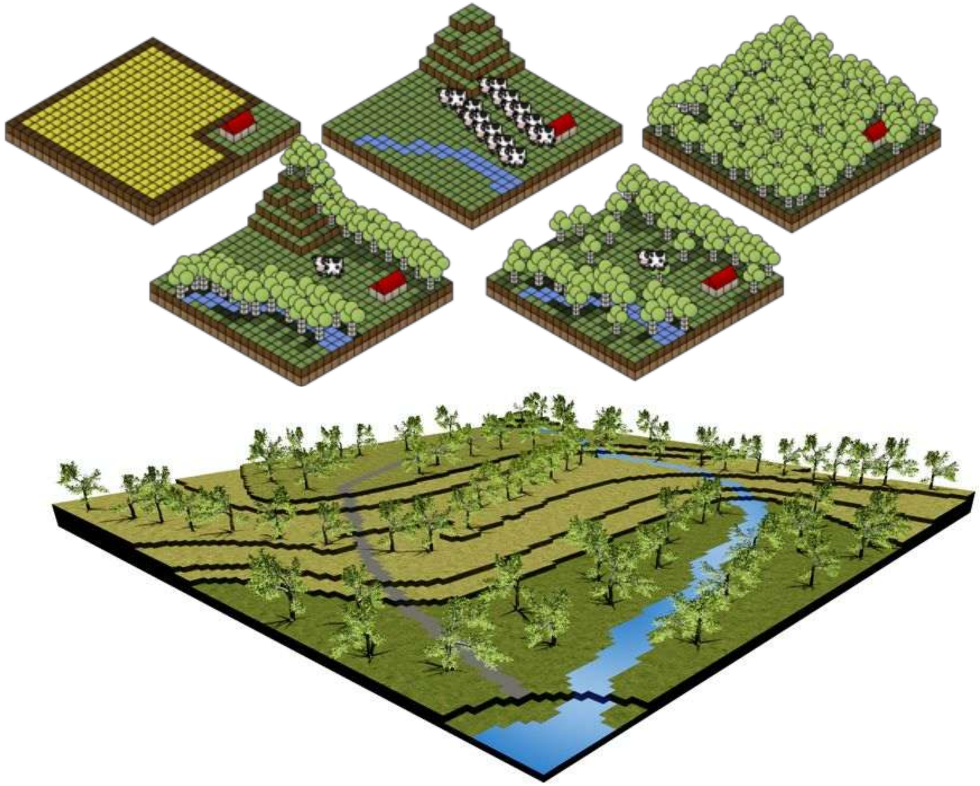




Dr John

Farming System – a collection of plant types

Farm Layout Model



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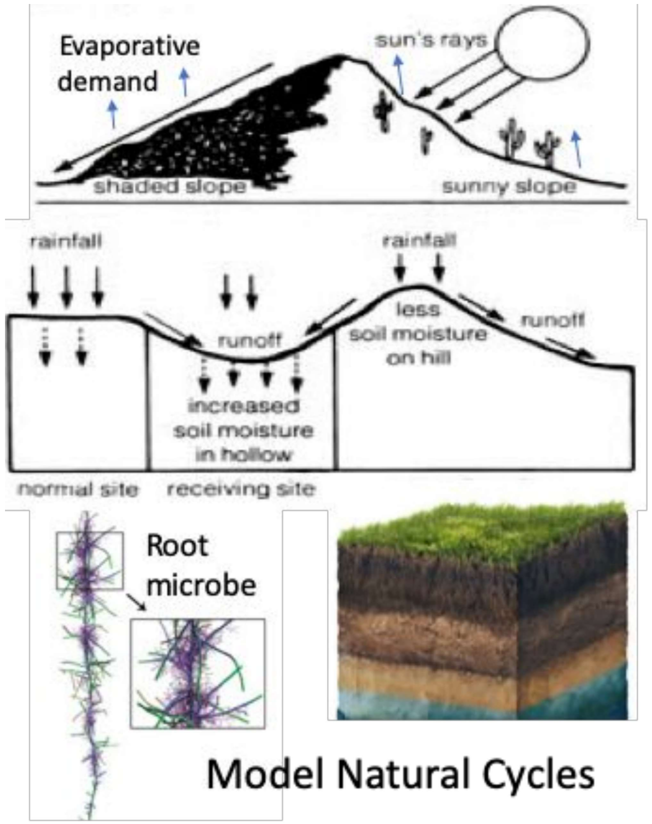


