Soil carbon in New Zealand hill country under contrasting phosphorus fertiliser and sheep stocking regimes

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AgResearch, Grasslands Research Centre

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Introduction

- Soil carbon (C) stored in soil organic matter – an important reservoir within the global C cycle[1]
- A 5% shift in C stored in the 0−2 m soil layer could reduce CO_2-C by 16%[2]

Challenges – Understanding practices that:

1. Encourage C sequestration
2. Limit C depletion

[1]Lal, R. 2004. *Nutrient Cycling in Agroecosystems 70*: 103-116
[2]Houghton, R.A. 2003. The Contemporary Carbon Cycle

Objective

To examine soil C stocks in 3 farmlets under different P fertiliser and livestock regimes since 1975

- Ballantrae Hill Country Research Station

Soil samples:

- 3 depths in 2003 (0-75, 75-150, 150-300 mm)
- 2 depths in 2014 (0-75, 75-150 mm)

3 slopes × 3 aspects × 2 replicates = 18 samples per farmlet

Farmlets

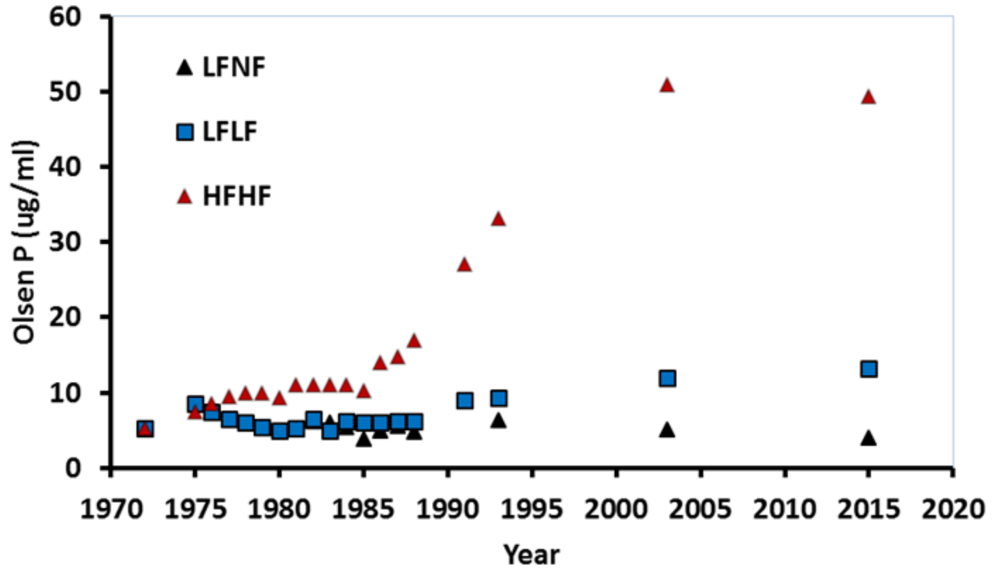
- NF – No SSP since 1980; 6.0 SU ha^{-1}
- LF – 125 kg SSP ha^{-1} since 1980; 10.6 SU ha^{-1}
- HF – 375 kg SSP ha^{-1} since 1980; 16.1 SU ha^{-1}

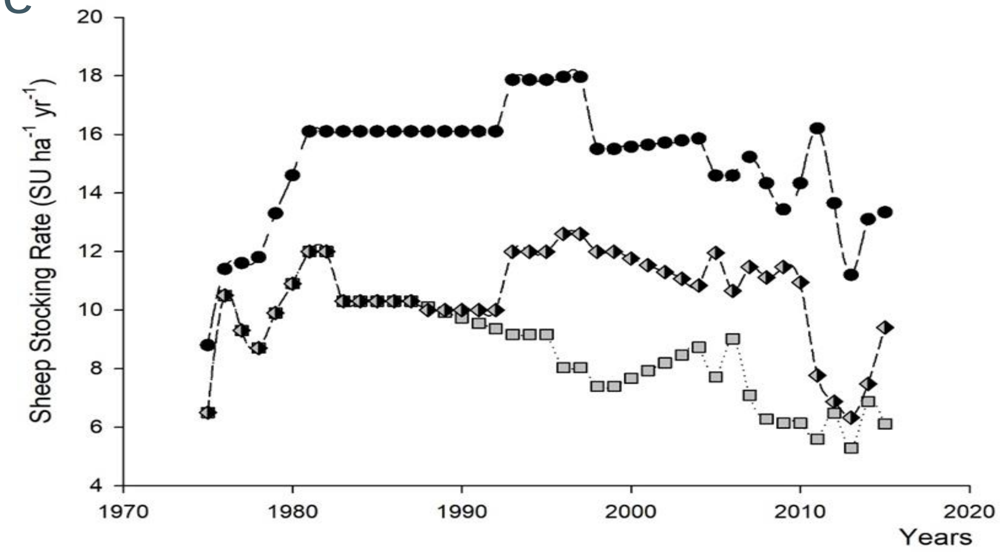
Stocked with ewes to maintain similar grazing pressure

