Landcare Research LINK Seminar
25 August 2015

2015 International Year of the Soil

Where has all the carbon gone?

The answer lies in the soil.....

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NEW ZEALAND AGRICULTURAL GREENHOUSE GAS Research Centre
PGgRc PASTORAL GREENHOUSE GAS RESEARCH CONSORTIUM
WORKING TOGETHER

Landcare Research
Manaaki Whenua

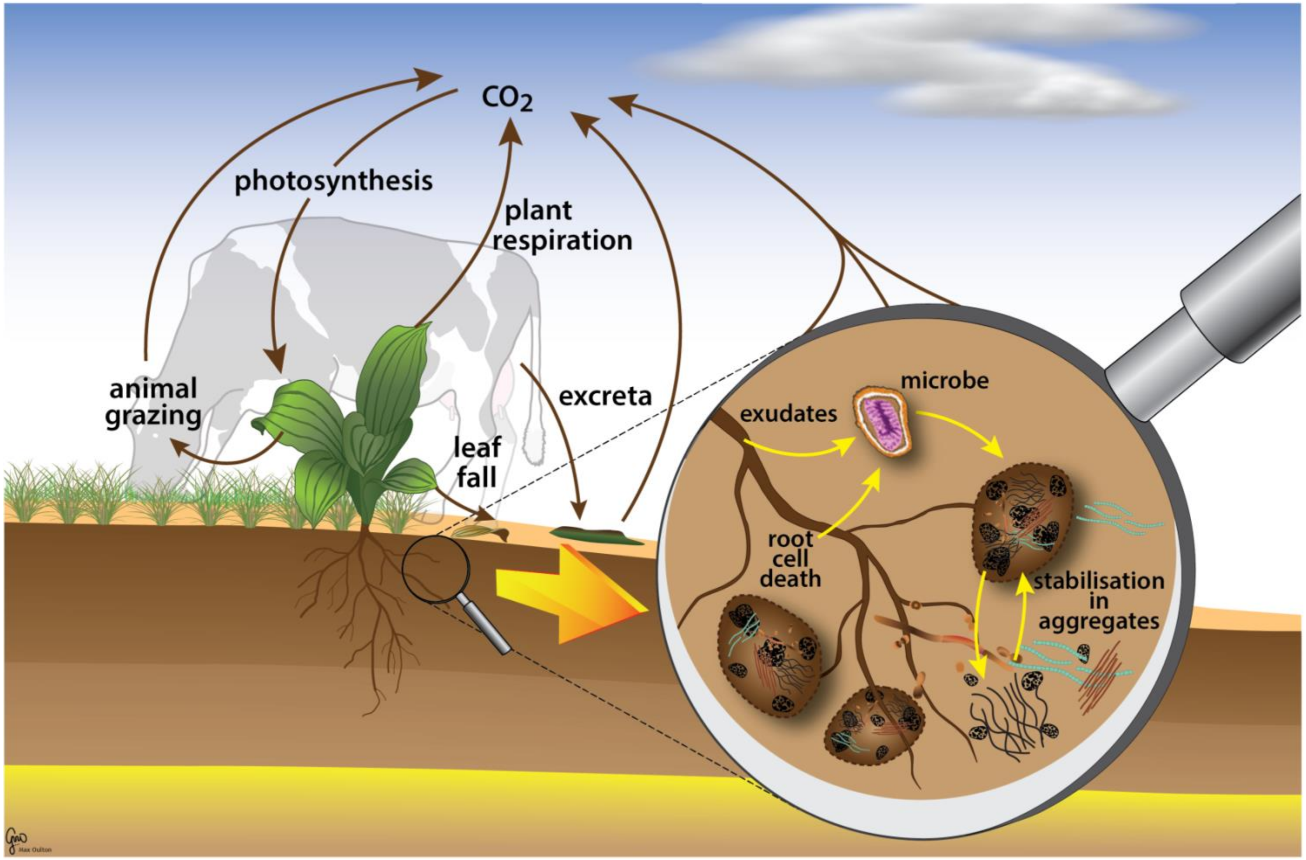
THE UNIVERSITY OF WAIKATO
Te Whare Wānanga o Waikato

Global carbon storage

23% atmosphere

15% vegetation

62% soil to 1 m



- Carbon input to soil is regulated by plants
- Carbon retention is regulated by physical and microbial processes
- Carbon is stored in a range of organic materials with turnover rates from days to centuries
- Disturbance can cause rapid losses and recovery is often slow

Soil carbon is essential for maintaining the productive potential of our primary industries

- soil physical structure and stability
- water retention
- nutrient cycling
- buffering and filtering

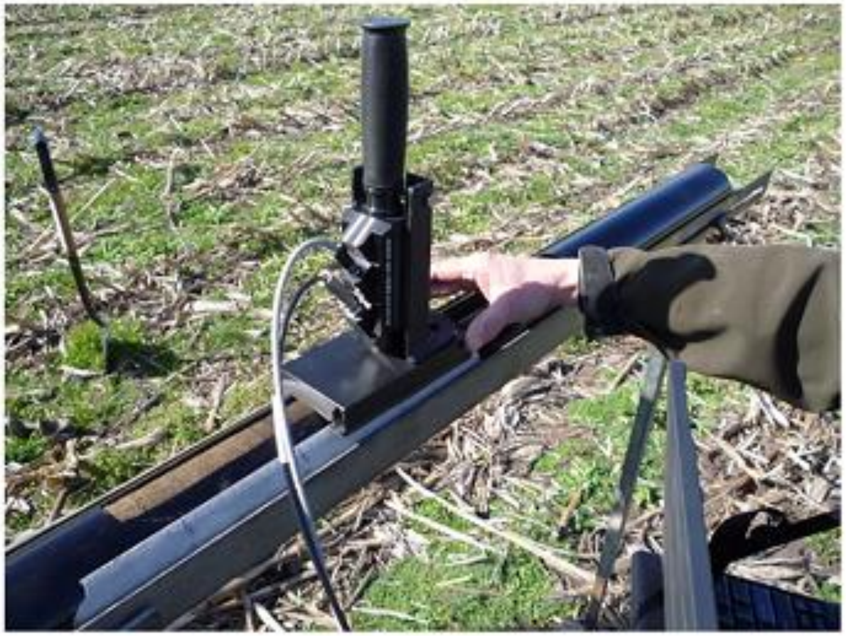
Identify land management practices to maintain soil carbon stocks and, if possible, achieve stable, increased stocks

Retaining and increasing soil carbon provides opportunity to offset our greenhouse gas emissions. Research is needed to inform our international negotiations

- Top soil carbon stocks can be high

  Average for NZ's grassland soils is 100 t C/ha to a depth of 0.3 m
- Deeper in soils, carbon stocks can be much lower but have higher potential to store carbon
- Carbon stability (longevity) in soils is not well understood
- *Between 1990 and 2013 increases in NZ's methane (8%) and soil nitrous oxide emissions (23%) are equivalent to 1 Mt C*
- *This could be offset with an increase in soil carbon of 1 t C/ha over 1 Mha or 0.1 t C/ha over NZ's approx. 10 Mha grassland estate ie. 0.1% increase*
- *Increasing soil carbon stocks commits nitrogen, phosphorus, sulphur and other nutrients. This represents of order $200 for 1 t C/ha based on today's fertiliser costs*

Improved measurements of soil carbon



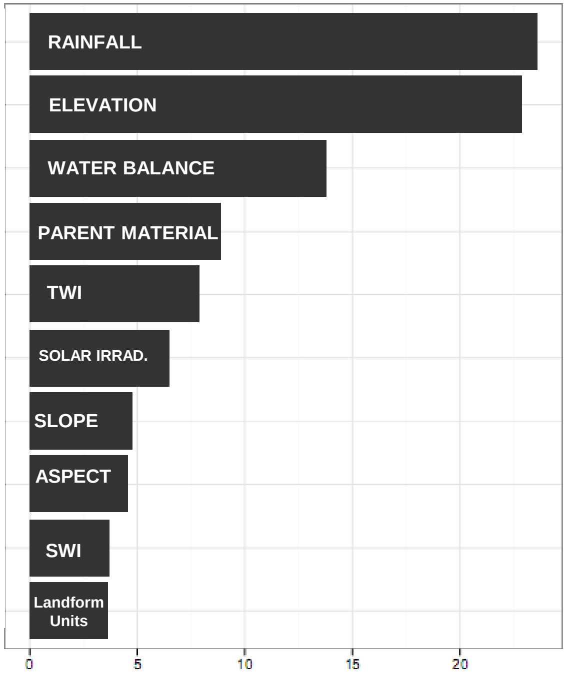
Visible near infra red spectroscopy

Hedley et al(2015), Roudier et al (2015)

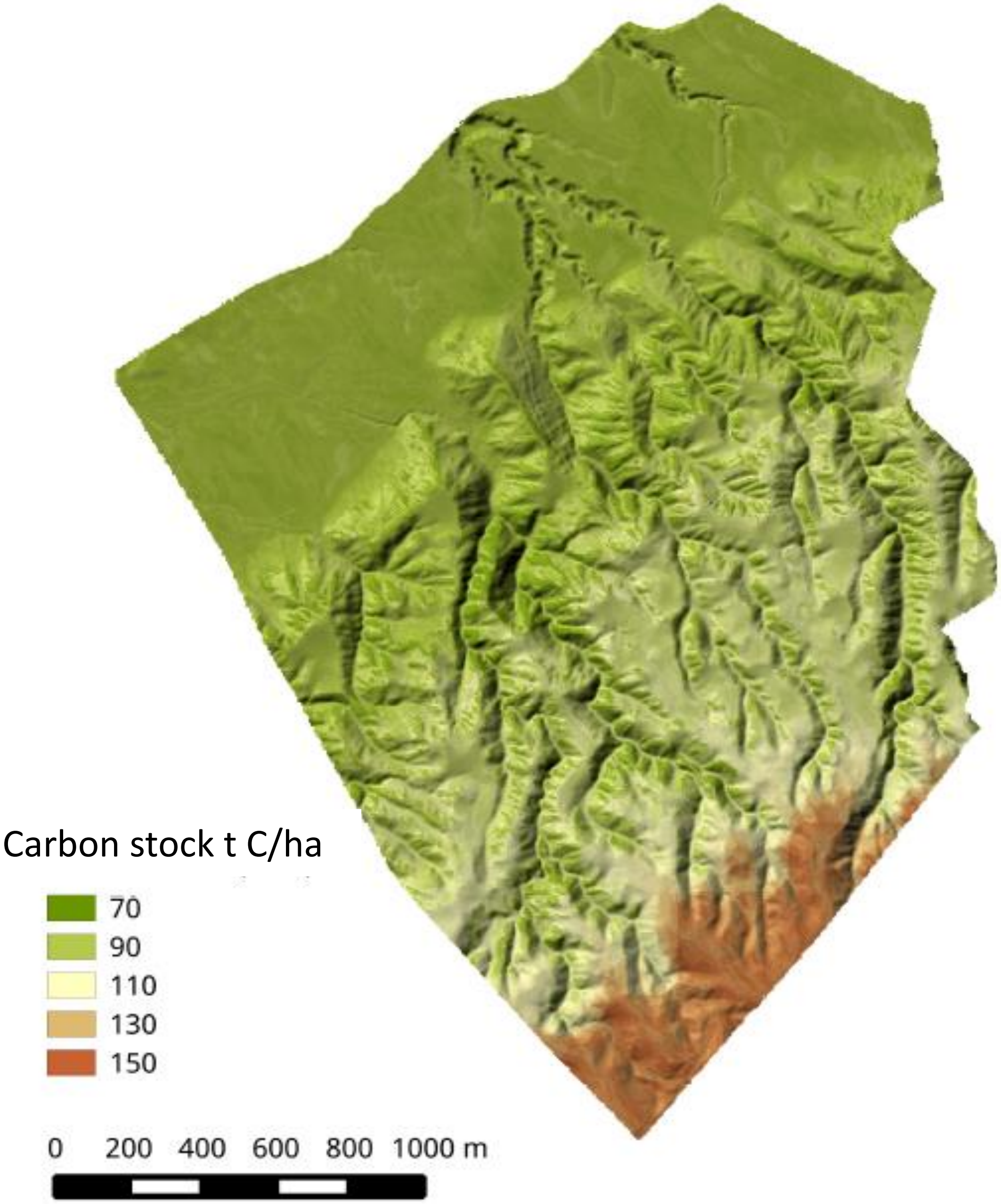
- rapid
- lower cost
- increased spatial and depth representation
- allows spatial scaling
- enables interpretation about carbon stability
- increased efficiency for accounting practices