Solar

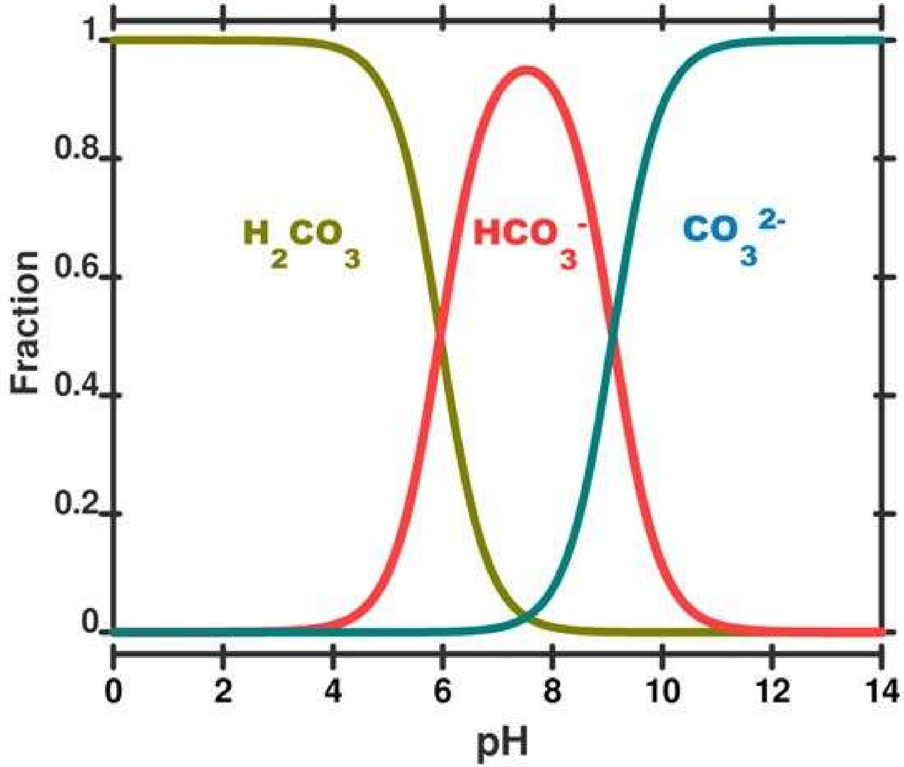
Water

Mineral

Nutrient Cycles

Optimising biology and chemistry to drive soil-based carbon dioxide removal

hydrocarbon



Hydrocarbon

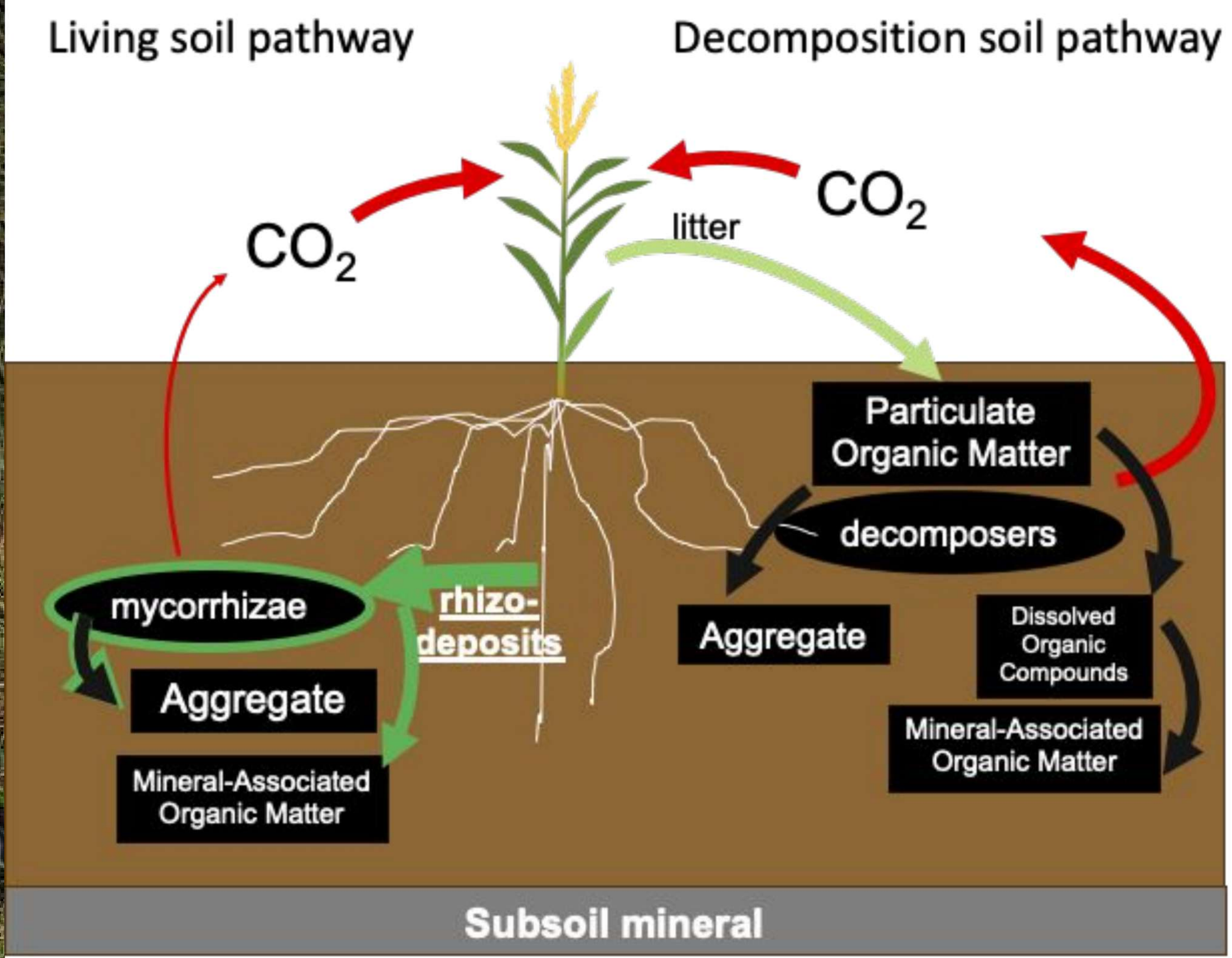
carbohydrate

Silicate – Mg,Ca

CO2 bicarbonate

Carbonate

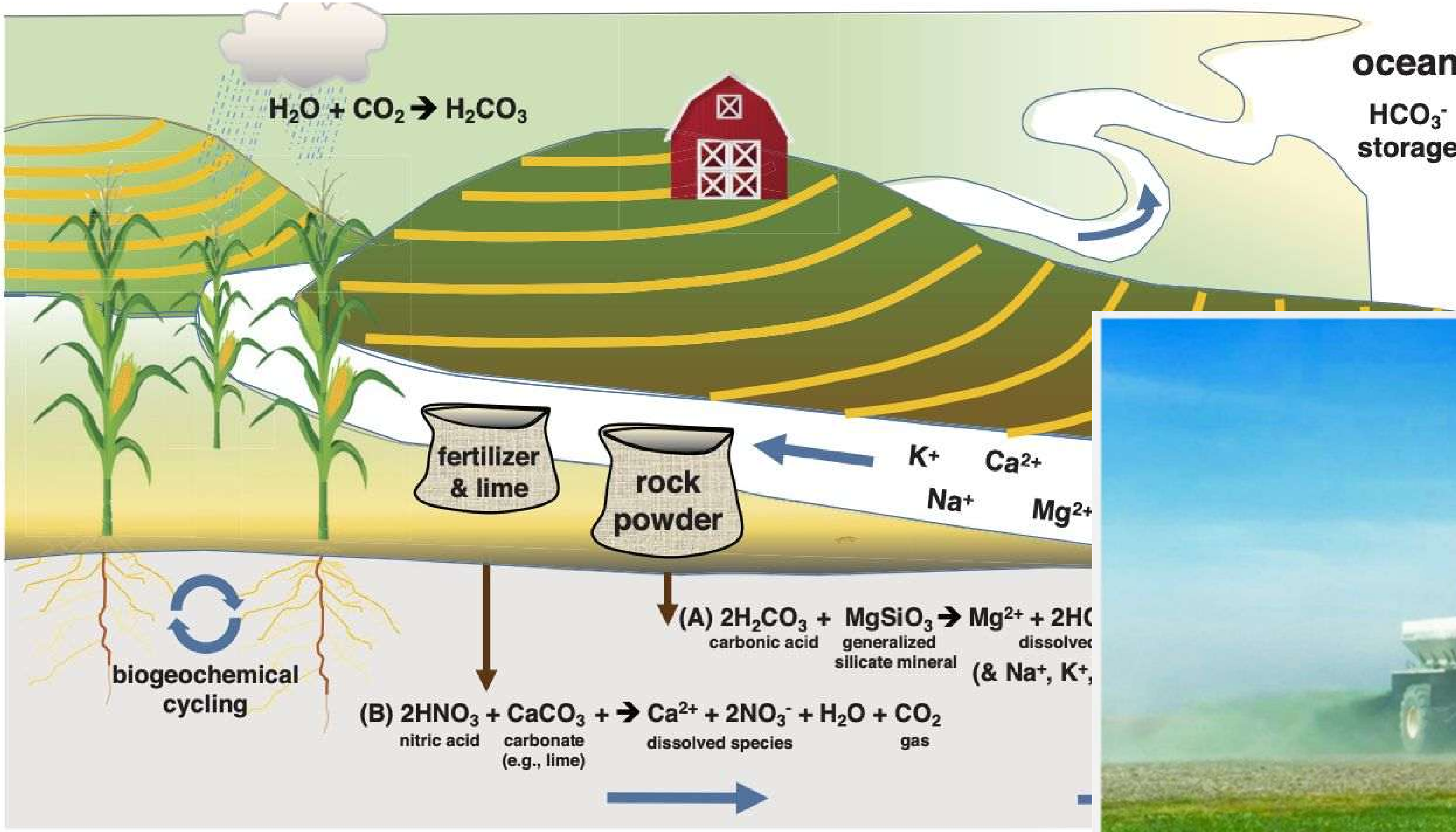
Dr Wolfram Buss

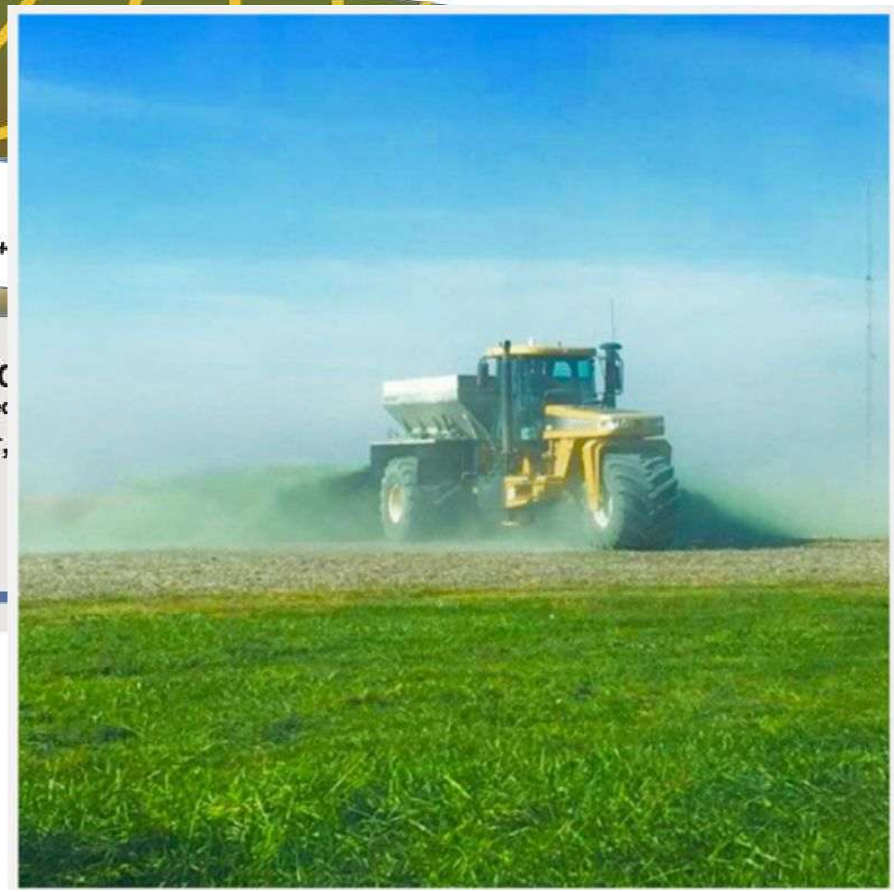


Soil Fractionation