- 6.0 SU ha^{-1} before 1975[1]

Slopes: L (0–12°), M (13–25°), H (>25°)

Aspects: E (35–155°), NW (155–275°), SW (275–35°)

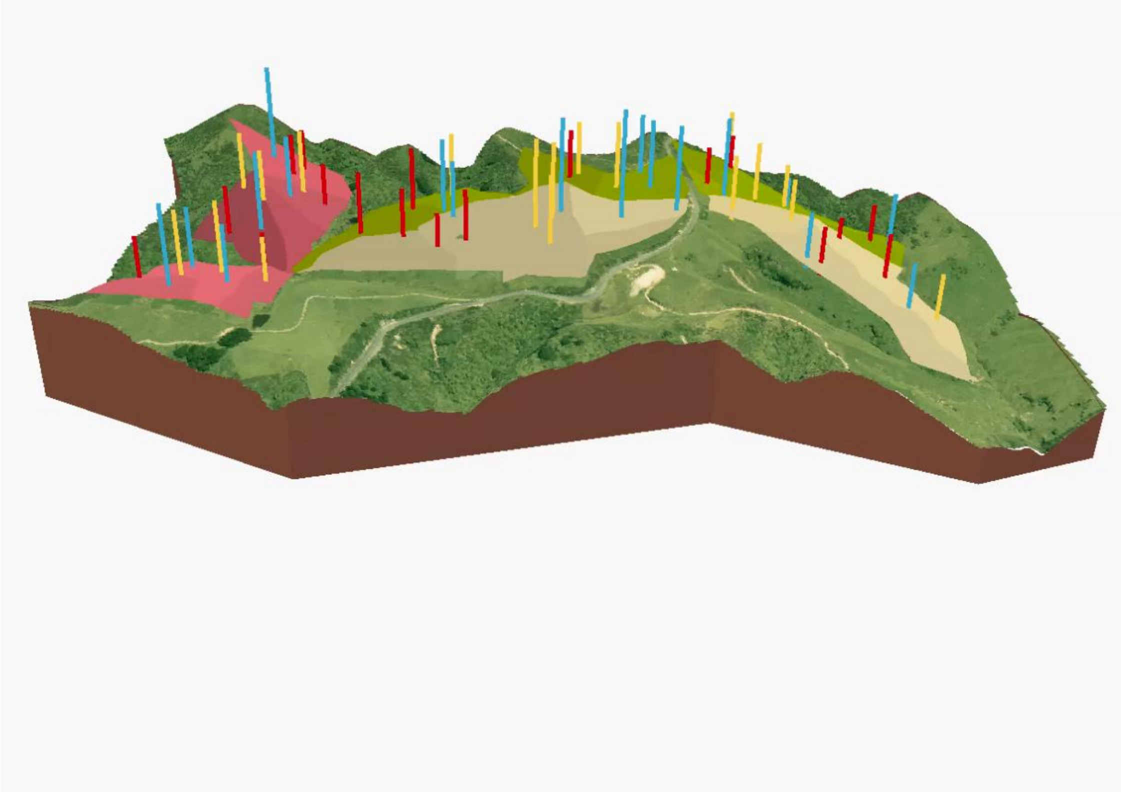




[1]Mackay, A.D.; Lambert, M.G. 2011. *Proc. NZGA 73*: 37-42

Farmlets

Soil C mass (Mg C ha^{-1}) calculated from C concentration (%) and BD (Mg m^{-3})



- Blue Bars are low slope 0-12°
- Yellow bars are med slope 13-25°
- Red Bars are high slope >26°
- Pink shaded area is HFHF farmlet
- Green shaded are is LFLF farmlet
- Cream shaded area is LFNF farmlet

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Changes in soil C stocks (Mg C ha^{-1}) across farmlets

Year & depth (mm)	Farmlet			P ≤
	NF	LF	HF	F
2003				
0 - 75	30.9^{b}	32.5^{ab}	35.1^{a}	**0.01**
0 - 150	59.4	61.5	63.1	0.39
0 - 300	110.9	111.5	110.8	0.98
2014				
0 - 75	31.5	30.4	32.3	0.47
0 - 150	63.4	61.7	63.0	0.83