Tuapaka Hill Country (Manawatu)
Soil organic carbon t C/ha
to 0.3m depth
at 50 sampling positions

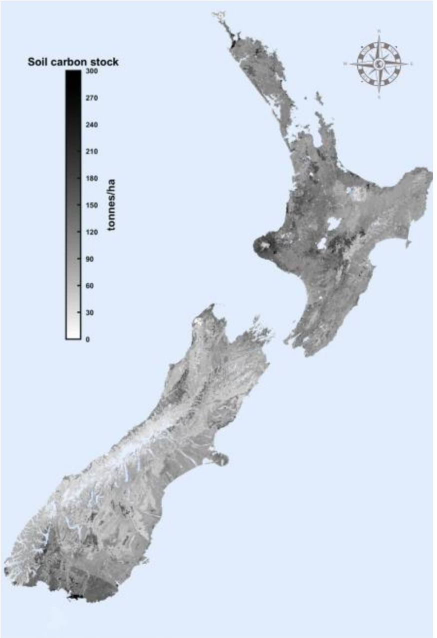
Carolyn Hedley, Pierre Roudier,
Leo Valette (CSIRO)
GRA funding



Relative importance of covariates (%)



What is the potential for increasing soil carbon stocks?



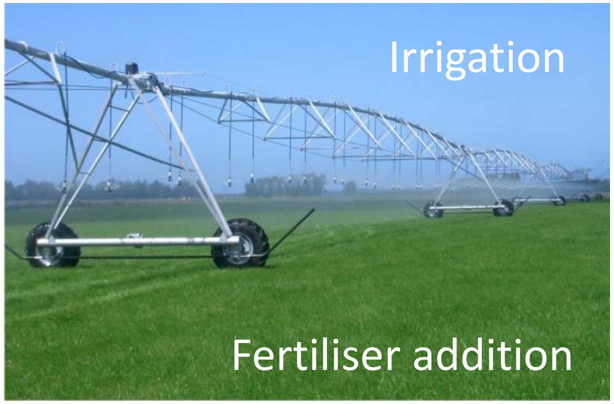
- From National Soils Database including long term grasslands
- Using a spatially explicit model, differences in carbon content were attributable to surface area, aluminium and pH
- Potential carbon saturation deficit was estimated from the difference between the upper (90th percentile) and current level 50th percentile)
- 0 – 0.15 m average potential saturation deficit 32%
- 0.15 – 0.3 m average potential saturation deficit 83%
- At 40 mg C/g (0 - 0.15 m) filling the deficit equivalent to 30% increase carbon stocks

Beare et al. (2014)

We need to use management practices that maintain and increase soil carbon

It's changes in carbon stocks that are important


Pasture renewal


Irrigation

Fertiliser addition


Exotic worms


Mixed swards

Stocking, supplemental feed


Biochar addition

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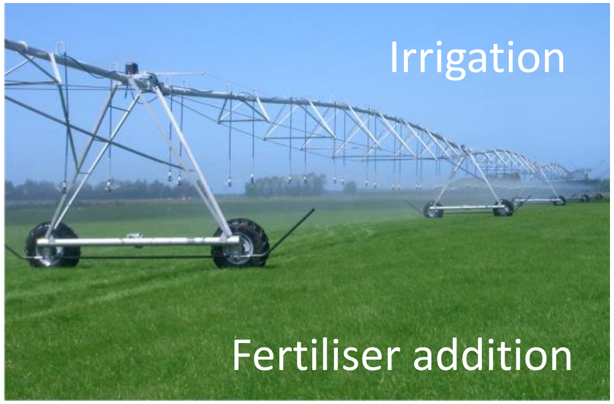
It's changes in carbon stocks that are important


Pasture renewal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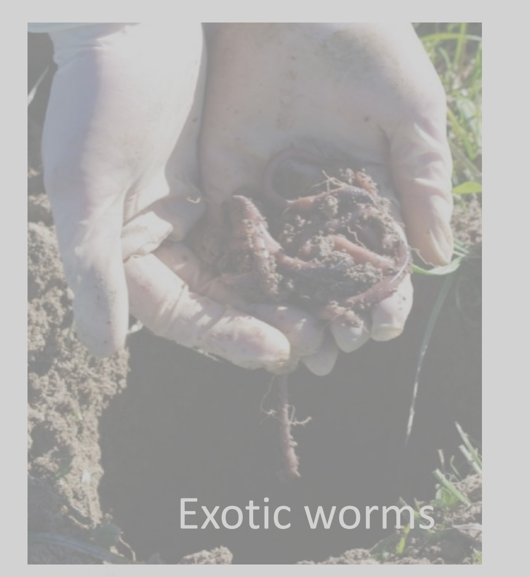
Exotic worms


Mixed swards

Stocking, supplemental feed


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Change in grassland carbon stocks

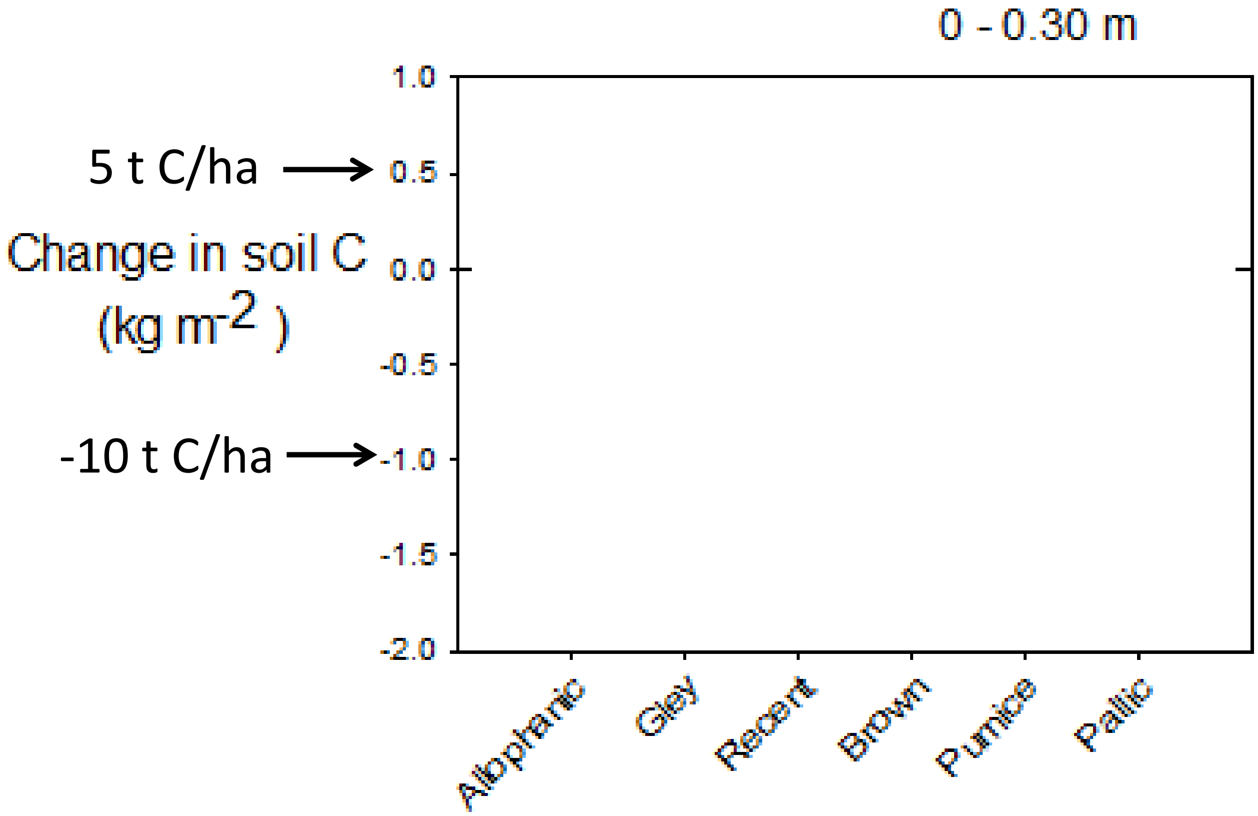
National Soils Database resampling

- Resampling sites to 1 m previously sampled 20-40 years previously
- Analysed archived soil samples

Schipper et al. (2014)

Change in grassland carbon stocks

National Soils Database resampling after 20-40 years



5 t C/ha →

-10 t C/ha →

Flat land

Schipper et al. (2014)

Change in grassland carbon stocks

National Soils Database resampling

2014 (148 sites)

- Allophanic (-0.5 t/ha/y) and Gley (-0.3 t/ha/y) losing carbon
- Other mineral soils no significant change
- Hill country gaining carbon (0.6 t/ha/y)

- No apparent effect of grazing type

Schipper et al. (2014)

Change in grassland carbon stocks

500 soils resampling

Approach

- 158 sites resampled after 7 years to 0.1 m depth
- Range of people collected samples
- No reanalysis of archived soils

Findings

- Gains on dairy 0.32 t C/ha/y and drystock 0.57 t C/ha/y
- Not significant from zero
- Combined was significant 0.42 t C/ha/y for flat land
- Gains on hill country 1.33 t C/ha/y

Parfitt et al. (2014)

Carbon changes in organic soils

- Loss of 2.9 t C/ha/y
- Size of error ? Only one site

- Many peats many metres deep and losses will continue as long as they are drained for farming: many centuries
  - at about 0.02 m/y