Dr Wolfram Buss – wolfram.buss@anu.edu.au

Model Carbon Pools



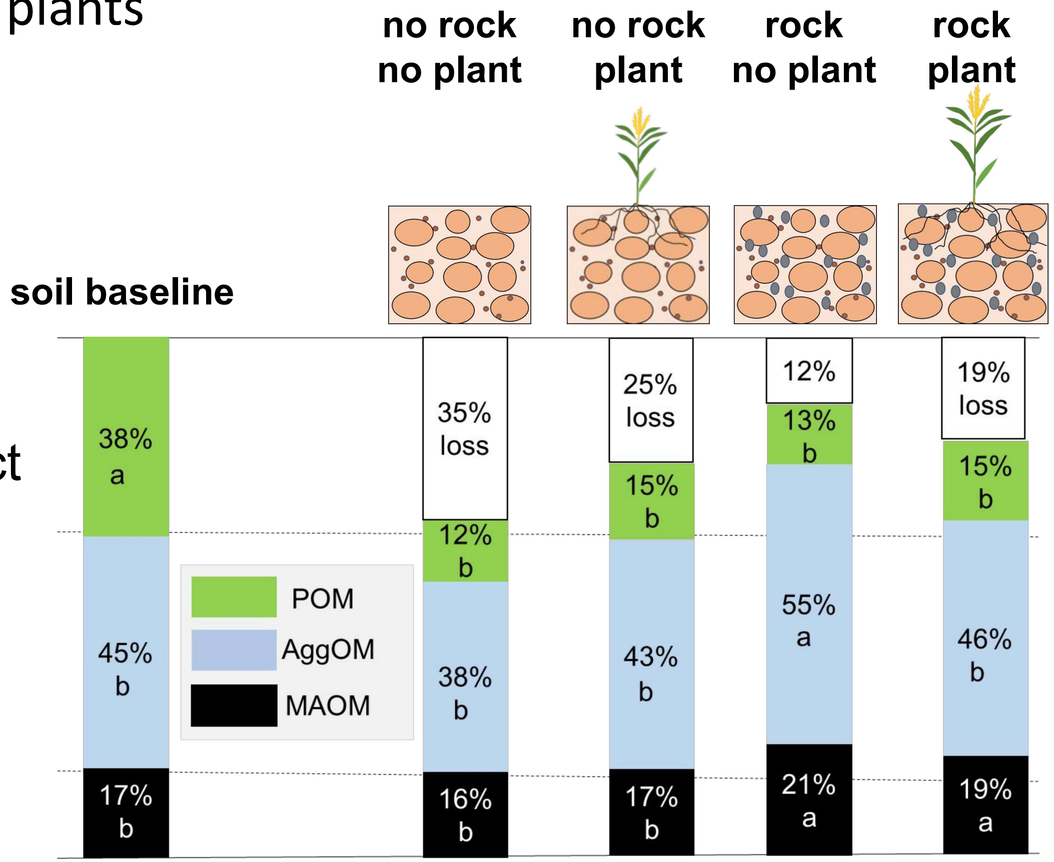


remineralizatio
n

Soil organic matter: mineral addition to soil

- 6-month soil 'incubation' trial with rock and plants

- Results: soil organic matter fractions
  - Loss of particulate organic matter
  - Rock decreased loss
  - Plant (exudates?) counteracted the effect
    - more organic matter/carbon loss