- In 2003, soil C stocks in the 0-75 mm differed between farmlets

Changes in soil C stocks across farmlets, slopes and aspects

Year & depth (mm)	Farmlet			P ≤		
	NF	LF	HF	F	S(F)	A(F)
2003						
0 - 75	30.9^{b}	32.5^{ab}	35.1^{a}	**0.01**	**0.001**	**0.01**
0 - 150	59.4	61.5	63.1	0.39	**<0.001**	**0.003**
0 - 300	110.9	111.5	110.8	0.98	**0.002**	**<0.001**
2014						
0 - 75	31.5	30.4	32.3	0.47	**<0.001**	0.20
0 - 150	63.4	61.7	63.0	0.83	**0.001**	0.07

- In 2003, soil C stocks in the 0-75 mm differed between farmlets
- Slope x farmlet and aspect x farmlet interactions ($P < 0.05$)

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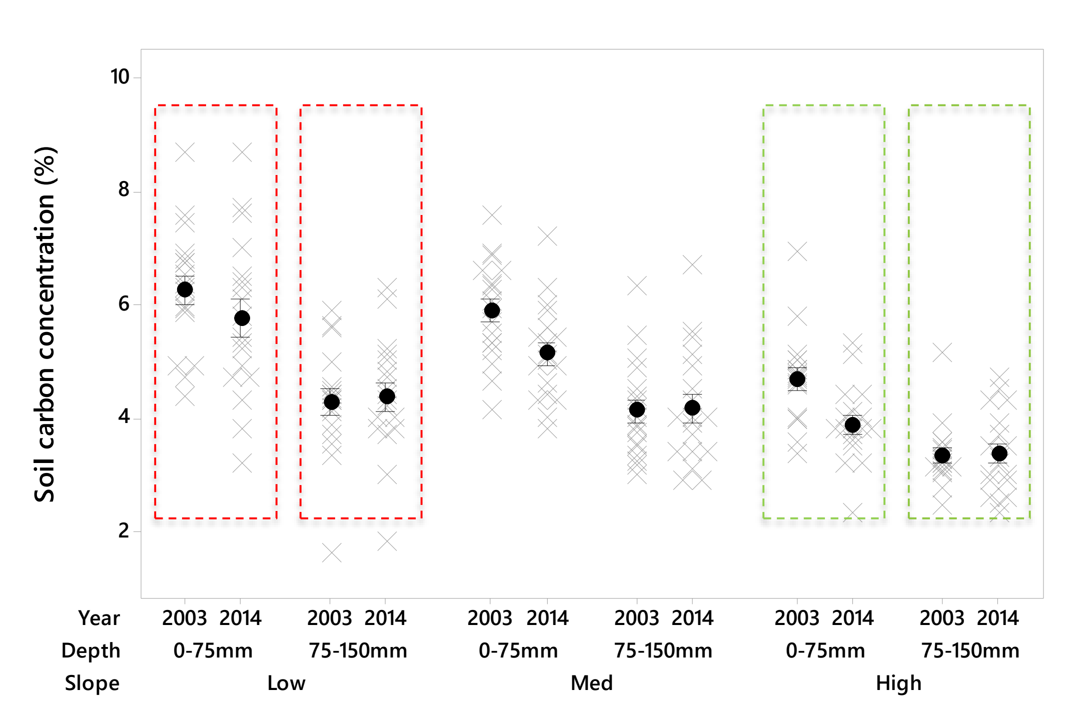
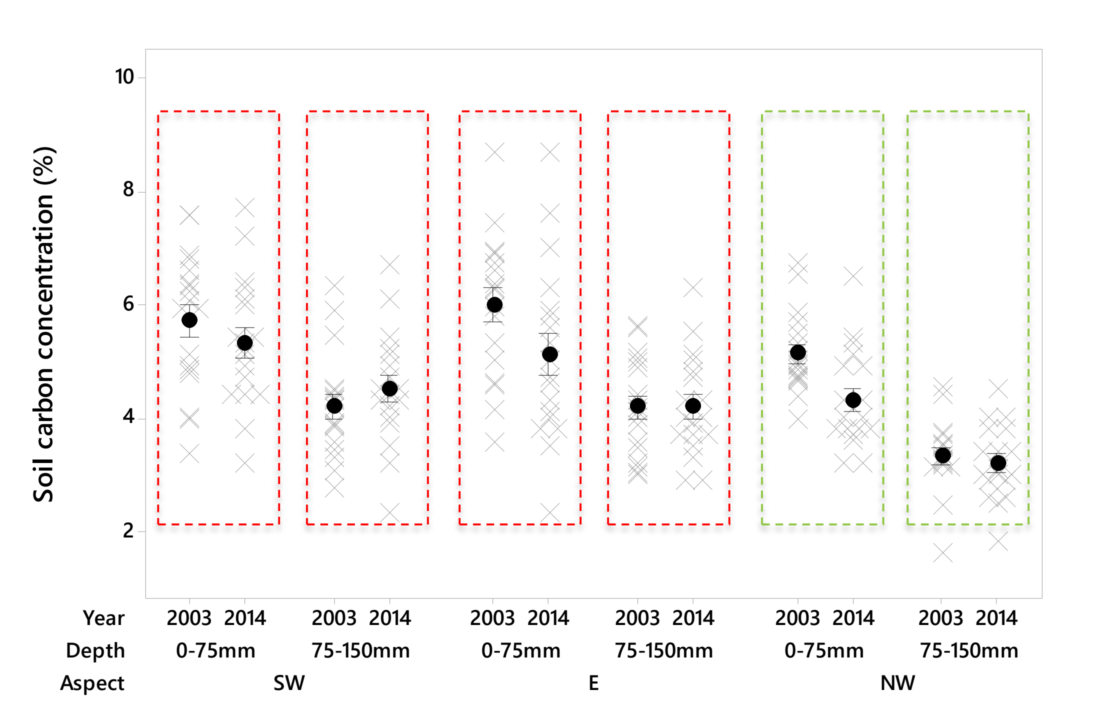
Slope