Excessive drainage, Moanatuatua

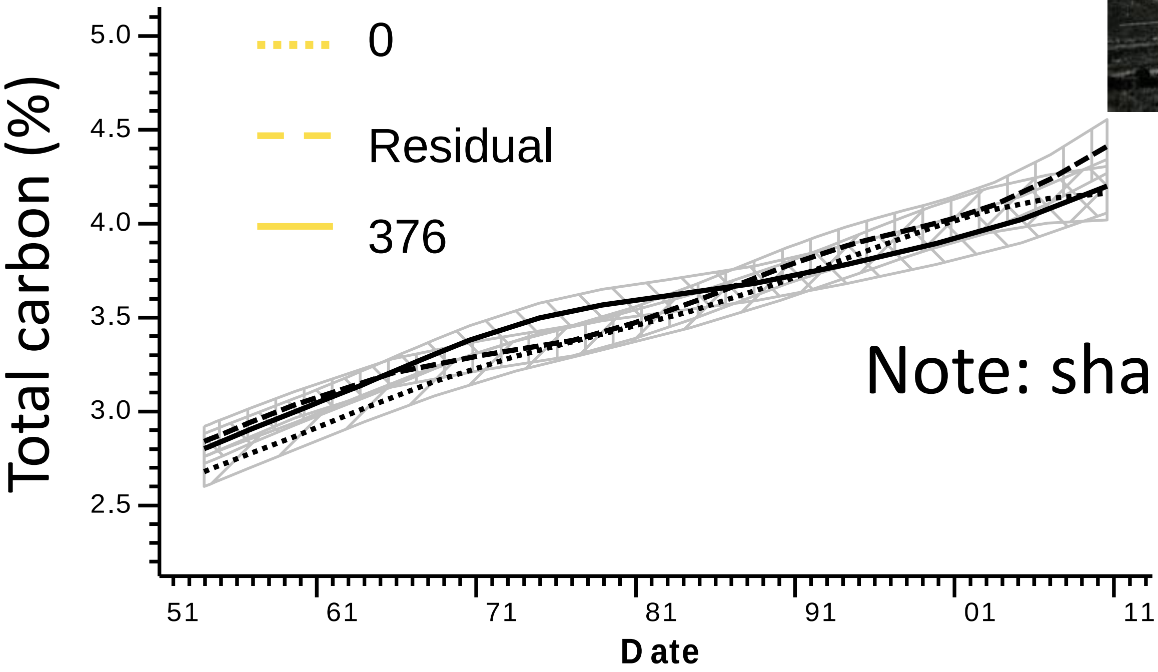
Campbell et al. (2015)

Management effects: P fertiliser

Winchmore, South Canterbury
Whatawhata, Waikato

No benefit of adding P on soil carbon recovery


Te Ara

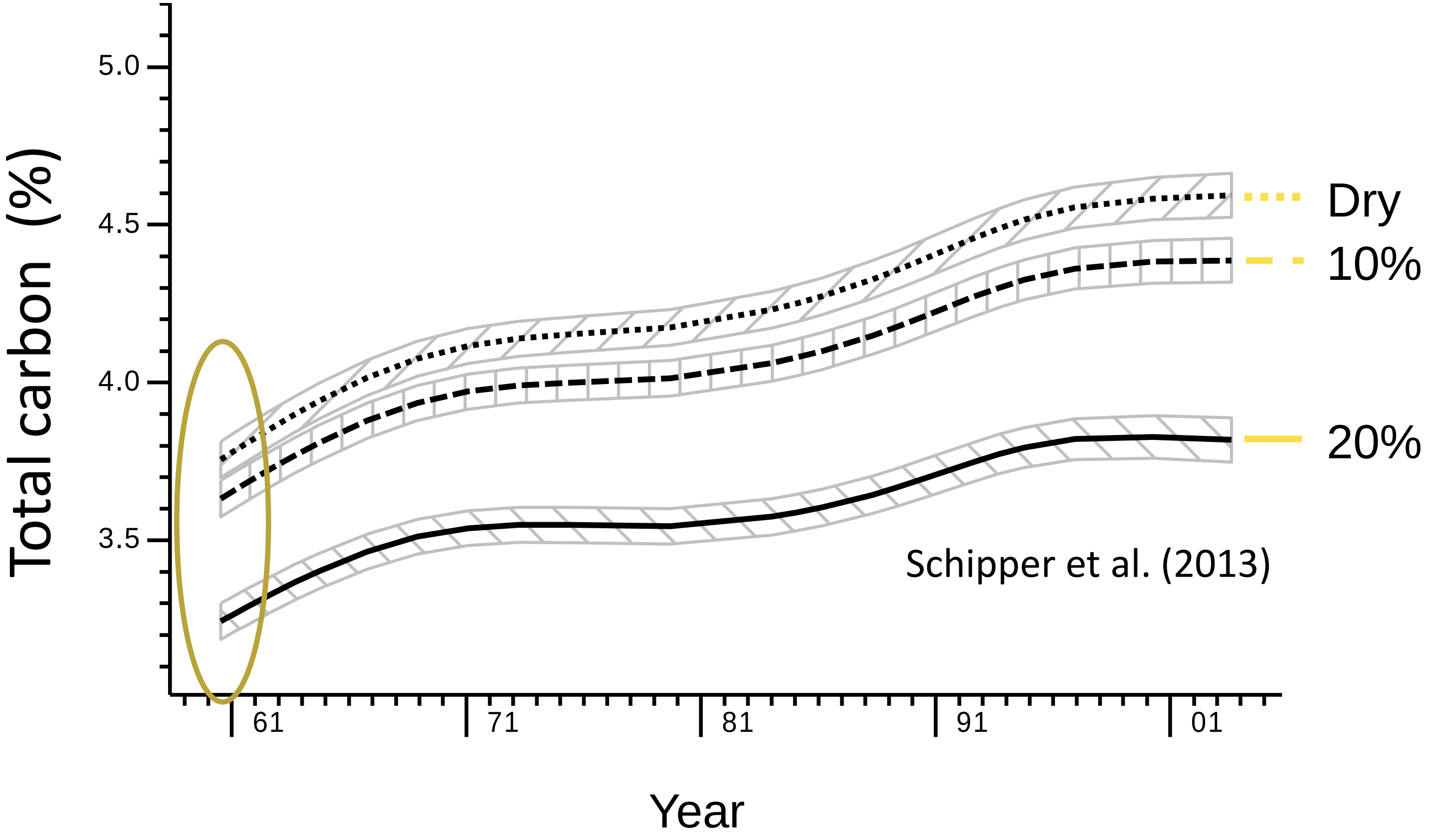


Note: shallow sampling

Schipper et al. (2013)

Management effects: irrigation

Winchmore, South Canterbury



Schipper et al. (2013)

Also confirmed to 1 m depth (Condron et al. 2014)

Management effects: irrigation

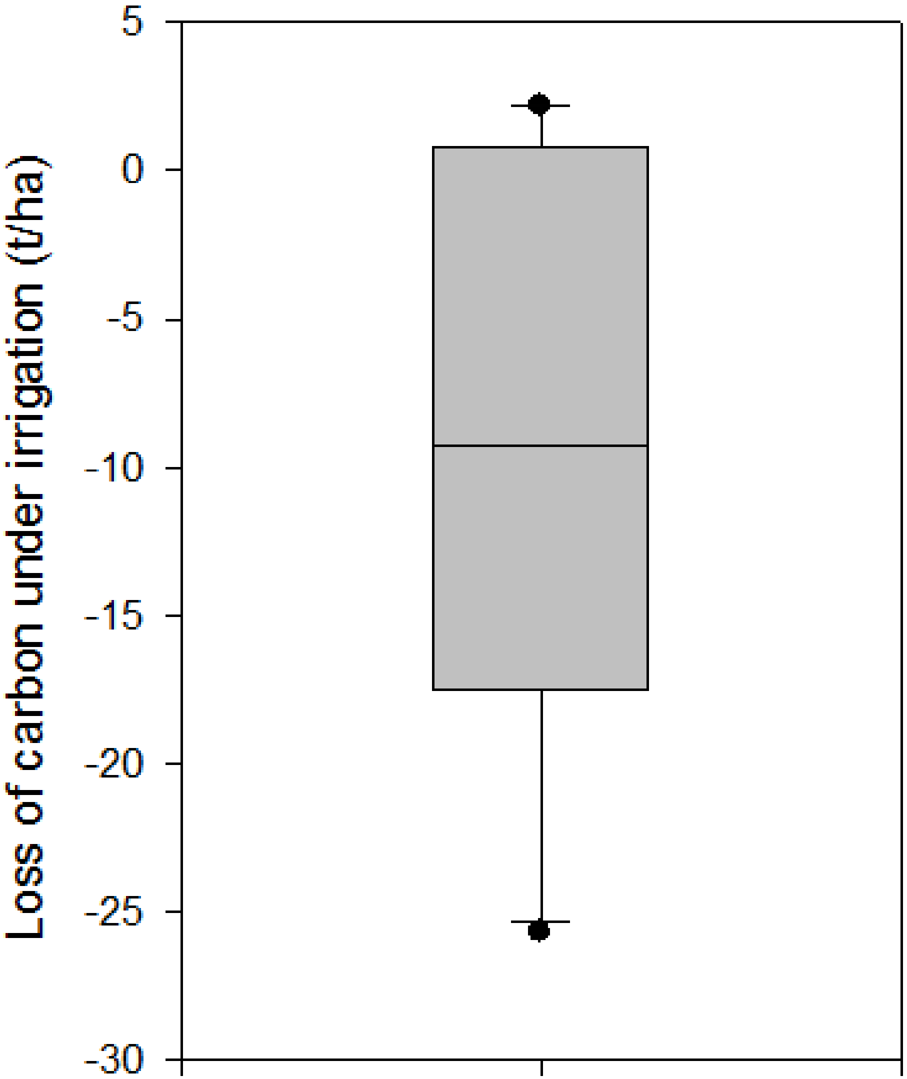
Preliminary data

South Island

0 – 0.3 m depth

10 farms

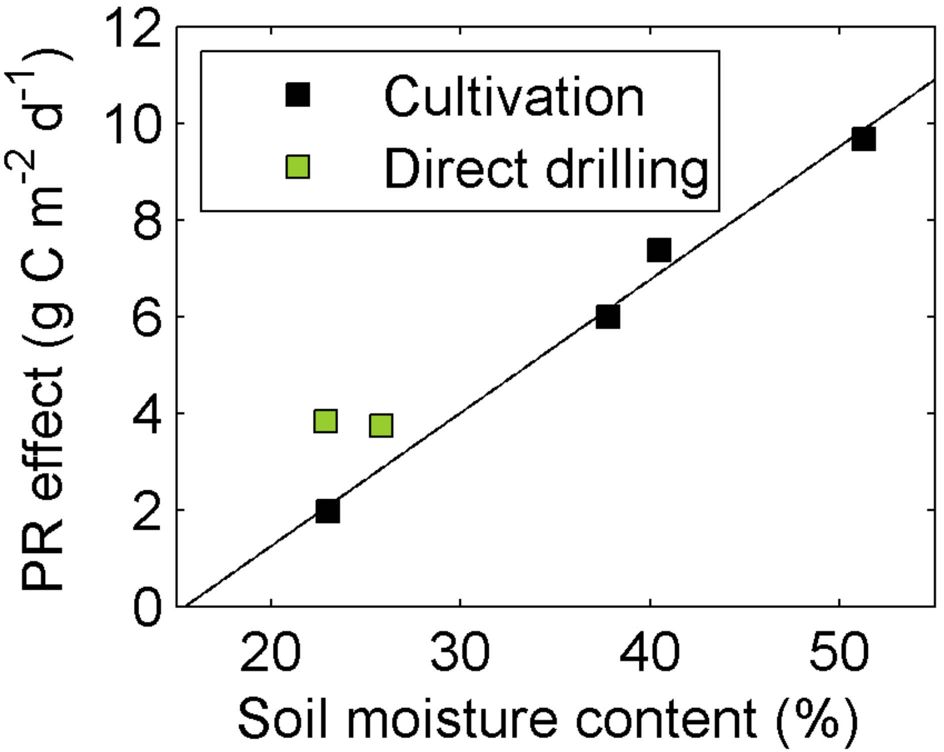
Similar but less significant effects at North Island sites