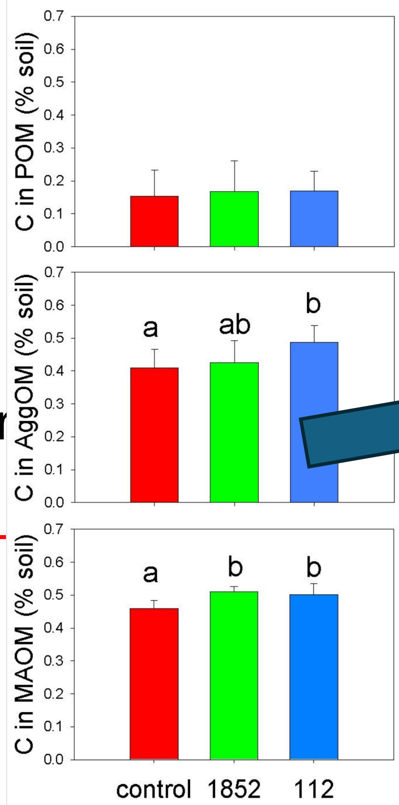


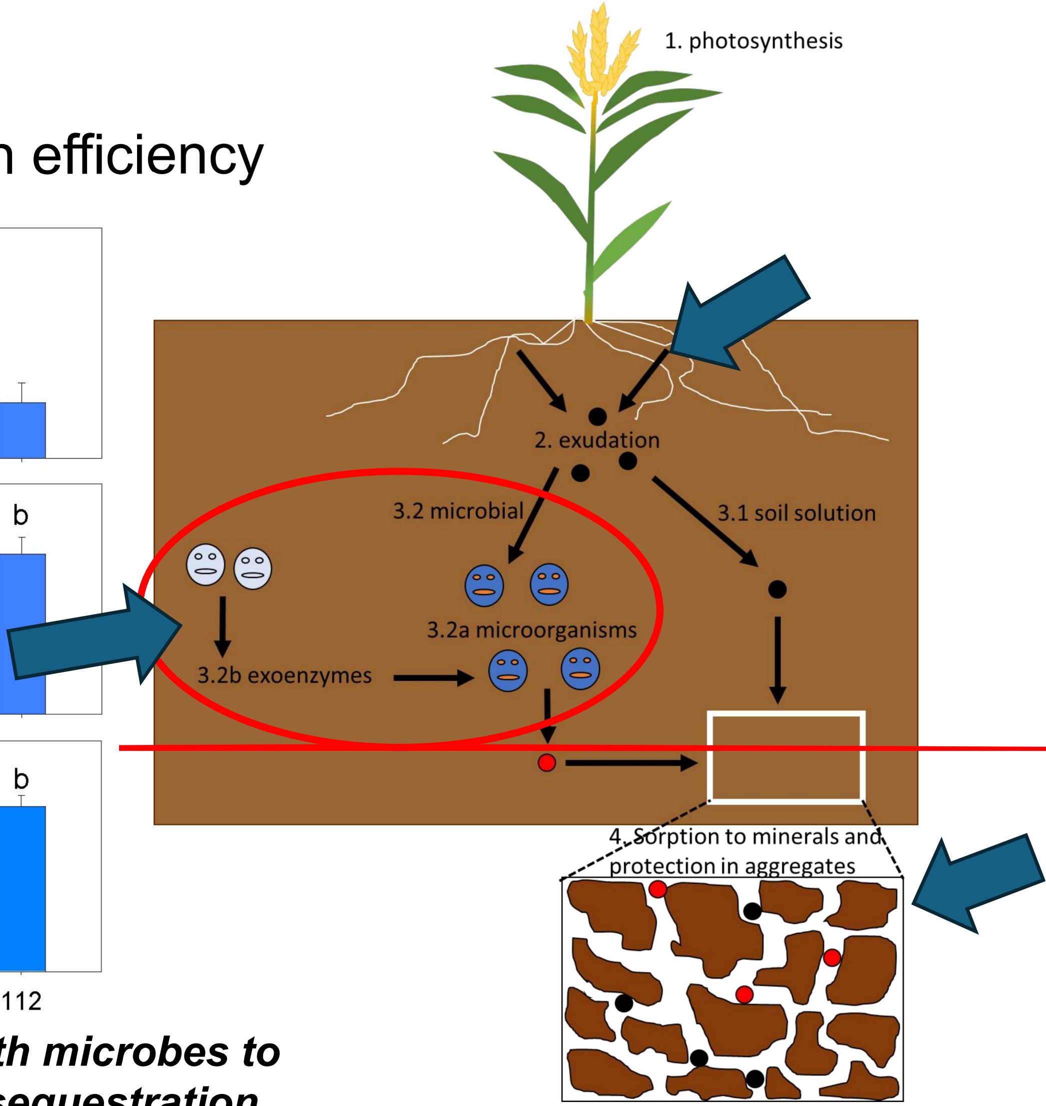
Biology/chemistry interactions

Buss et al Global Change Biology 2024

Soil organic matter

- Management to increase carbon sequestration efficiency
  - Input: Plant exudation or litter amendment – biology
  - Mediator: Microbes – biology
  - Sink capacity: Minerals – chemistr





Inoculating soil with microbes to increase carbon sequestration

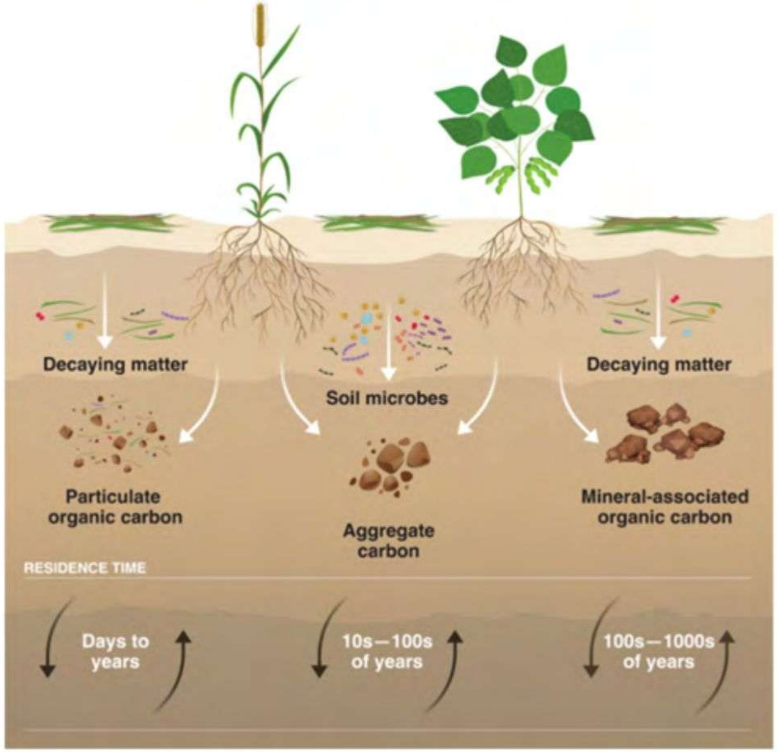
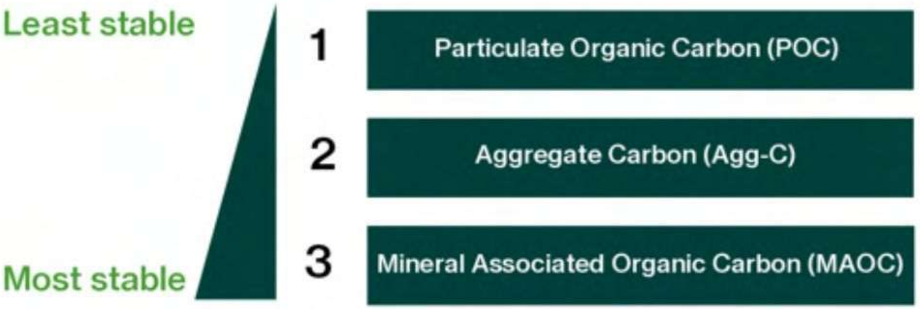


Figure 5. Soil carbon fractions. Particulate organic carbon is fast cycling, while carbon in aggregates and on mineral surfaces cycles more slowly.



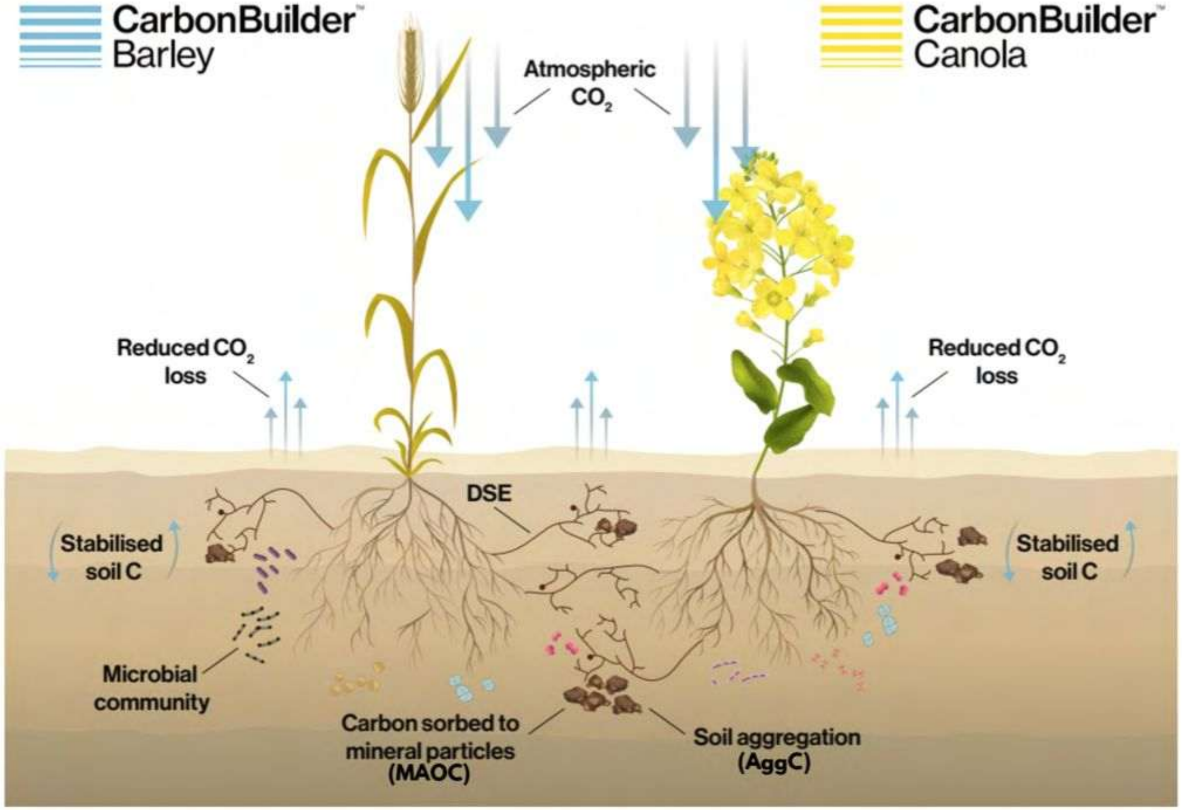
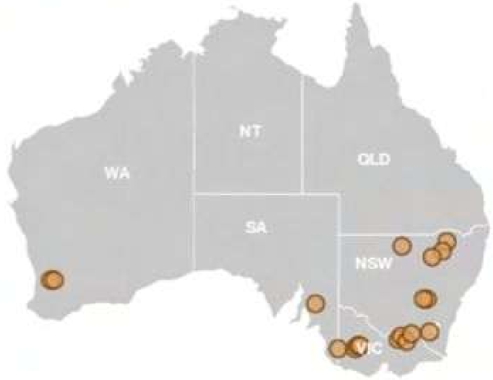