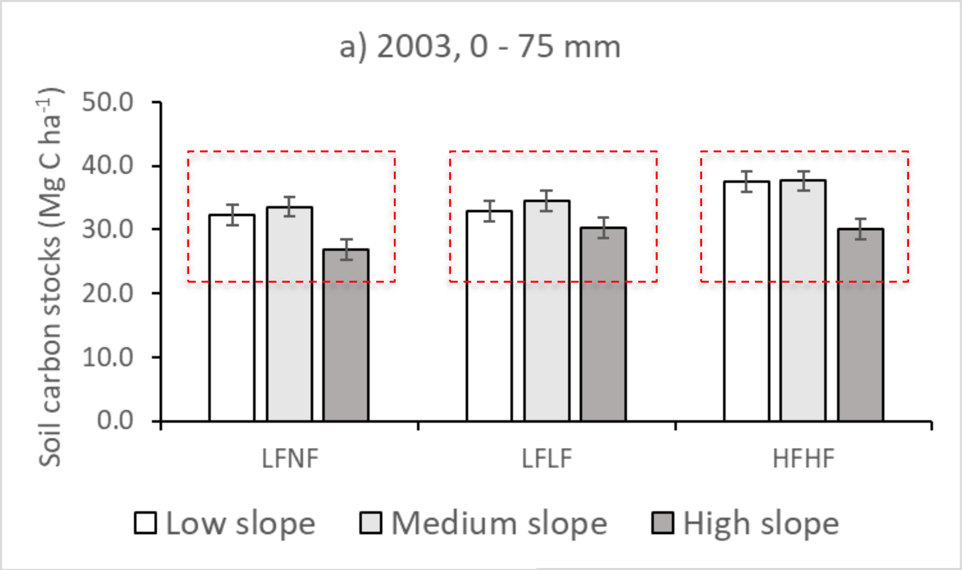


Aspect



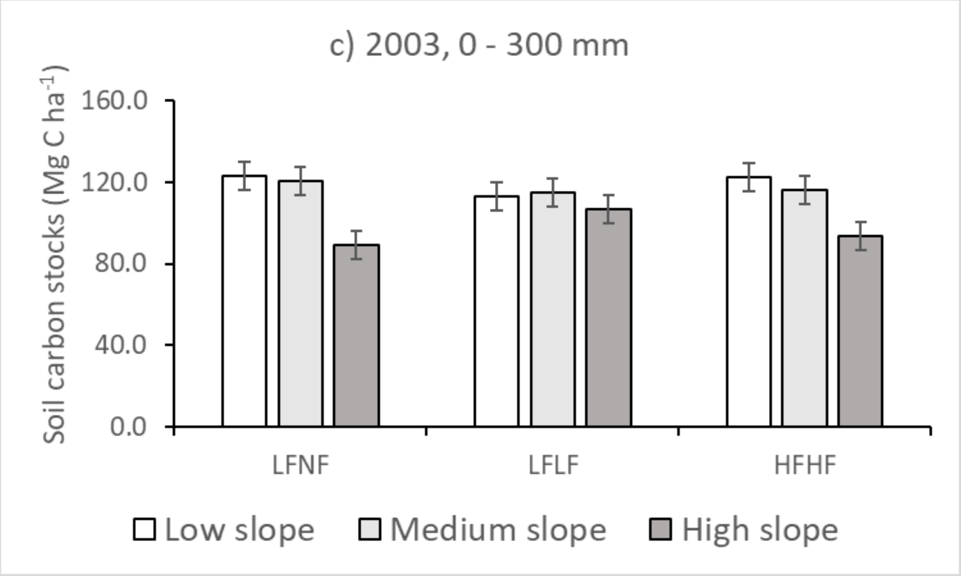
Soil C (%) within the 0-75 mm and 75-150 mm soil depths not influenced by farmlet history, but significant ($P < 0.001$) slope x farmlet and aspect x farmlet interactions