Kelliher, Mudge, Schipper
Report due soon

Management effects: pasture renewal

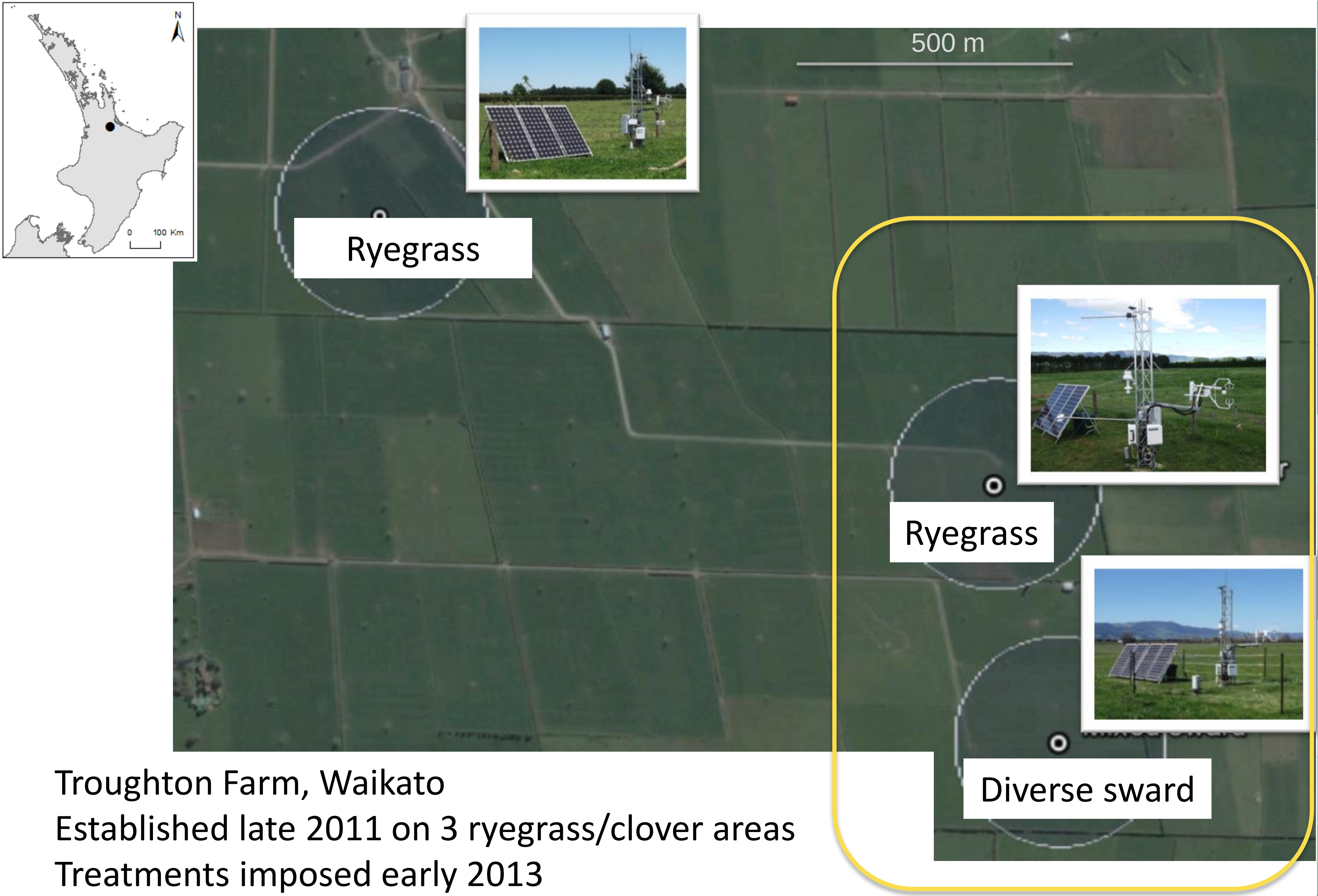
- Occurs every 5 to 10 years
- Sprayed off and can involve cultivation
- Total carbon losses of between 0.8 and 4.1 t C/ha (2-3% of carbon stock to 0.3 m)
- Losses and gains dependent on soil water availability
- Likely recovered between renewals
- 2 farms only



Rutledge et al. (2014)

Can diverse pastures capture more carbon?

Lucerne
Chicory
Plantain
Ryegrass
Clover

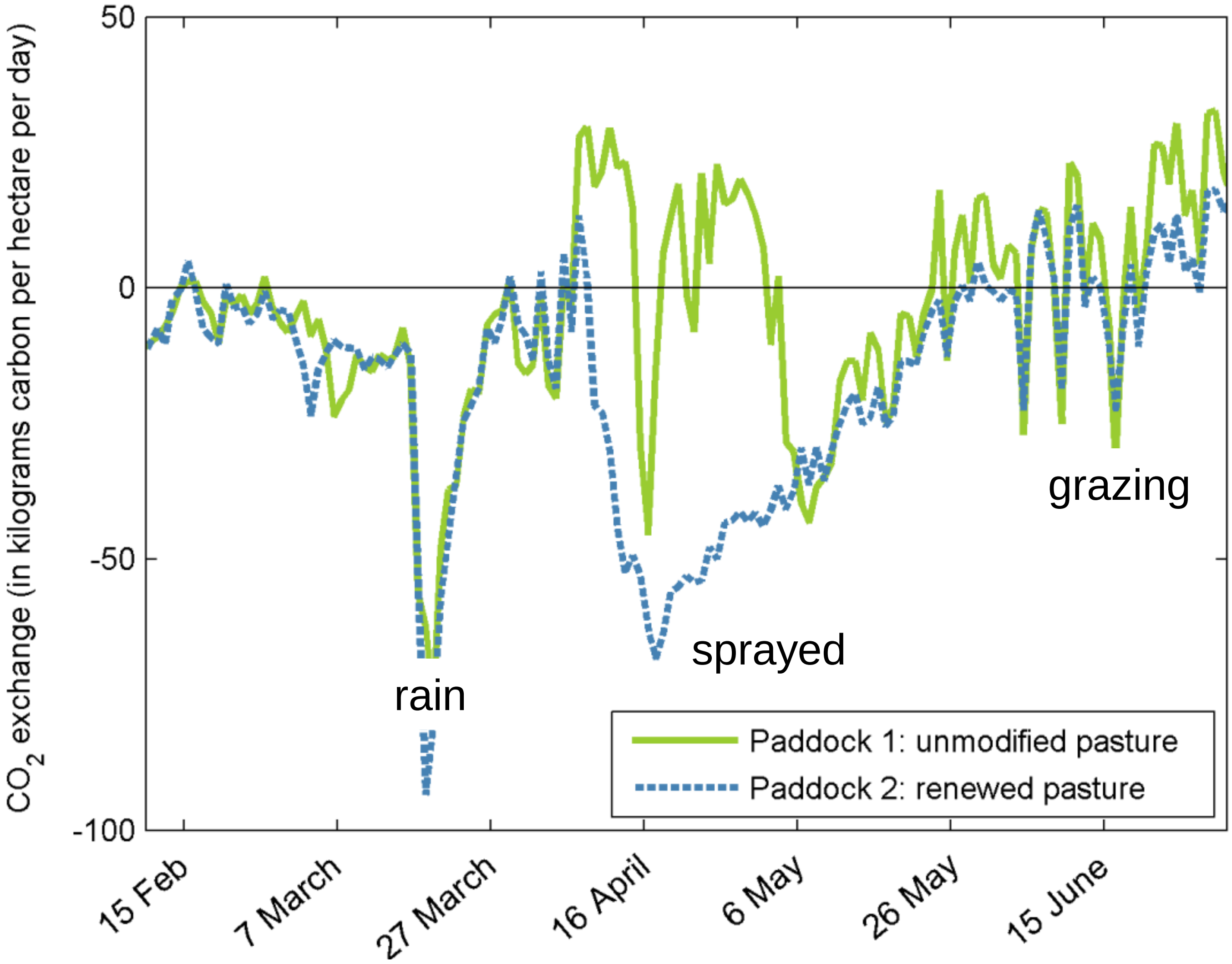


Troughton Farm, Waikato
Established late 2011 on 3 ryegrass/clover areas
Treatments imposed early 2013

Can diverse pastures capture more carbon?