Figure 6. Building carbon in cropping systems. Atmospheric carbon dioxide is sequestered via plant photosynthesis and transferred into the soil via root exudation and the decomposition of plant biomass. Soil carbon may either return to the atmosphere via respiration, or be stabilised within soil aggregates or on mineral surfaces.

Small plot trial locations (2021 -2024)

Canola

Wheat



- 2×12 m plots
- 6 replicate plots per treatment at a trial site
- 30-60 plots per location, depending on the number of treatments
- Randomised control block arrangement of plots at
- The trial site
  - Trial sites located on farm
  - Management following local practices

Barley

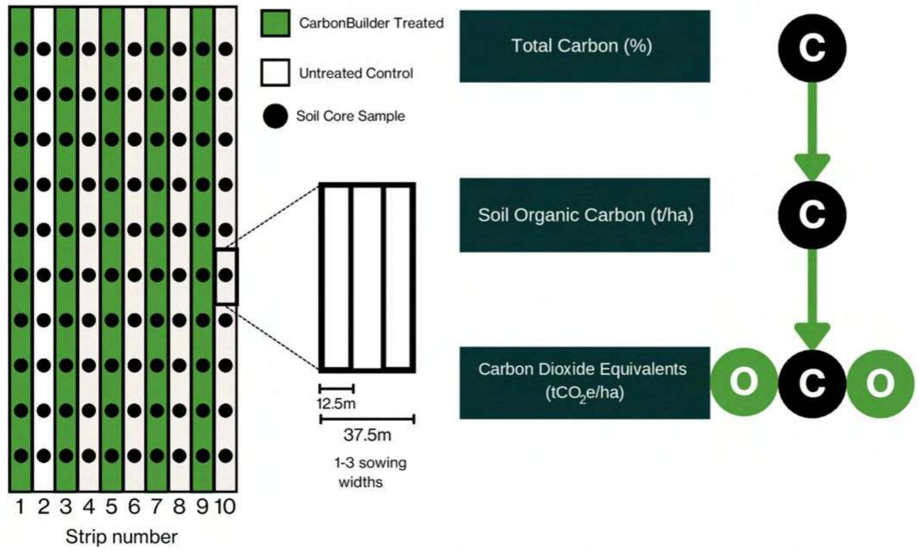


Figure 14 A) Strip trial design consists of 10 strips (5 treated with CarbonBuilder & 5 untreated), measuring both crop yield and the change in total carbon (TC). **B)** Calculating carbon dioxide equivalents (tCO2e/ha) using Total Carbon (%).

5MRV
Accounting system

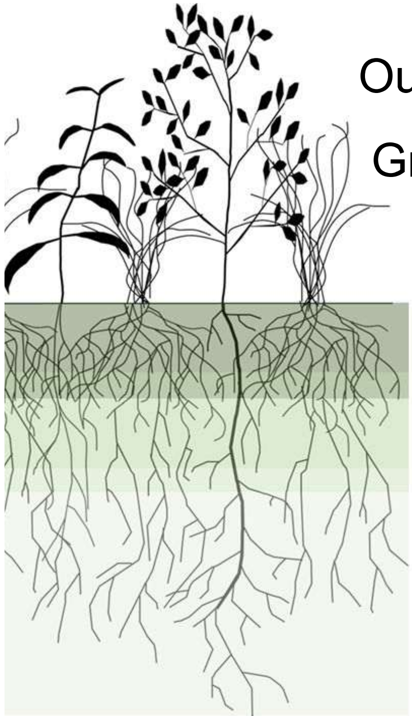
observe plant types
simulate processes with
local environment
Add up cells on a farm