Slope



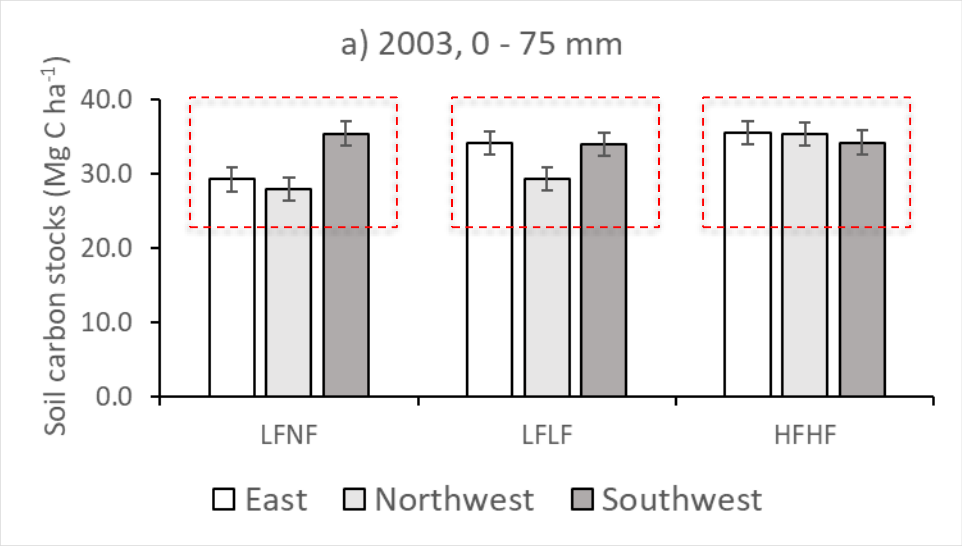
a) 2003, 0 - 75 mm
Soil carbon stocks (Mg C ha-1)
50.0
40.0
30.0
20.0
10.0
0.0
LFNF
LFLF
HFHF
Low slope
Medium slope
High slope

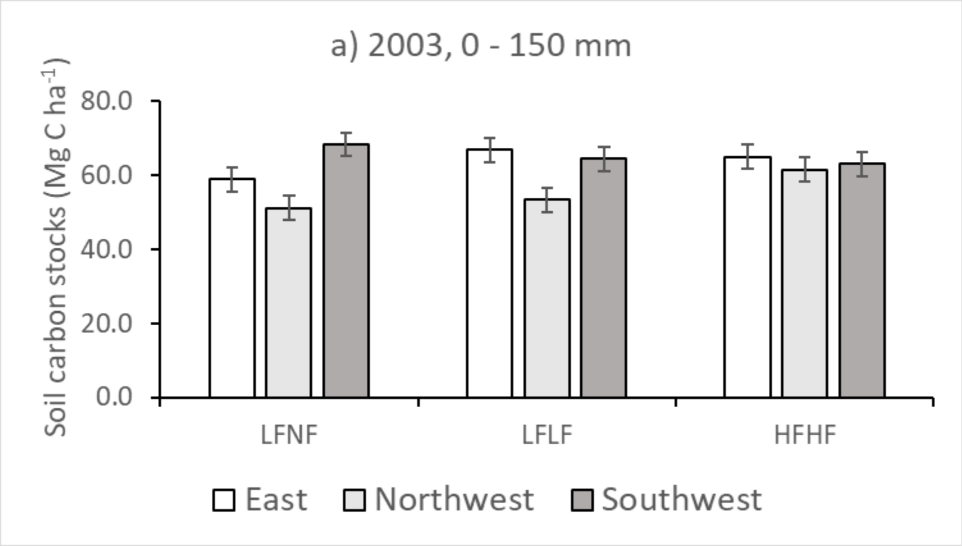
b) 2003, 0 - 150 mm
Soil carbon stocks (Mg C ha-1)
80.0
60.0
40.0
20.0
0.0
LFNF
LFLF
HFHF
Low slope
Medium slope
High slope