Carbon gain

Carbon loss

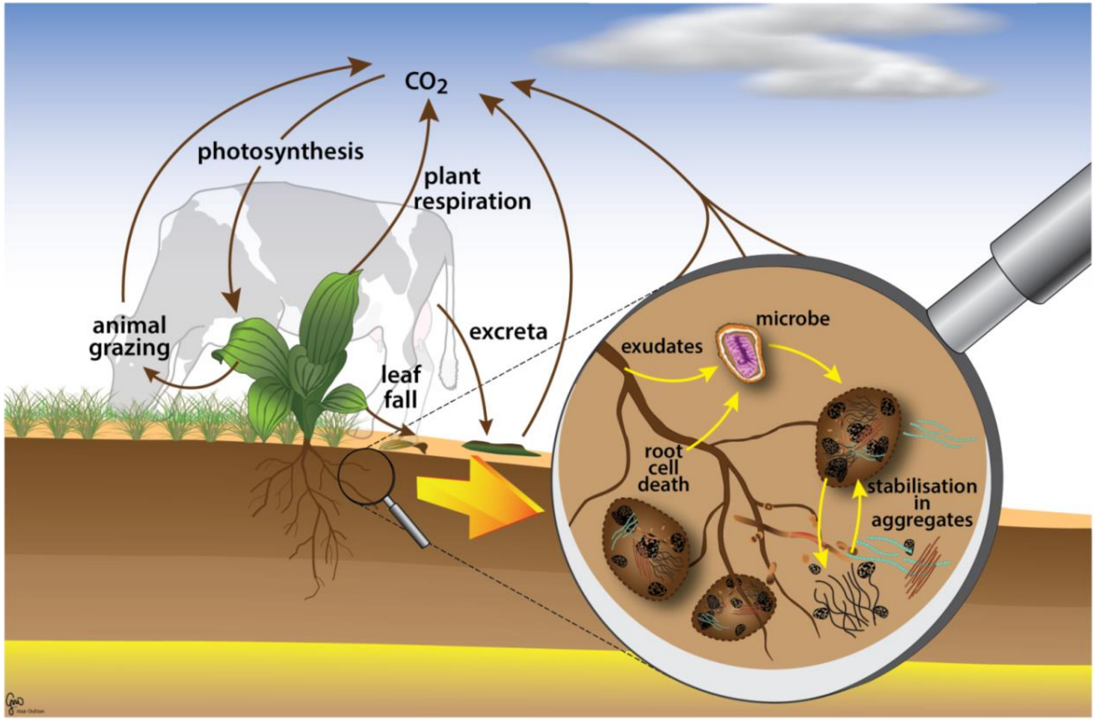


Carbon balance

Net carbon exchange

Methane

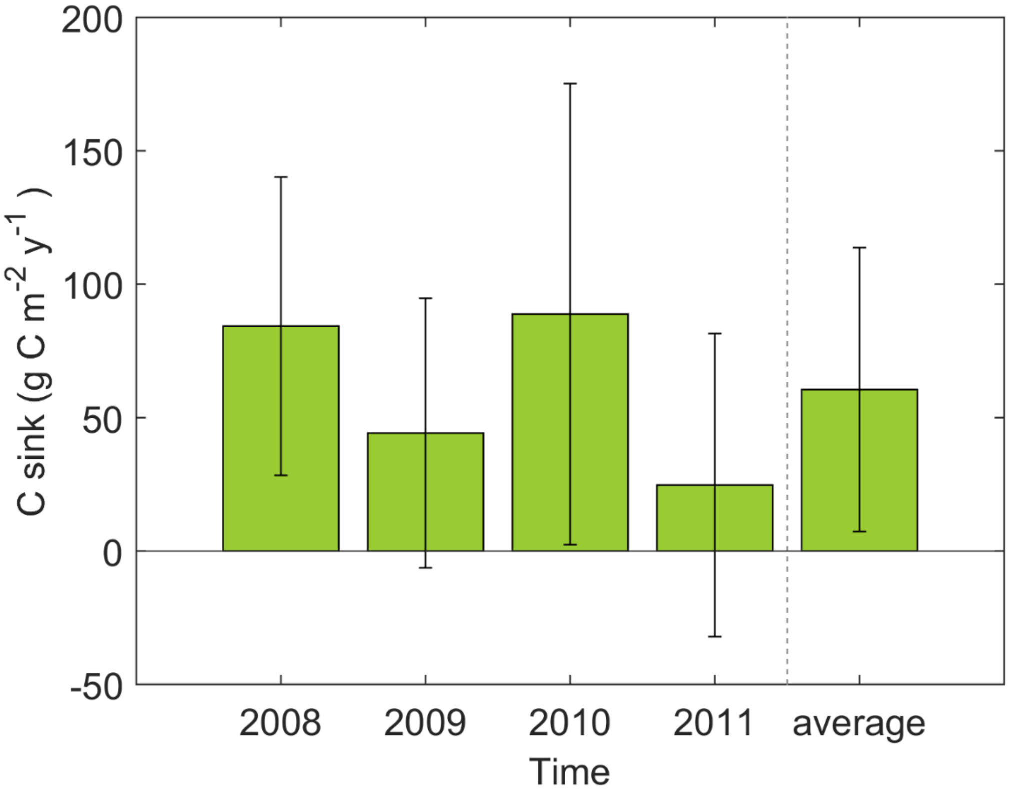
Carbon imports
(feed, effluent)



Carbon exports
(milk/silage)

Farm scale carbon balance

Scott Farm, Waikato, 4 years



Carbon sink overall
average ~600 ± 320 kg C/ha/y

Both weather and
management impact
the annual carbon balance

But how stable is this carbon and how much more can NZ soil store?

Summary from historical observations

Time trends in soil carbon stocks

Flat land

- losses up to 0.5 t C/ha/y from Allophanic and Gley soils to 0.3 m depth over 30 years
- large ongoing losses up to 2.9 t C/ha/y from organic soils (1 site!)
- no change other soil orders
- some evidence of recent increases in top 0.1 m depth (method?)

Hill country

- increases up to 0.6 t C/ha/y observed both short and long term

Summary from historical observations

Management effects on soil carbon stocks

- P fertiliser: no detectable change
- N fertiliser: no information available
- Irrigation: decrease BUT size of loss to be determined shortly
- Pasture renewal: small decrease probably recovers if infrequent
- Diverse swards: short-term increases but no long-term data yet

How to estimate changes at national scale?

- Limited historical observations do not provide clarity
- Trends depend on soil type, slope and management
- Complexities of multiple variables interacting

  eg. soil type, climate, irrigation, fertiliser, animal stocking
- Currently no regular soil carbon monitoring in New Zealand

How to forecast future soil carbon changes?

- Continue re-sampling and analysis at historically sampled sites
- Need process-based studies to understand and predict

- **Future progress depends on the use of models to interpret and forecast management effects and best practices**

National scale soil carbon trends

	Per area change (t C ha^{-1} yr^{-1})	**Area (ha)**	**Total change (MtCO$_2$ C yr^{-1})**
Tussocks/ low-producing	0.0 ± 0.26	4 116 750	0.0 (-3.92 to 3.92)
Allophanic soils/ flat land	–0.54 ± 0.32	454 182	-0.9 (-1.43 to -0.37)
Gley soils/ flat land	–0.32 ± 0.31	655 411	-0.77 (-1.51 to -0.02)
Organic soils	–2.9 ± 1.3	140 589	-1.49 (-2.17 to -0.82)
Other soils/ flat land	0.0 ± 0.19	3 492 757	0.0 (-2.43 to 2.43)
Hill-country soils (mid-slope)	0.6 ± 0.31	1 047 042	2.3 (1.11 to 3.49)
Hill-country soils (other slopes)	no data	2 330 473	no data
National total			**-0.86 (-5.76 to 4.04)**

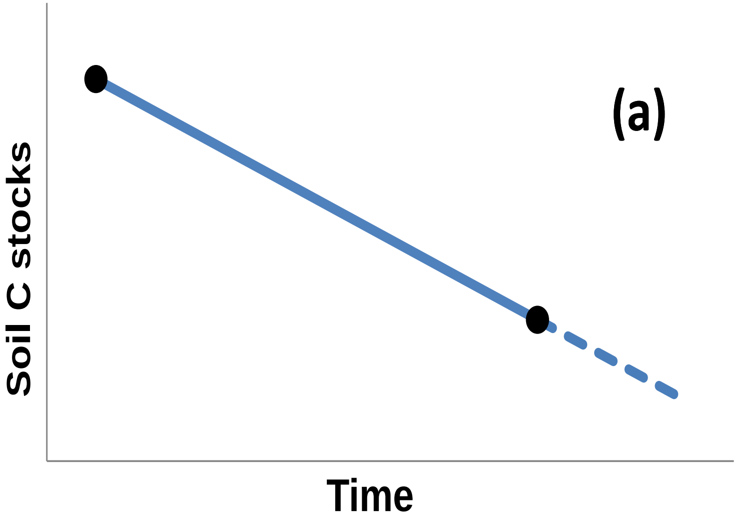
30-year analyses of carbon stocks in upper 0.3 m
Schipper et al. (2014)

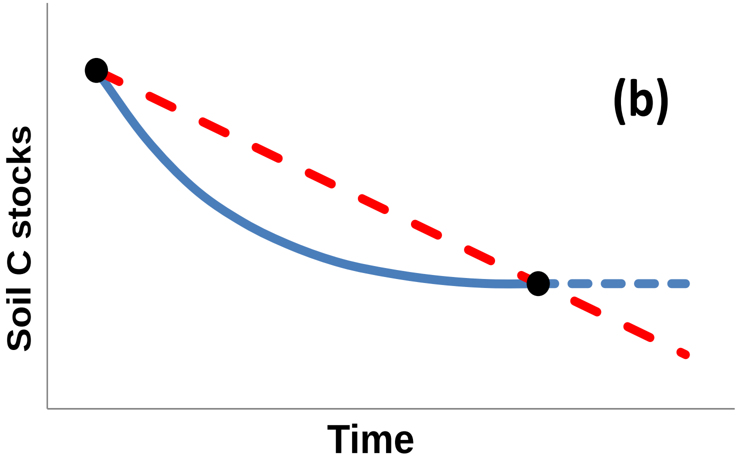
National scale soil carbon trends

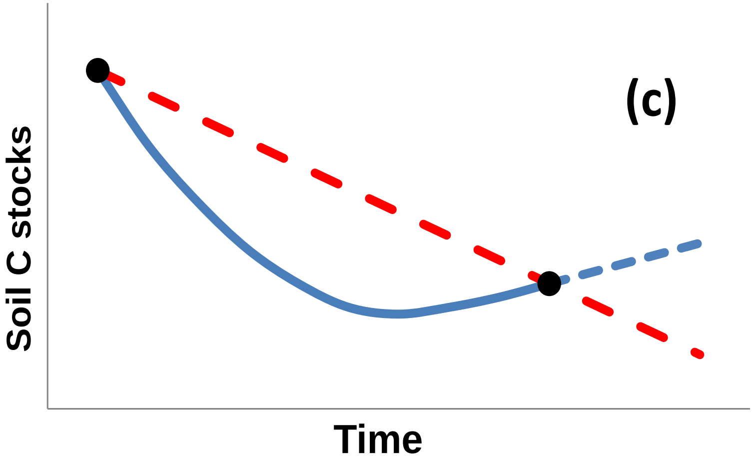
	Per area change (t C ha^{-1} yr^{-1})	**Area (ha)**	**Total change (Mt C yr^{-1})**
Tussocks/ low-producing	0.0 ± 0.26	4 116 750	0.0 (-3.92 to 3.92)
All flat land	0.4 ± 0.33	4 602 350	7.09 (1.52 to 12.66)
Organic soils	–2.9 ± 1.3	140 589	-1.49 (-2.17 to -0.82)
Hill-country soils (mid-slope)	1.33 ± 1.02	1 047 042	5.11 (1.19 to 9.02)
Hill-country soils (other slopes)	no data	2 330 473	no data
National total			**10.7 (2.81 to 18.59)**

7-year analyses of soil quality in upper 0.1 m
Parfitt et al. (2014)