Monitorin
g

Modellin
g

Verification

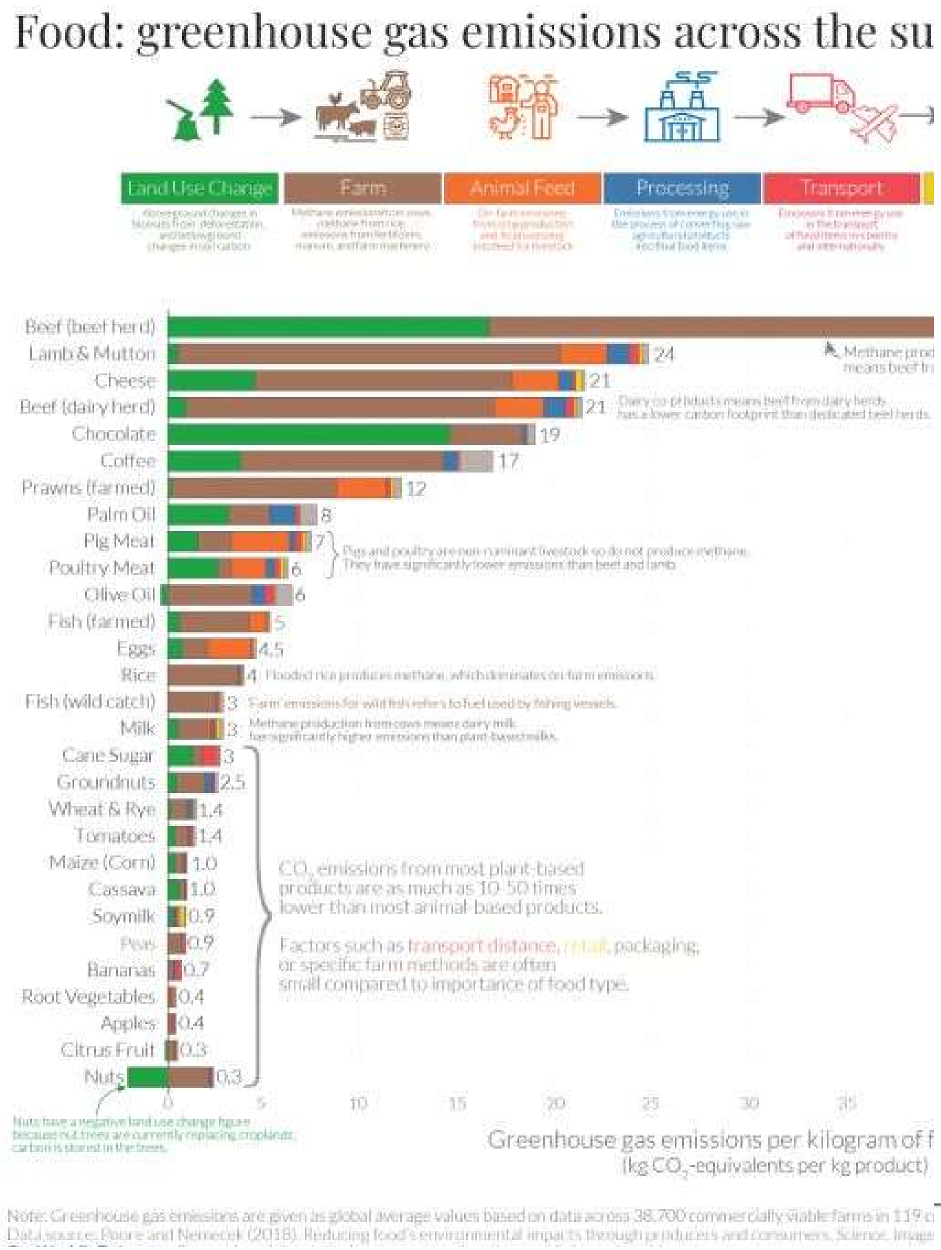
Modular Reporting



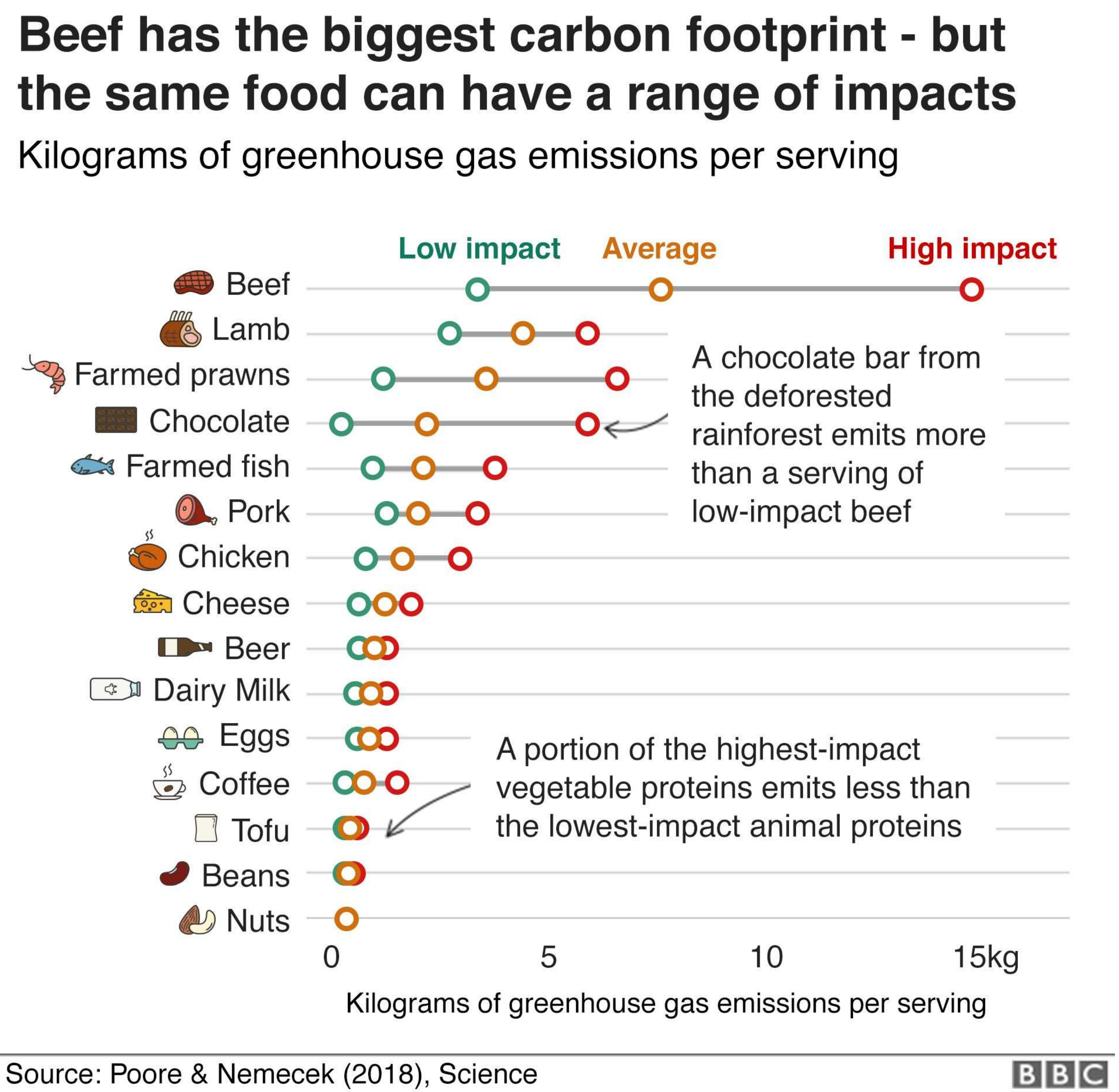
Output
Grass
Tree
Soils
Input

Manageme

Measureme



Food: greenhouse gas emissions across the su
Land Use Change
Farm
Animal Feed
Processing
Transport
Beef (beef herd)
Lamb & Mutton 24
Cheese 21
Beef (dairy herd) 21
Chocolate 19
Coffee 17
Prawns (farmed) 12
Palm Oil 8
Pig Meat 7
Poultry Meat 6
Olive Oil 6
Fish (farmed) 5
Eggs 4.5
Rice 4
Fish (wild catch) 3
Milk 3
Cane Sugar 3
Groundnuts 2.5
Wheat & Rye 1.4
Tomatoes 1.4
Maize (Corn) 1.0
Cassava 1.0
Soymilk 0.9
Peas 0.9
Bananas 0.7
Root Vegetables 0.4
Apples 0.4
Citrus Fruit 0.3
Nuts 0.3
Pigs and poultry are non-ruminant livestock so do not produce methane.
Flooded rice produces methane, which dominates on-farm emissions.
CO2 emissions from most plant-based products are as much as 10-50 times lower than most animal-based products.
Factors such as transport distance, retail, packaging, or specific farm methods are often small compared to importance of food type.
0 5 10 15 20 25 30 35
Greenhouse gas emissions per kilogram of f
(kg CO2-equivalents per kg product)