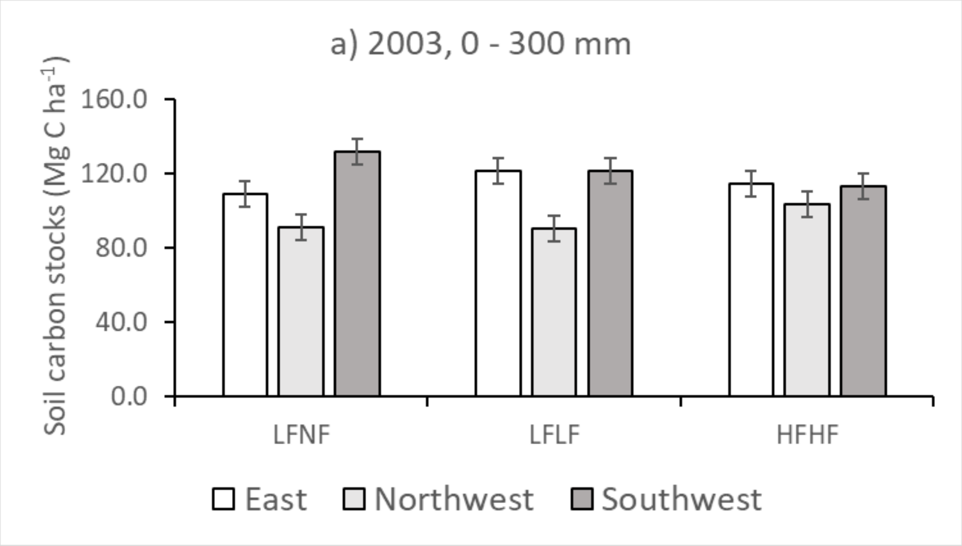


c) 2003, 0 - 300 mm
Soil carbon stocks (Mg C ha-1)
160.0
120.0
80.0
40.0
0.0
LFNF
LFLF
HFHF
Low slope
Medium slope
High slope

Aspect


a) 2003, 0 - 75 mm
Soil carbon stocks (Mg C ha-1)
40.0
30.0
20.0
10.0
0.0
LFNF
LFLF
HFHF
East
Northwest
Southwest


a) 2003, 0 - 150 mm
Soil carbon stocks (Mg C ha-1)
80.0
60.0
40.0
20.0
0.0
LFNF
LFLF
HFHF
East
Northwest
Southwest


a) 2003, 0 - 300 mm
Soil carbon stocks (Mg C ha-1)
160.0
120.0
80.0
40.0
0.0
LFNF
LFLF
HFHF
East
Northwest
Southwest

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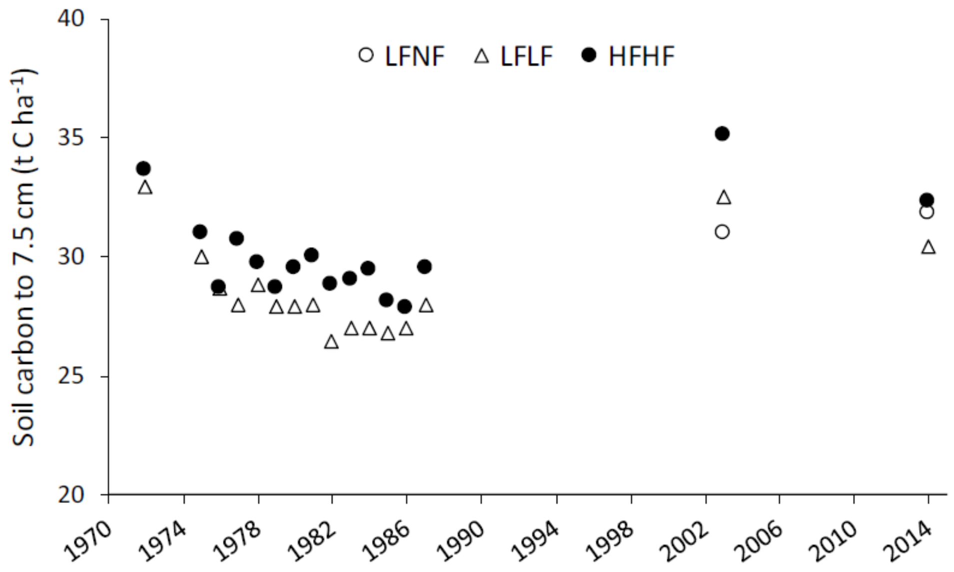
Summary