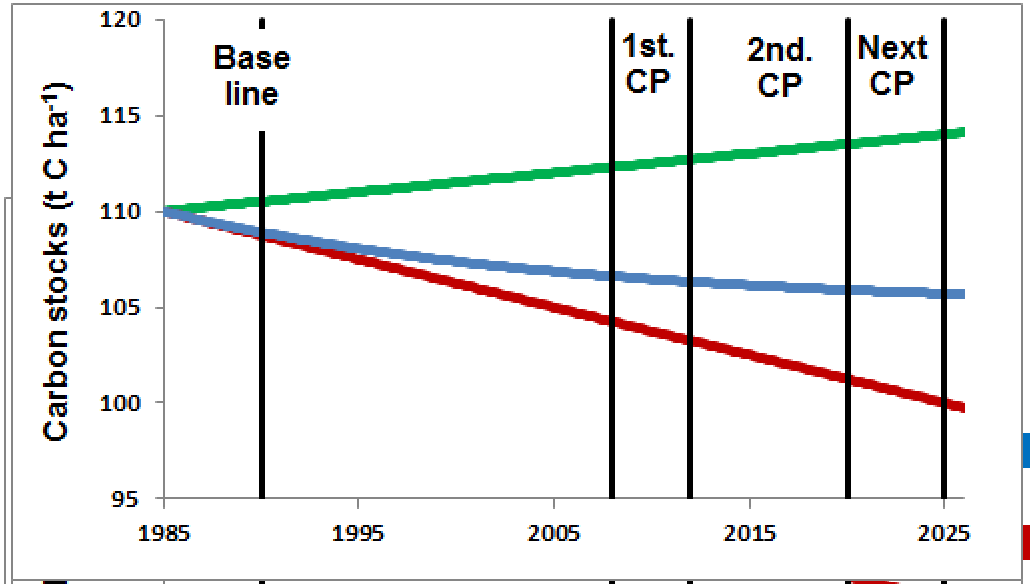
Soil carbon trends - extrapolation





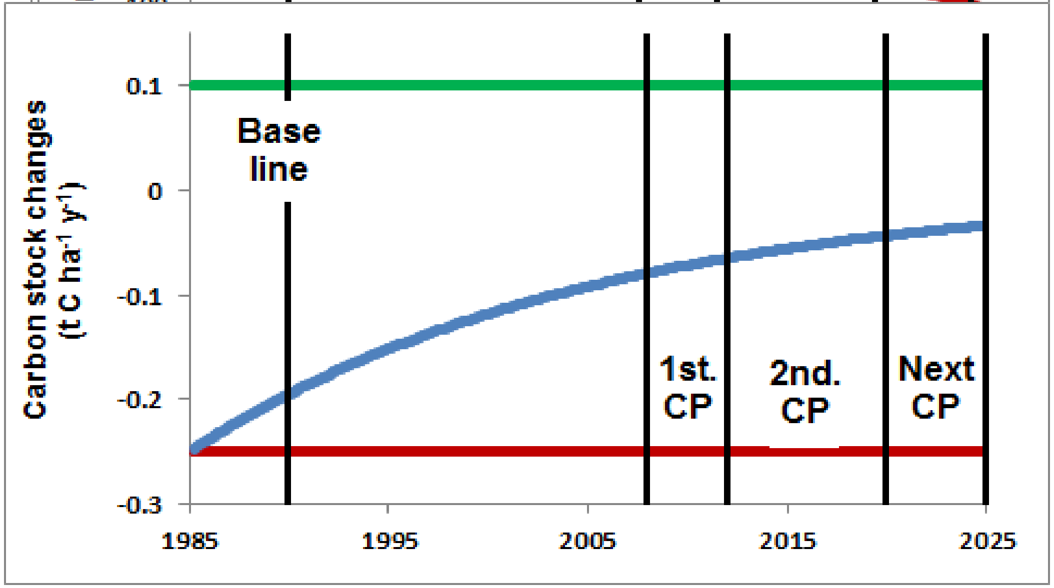


Carbon accounting rules (Net-Net)

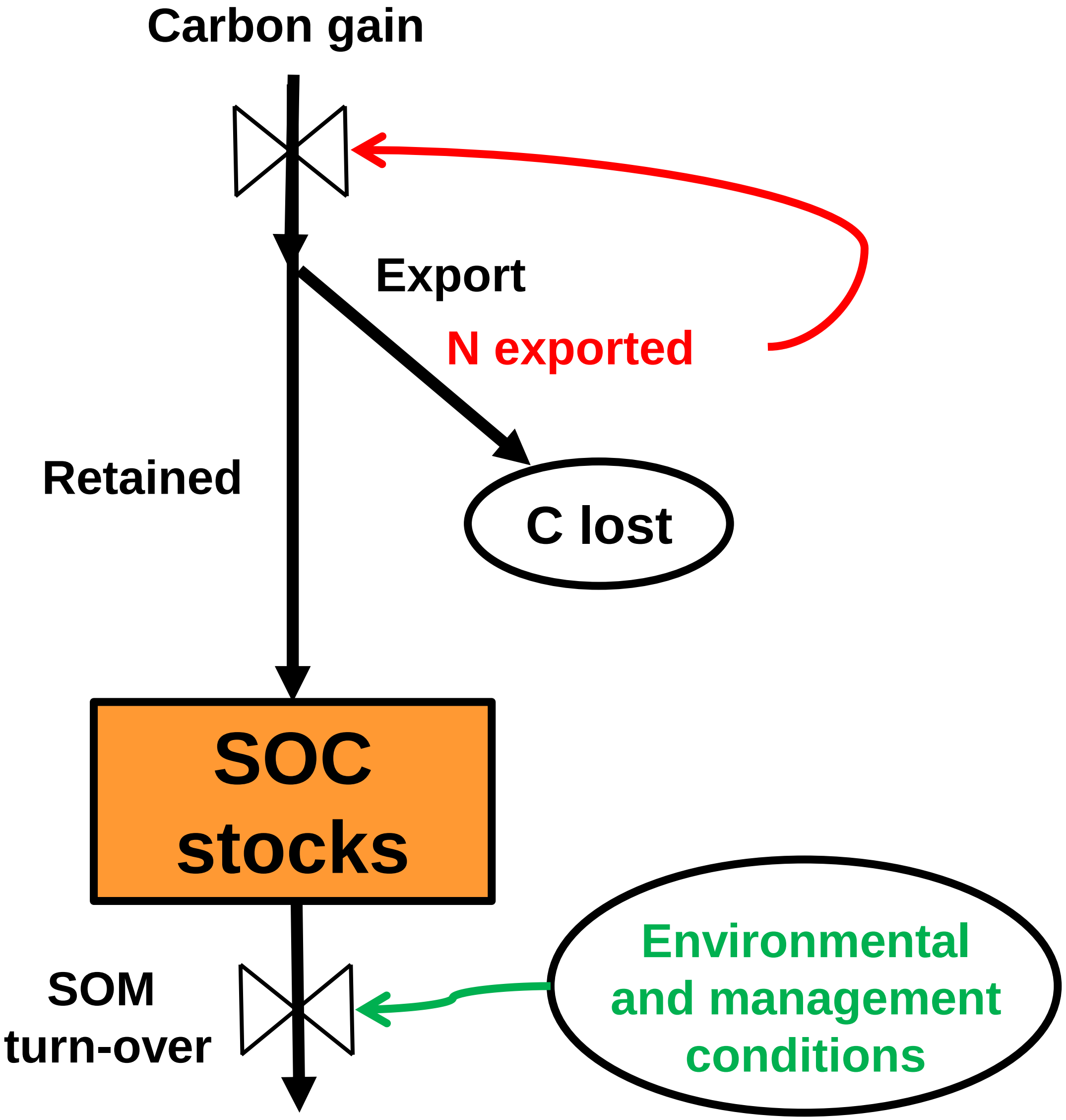


lat land?

lat land?