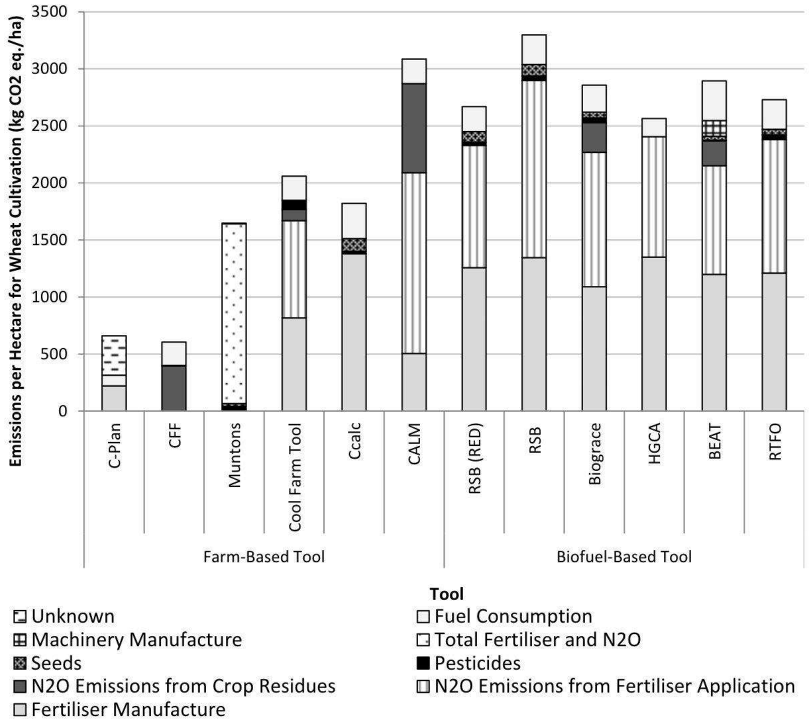


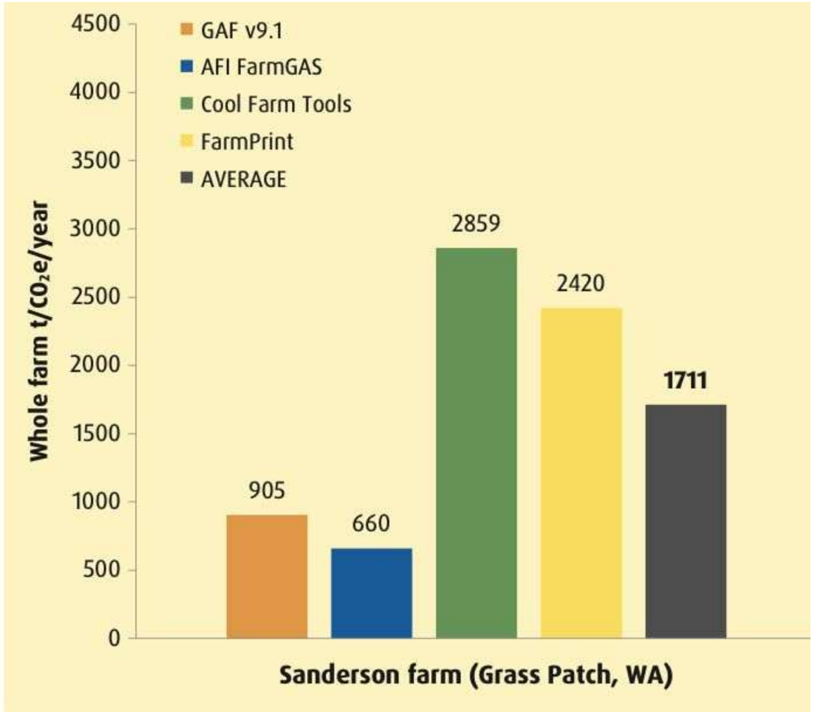
Beef has the biggest carbon footprint - but the same food can have a range of impacts
Kilograms of greenhouse gas emissions per serving
Low impact
Average
High impact
Beef
Lamb
Farmed prawns
Chocolate
Farmed fish
Pork
Chicken
Cheese
Beer
Dairy Milk
Eggs
Coffee
Tofu
Beans
Nuts
A chocolate bar from the deforested rainforest emits more than a serving of low-impact beef
A portion of the highest-impact vegetable proteins emits less than the lowest-impact animal proteins
0
5
10
15kg
Kilograms of greenhouse gas emissions per serving
Source: Poore & Nemecek (2018), Science
BBC

HOW ARE WE COUNTING EMISSIONS ON FARM?

The number of farm level emission accountings tools increased (around 60 tools currently)