- Soil C stocks in 2003 increased from 30.9 to 32.5 and 35.1 Mg C ha^{-1} in the 0-7.5 cam depth on the NF, LF and HF farmlets, but remained relatively unaffected at greater depths in 2003 and both depths in 2014

- Adding these findings to earlier measures from the same farmlets provides a time series (1972-2014) that supports the view that soil C stocks (0-7.5 cm depth) are relatively stable under permanent pastures managed under the current conditions



Conclusions

- In contrast to farmlet effects, both slope and aspect had pronounced effects on soil C stocks. These effects varied by farmlet
- An understanding of the attributes of the landscape and the possible influence on livestock behaviours become critical in estimating soil C stocks
- The long-term P fertiliser and sheep grazing experiment is an invaluable resource for exploring the long-term changes in pastoral hill systems
- Data from this long-term study provides science, policy and industry with invaluable insights into the changes in soil C stocks in pastoral hill country soils

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Acknowledgements

All the science, technical and farm staff and service staff involved with the AgResearch Hill Country Research Station, Ballantrae since its establishment in 1972

Funding from the Sustainable Land Management and Climate Change fund of the Ministry for Primary Industries and the AgResearch Strategic Science Investment Fund

Simulating long-term changes in soil phosphorus (P) and carbon (C) in hill country pastures in New Zealand

Wellington, 30 September 2019

Franco Bilotto, Ronaldo Vibart, Alec Mackay, Des Costall

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Why are we interested in soil carbon?

- Soil C sequestration can strengthen land-based C sinks and off-set anthropogenic emissions (Lal et al. 2015)

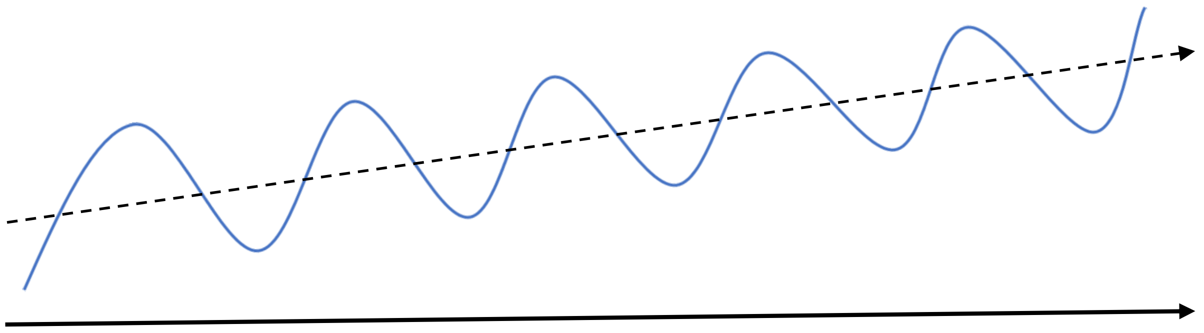
- Other benefits of soil C sequestration:
  - Advancing food security
  - Increasing supply and quality of water
  - Enhancing biodiversity

- Increasing soil C stocks under NZ's hill country pastures is a challenge
  - Levels are already high
  - Spatial and temporal dynamics