CenW model


Carbon gain

Export

N exported

Retained

C lost

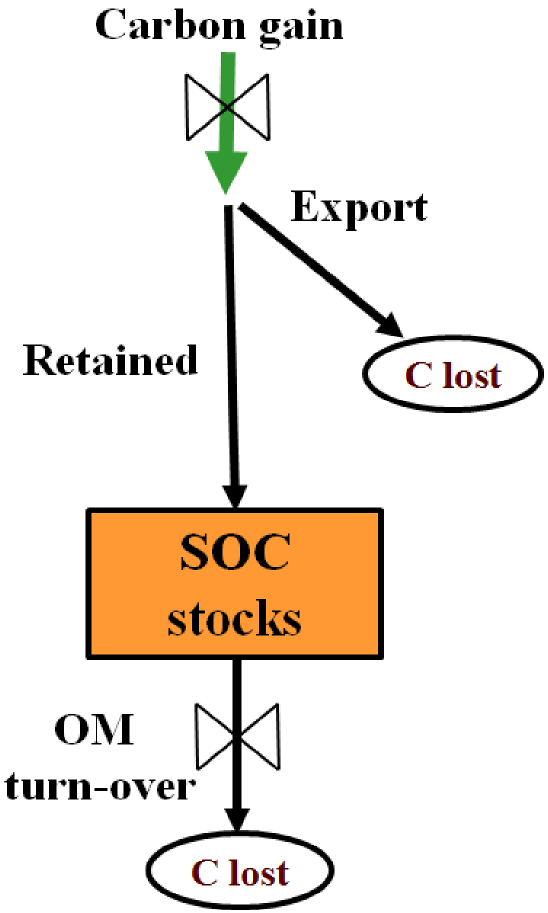
SOC stocks

SOM turn-over

Environmental and management conditions

Modelling results are consistent with observations

Supplemental feed



Carbon gain

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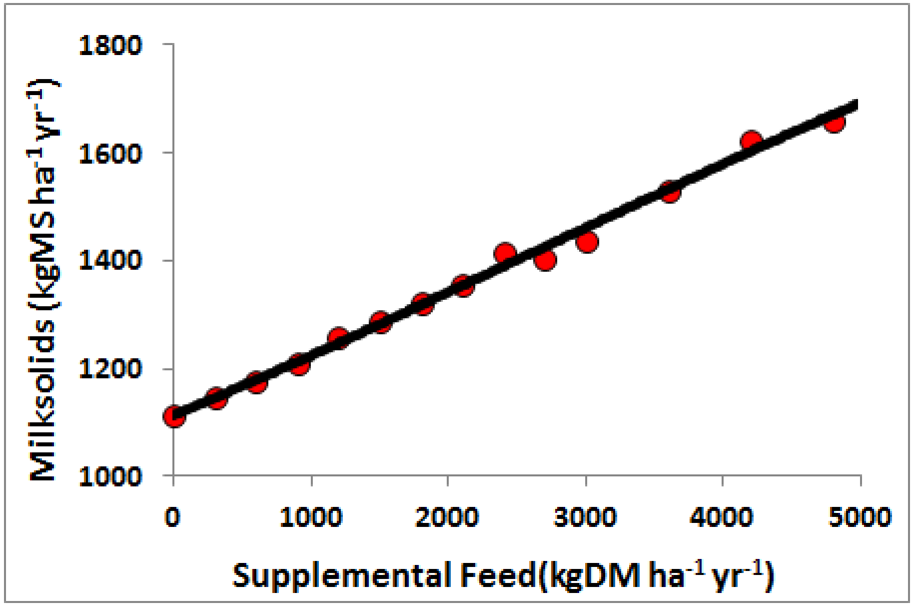
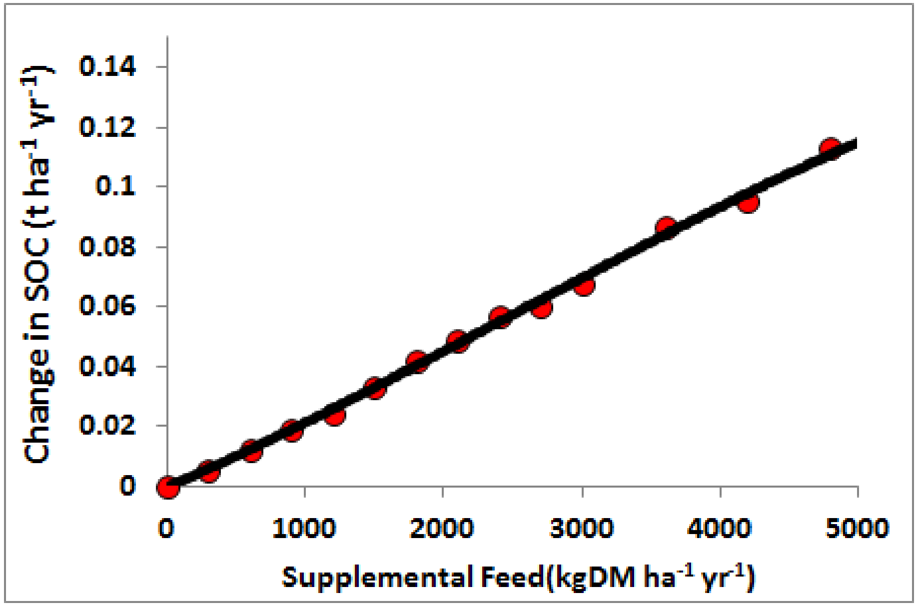
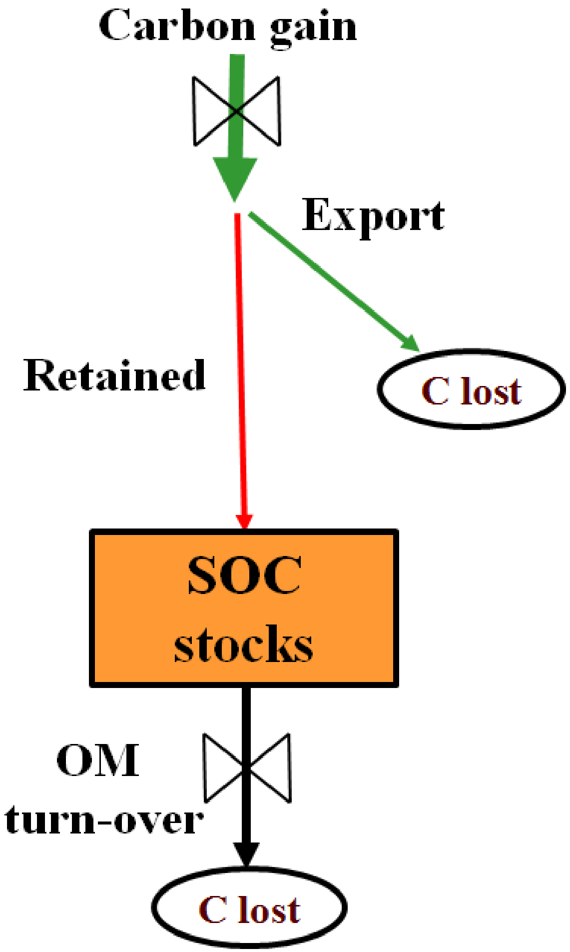
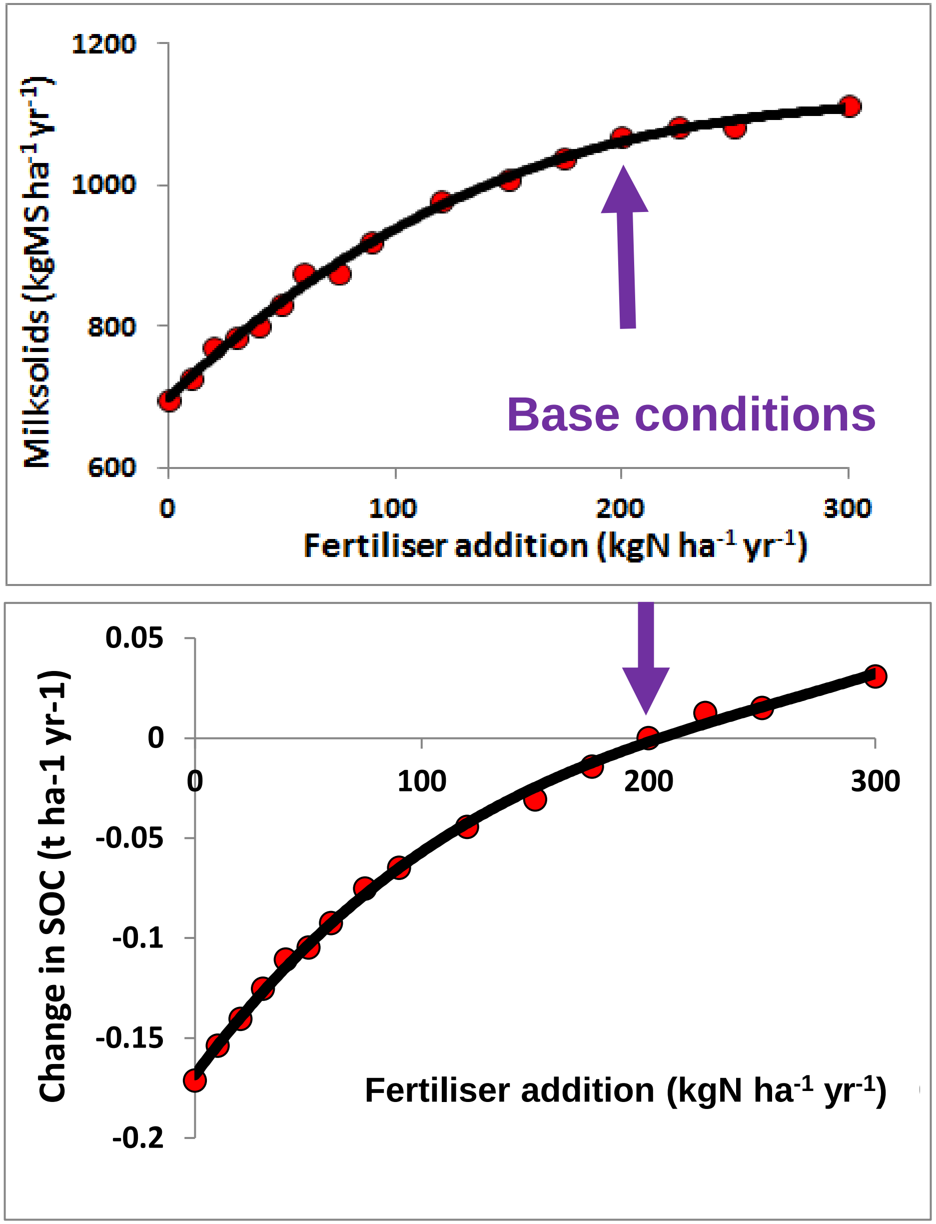


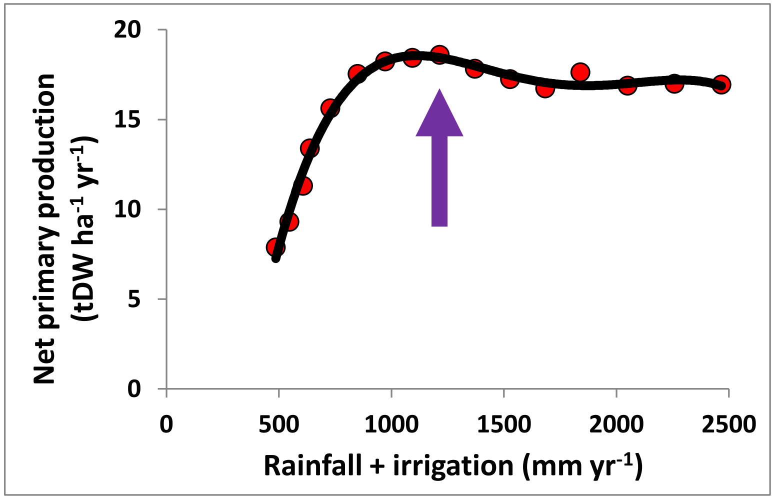


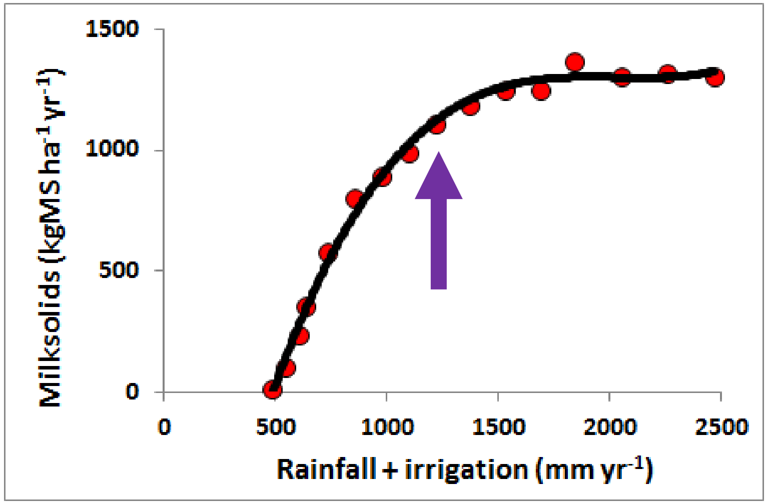
Fertiliser addition

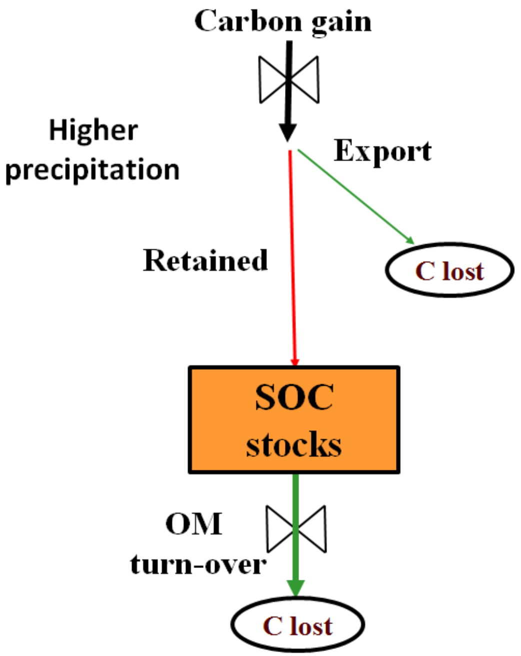




Changing rainfall, irrigation






Carbon gain

Higher precipitation

Export

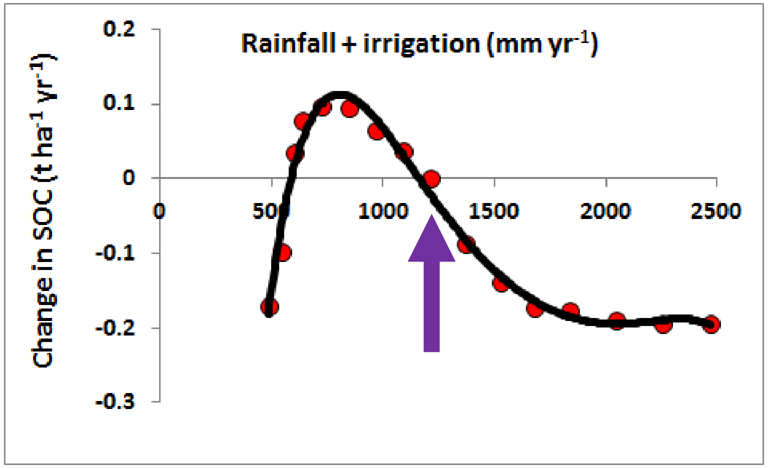
Retained

C lost

SOC stocks

OM turn-over

C lost



Conclusions

- National-scale estimates of carbon stocks changes rely on a small number of measurements
- Changing trends could be real or not! Many questions remain

- There is potential to increase carbon in New Zealand soils
- Changes depend on carbon gain, grazing off-take, carbon stabilisation and turn-over
- Carbon can increase with supplemental feeding, fertiliser addition, and irrigation on very dry sites
- Carbon increases can be achieved at the cost of reduced milk production

- Management practices most likely to achieve increase are:
  - optimising nitrogen addition and irrigation
  - increasing carbon inputs from roots eg. mixed swards

Landcare Research

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Paul Mudge
Roger Parfitt
Beckie Phillips
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Aaron Wall