But, they all produce significantly different results

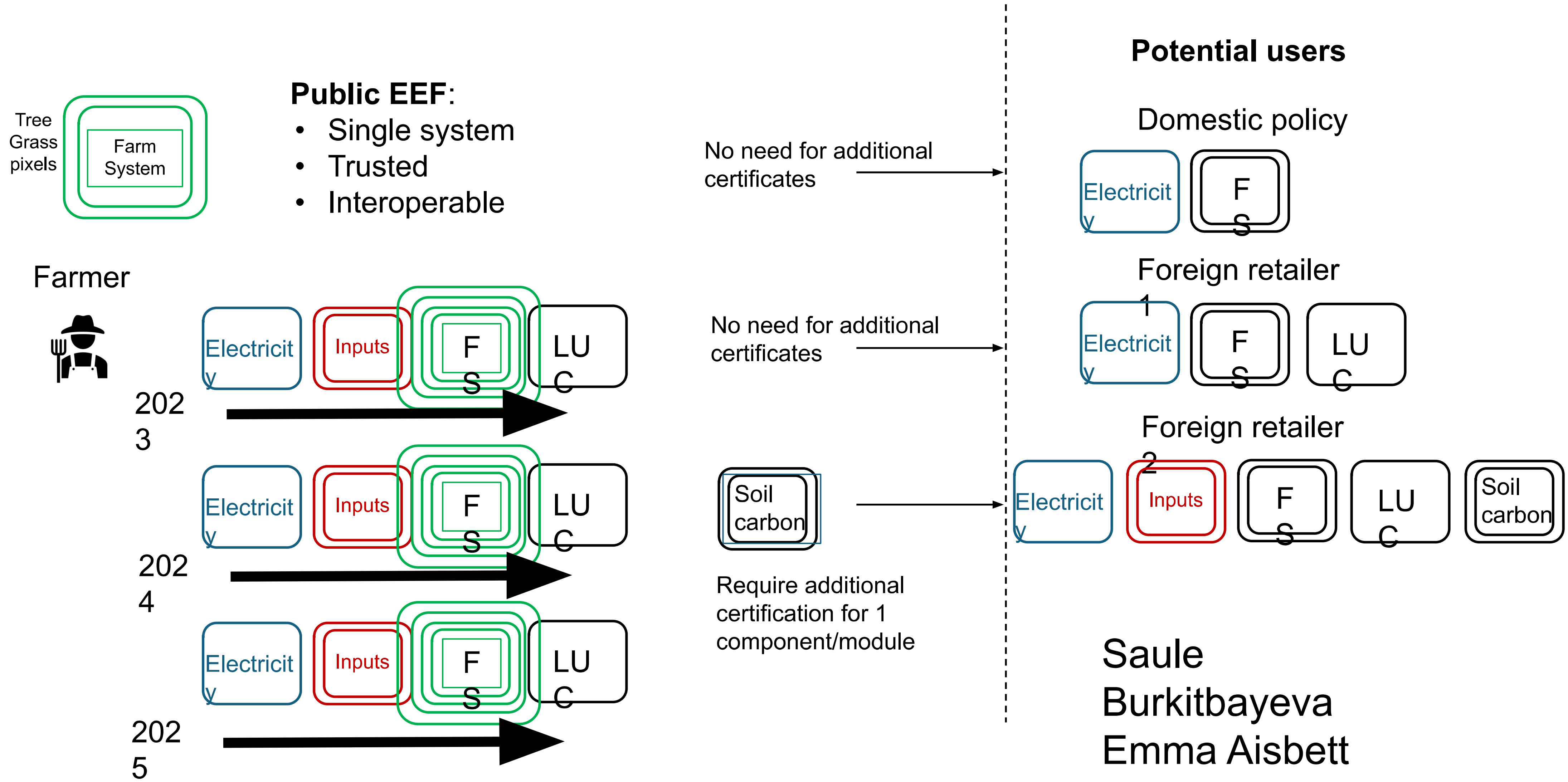




Source: GrainGrowers, 2020

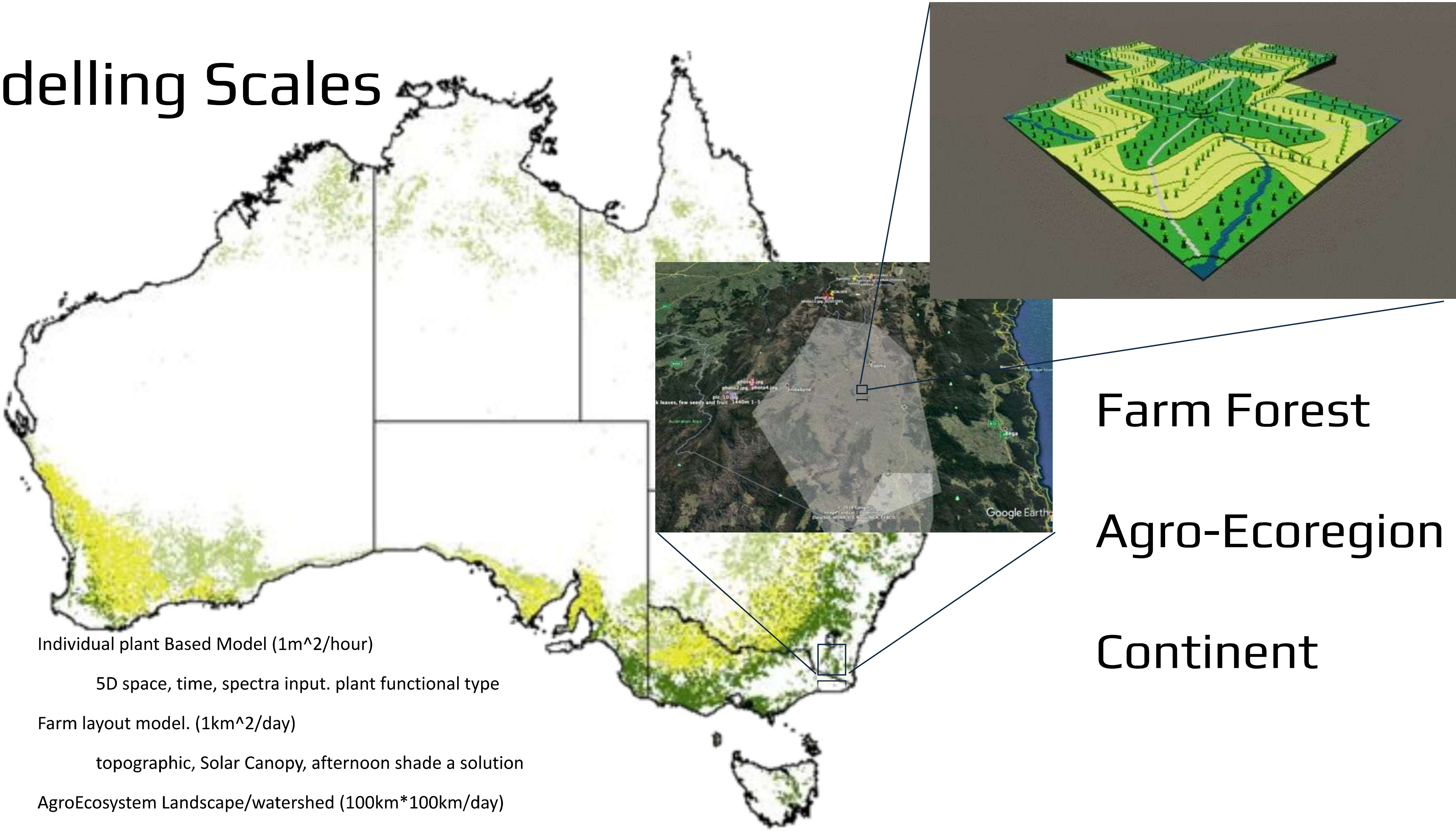
Saula

A framework for farm products to embedded emissions?



Saule Burkitbayeva
Emma Aisbett

Modelling Scales



Farm Forest

Agro-Ecoregion

Continent

Individual plant Based Model (1m^2/hour)

5D space, time, spectra input. plant functional type

Farm layout model. (1km^2/day)

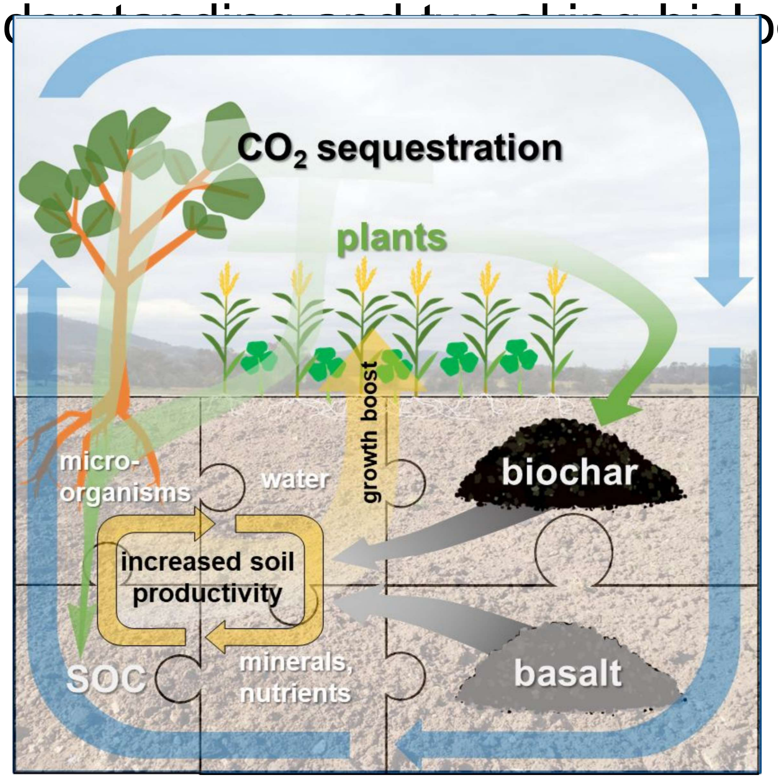
topographic, Solar Canopy, afternoon shade a solution

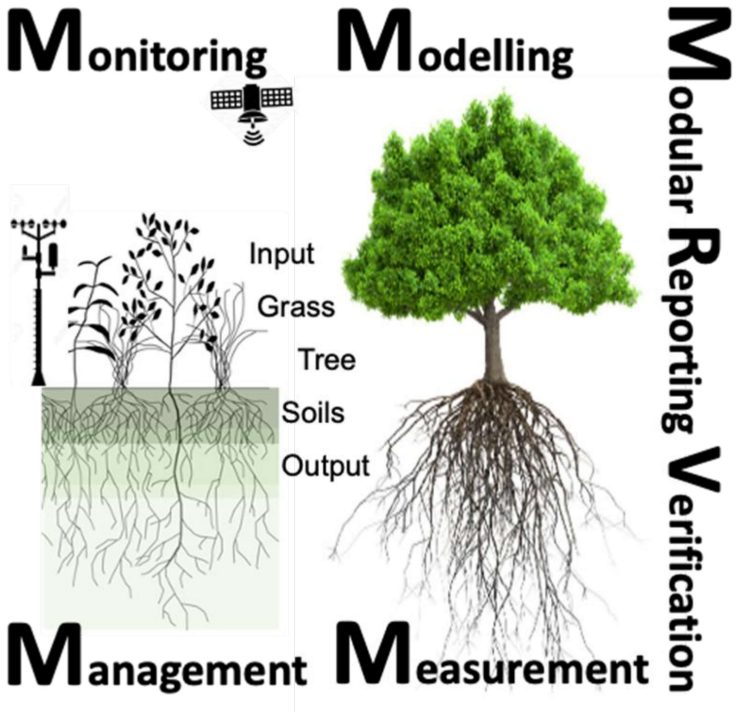
AgroEcosystem Landscape/watershed (100km*100km/day)

Continental/Global (100M km pixels)

Vision

- Managing agricultural system for maximum carbon sequestration while providing co-benefits
- Understanding and tweaking biology and chemistry





Buss et. al., 2021. Enhancing natural cycles in agro-ecosystems to boost plant carbon capture and soil storage. Oxford Open Climate Change.


Reboot Primary Industries of Agriculture, Forestry
Biomass, hard rock mining, Wind development?
Dr Wolfram Buss
Dr Alexander Norton
Dr John Burley
Dr Saule
Chris Bradley
Dmitry Grishin
Huyue Wu
Viraj Kolhapuri
Landscaperegeneration