Scion

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GNS Science

Troy Baisden

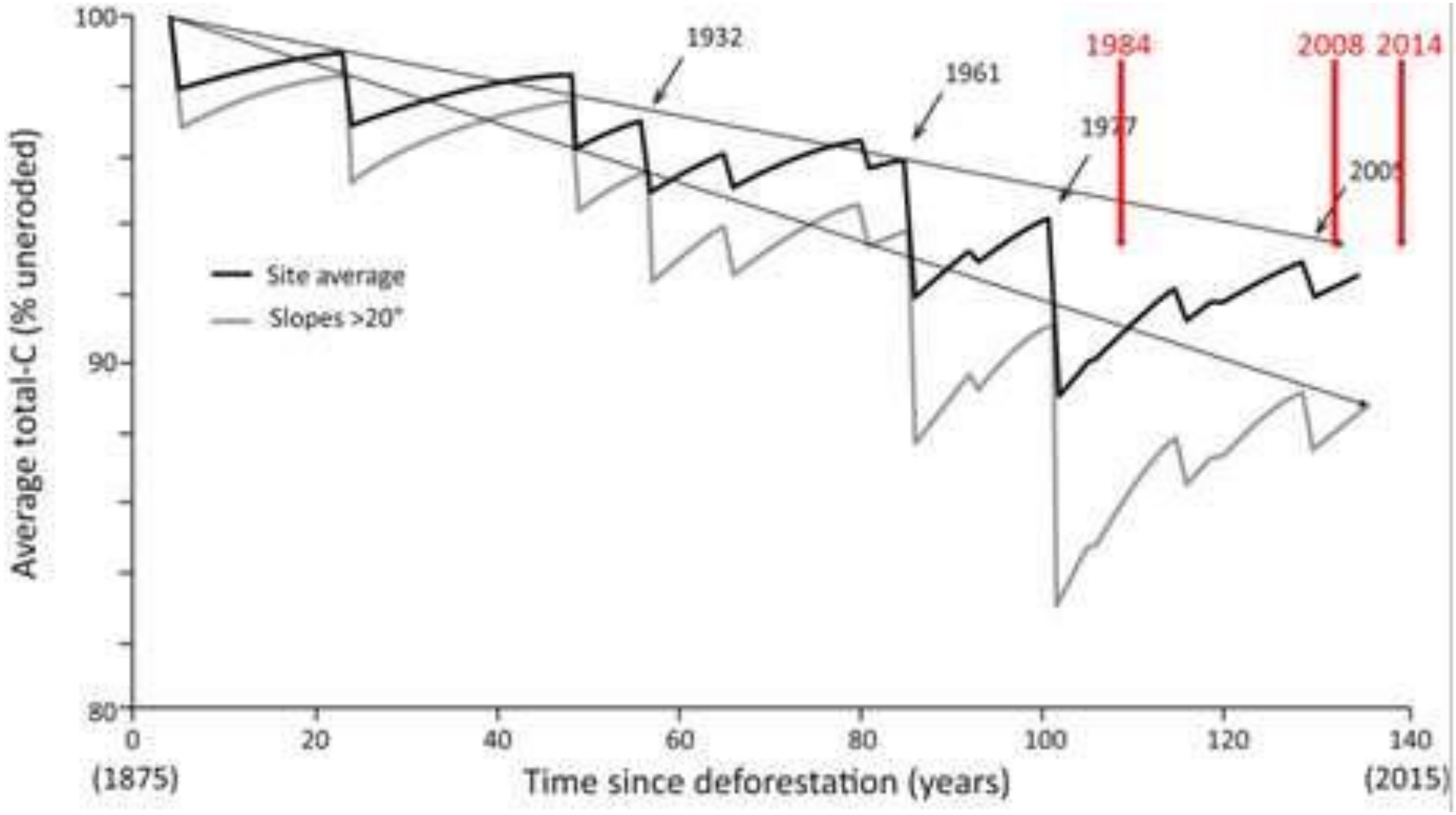
NZAGRC PGgRc

Harry Clark
Andy Reisinger

CSIRO
Jeff Baldock

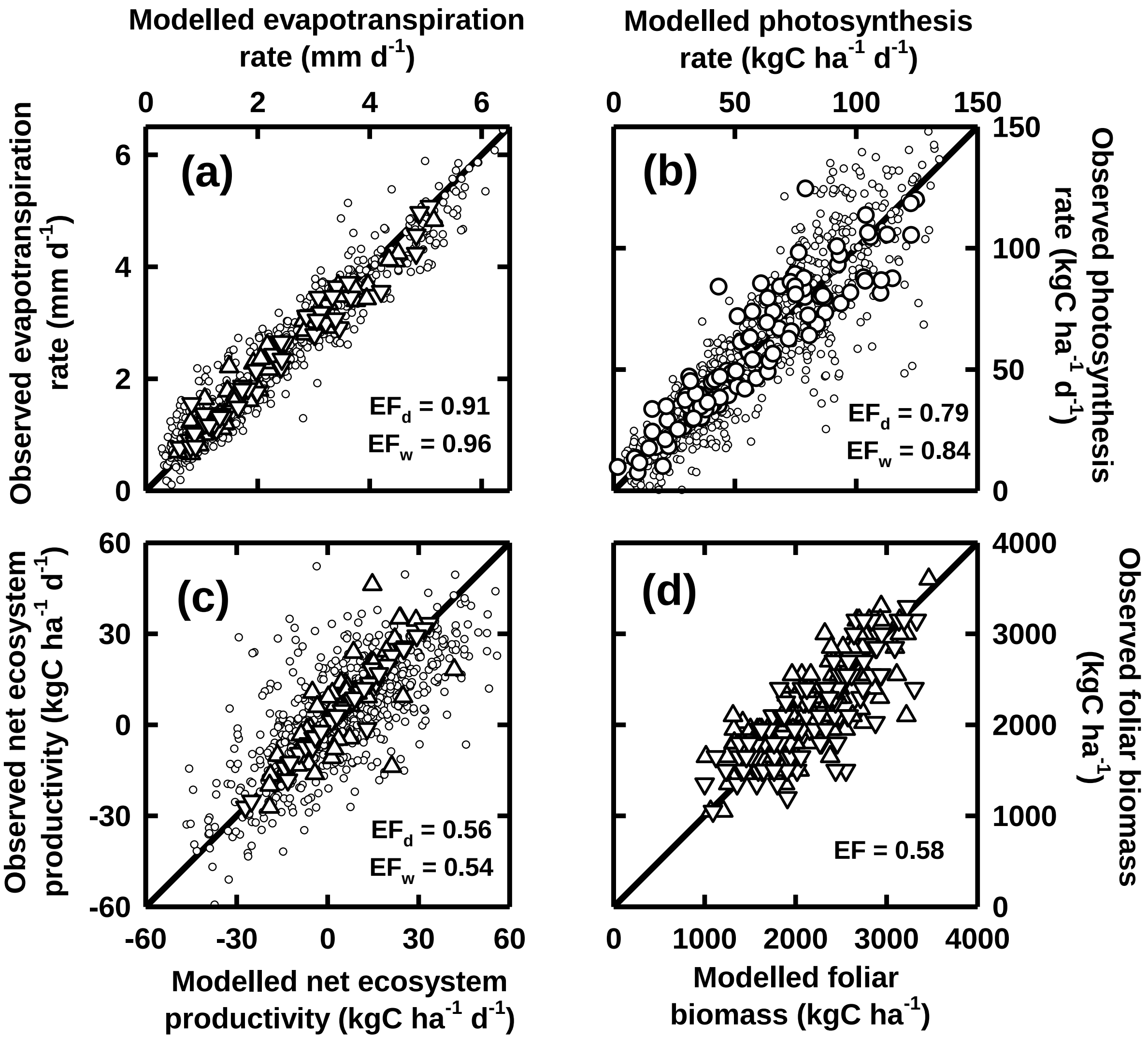
MPI
Gerald Rys

Soil C trends – temporal variability



Case study from Te Whanga catchment (de Rose, 2013)

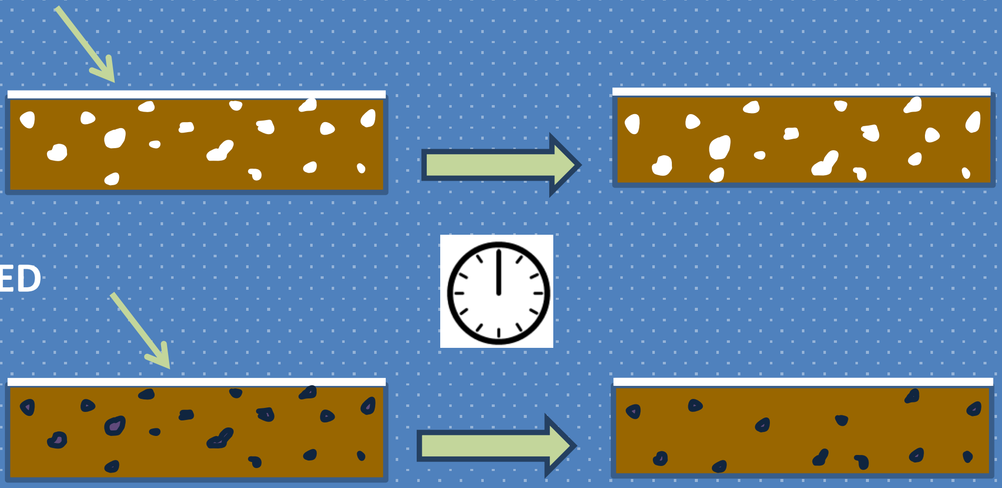
Model-data comparison



Simulations with CenW (Kirschbaum et al., 2015)
Data from Waikato University (Rutledge, Mudge, Schipper et al.)

Understanding Biochar

Biochar and Carbon Stability



BIOCHAR

UNPYROLYZED BIOMASS

Biochar mineralizes more slowly than the biomass it was produced from

Biochar C storage capacity differs widely!

Biochars produced from ash rich material (e.g., manure) at low temperature

C storage value

Biochars produced from woody material at high temperature

Class 1 (< 300 g C kg^{-1} biochar will remain stable for > 100 years)

Class 5 (> 600 g C kg^{-1} biochar will remain stable for > 100 years)

Camps Arbestain et al. (2015)

Biochar and Fertiliser Value

Biochars produced from pine

Fertiliser value

Biochars produced from poultry litter, tomato waste

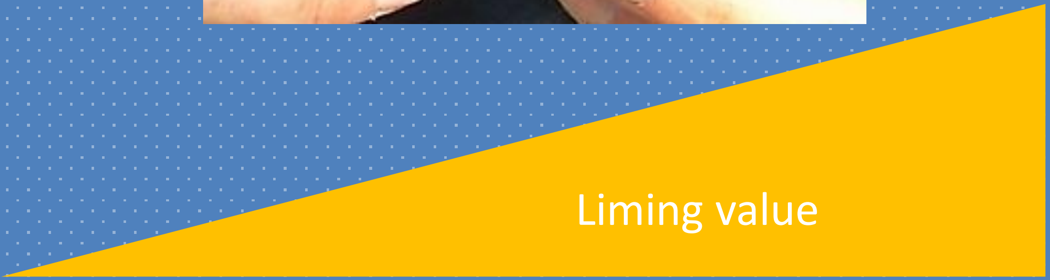
Class 0 (no fertiliser value for hypothetical Corn needs at doses ≤ 10 t ha^{-1})

Class 4 (fertiliser class 4; e.g., K_{2t}, P_{2t}, S_{5t}, Mg_{3t})

Camps Arbestain et al. (2015)

Biochar and Liming Value

Biochars
produced from
pine at low
temperature



Biochars
produced from
tomato waste,
Paper sludge

Class 0 (liming eq < 1%)

Class 3 (liming eq > 20%)

Camps Arbestain et al. (2015)