Trends in soil organic C in New Zealand

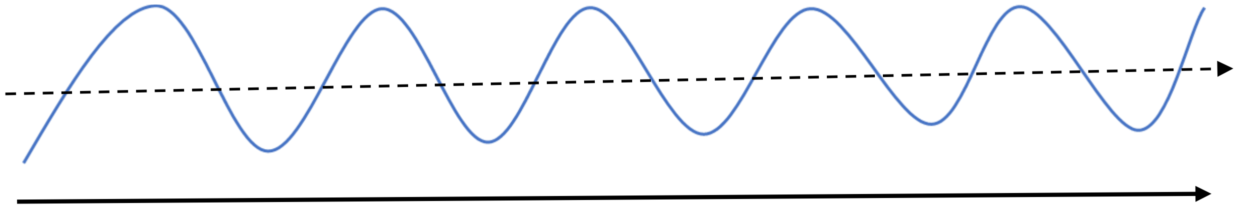
a) Gaining soil C

Parfitt et al. 2014



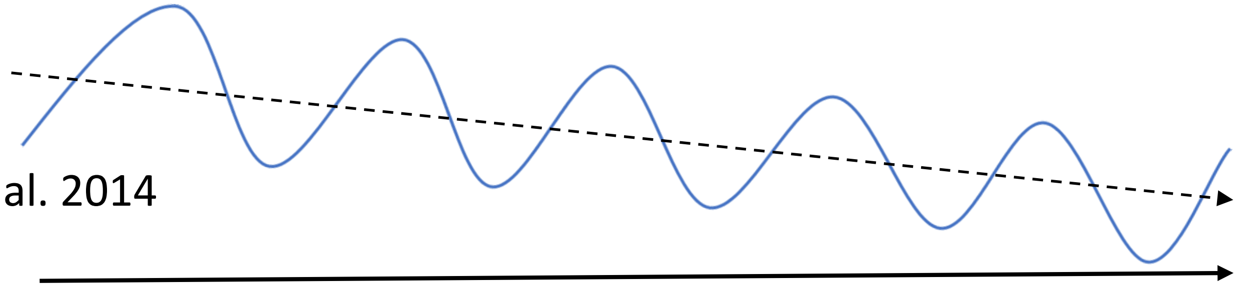
b) Steady state

Tate et al. 1997



c) Lossing soil C

Schipper et al. 2007, Shipper et al. 2014



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Objectives

A better understanding of the landscape (slopes and aspects) and livestock behaviour are essential to assess soil C dynamics in hill country

Establish whether or not:

i) a long-term spatial nutrient balance budget model could be developed to capture the effects of slope and aspect on P and C dynamics in a grazed hill country pasture

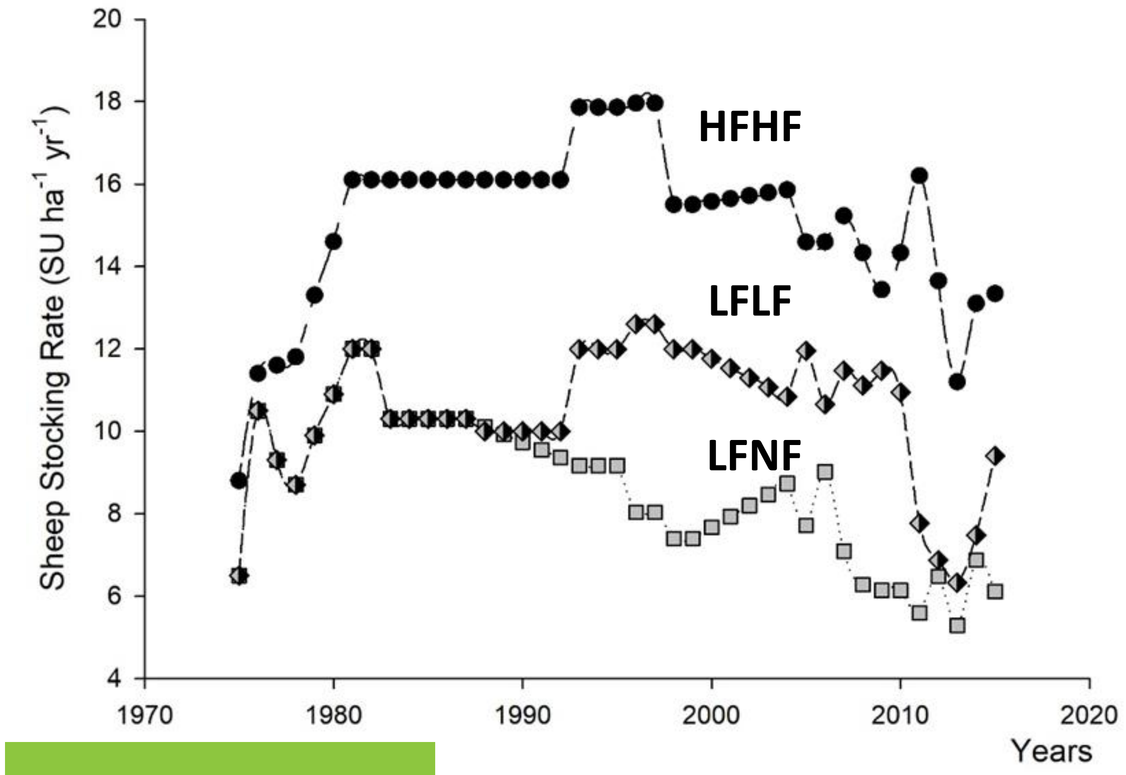
ii) the spatial model could simulate the distribution of soil P and C as affected by P fertiliser and sheep stocking regimes

- Valuable to explore options for change in soil P & C sequestration rates
- Valuable for informing the design of relevant sampling regimes

Ballantrae case study

Three self-contained farmlets:

- LFNF: 0 kg SSP ha^{-1} yr^{-1}
- LFLF: 125 kg SSP ha^{-1} yr^{-1}
- HFHF: 375 kg SSP ha^{-1} yr^{-1}



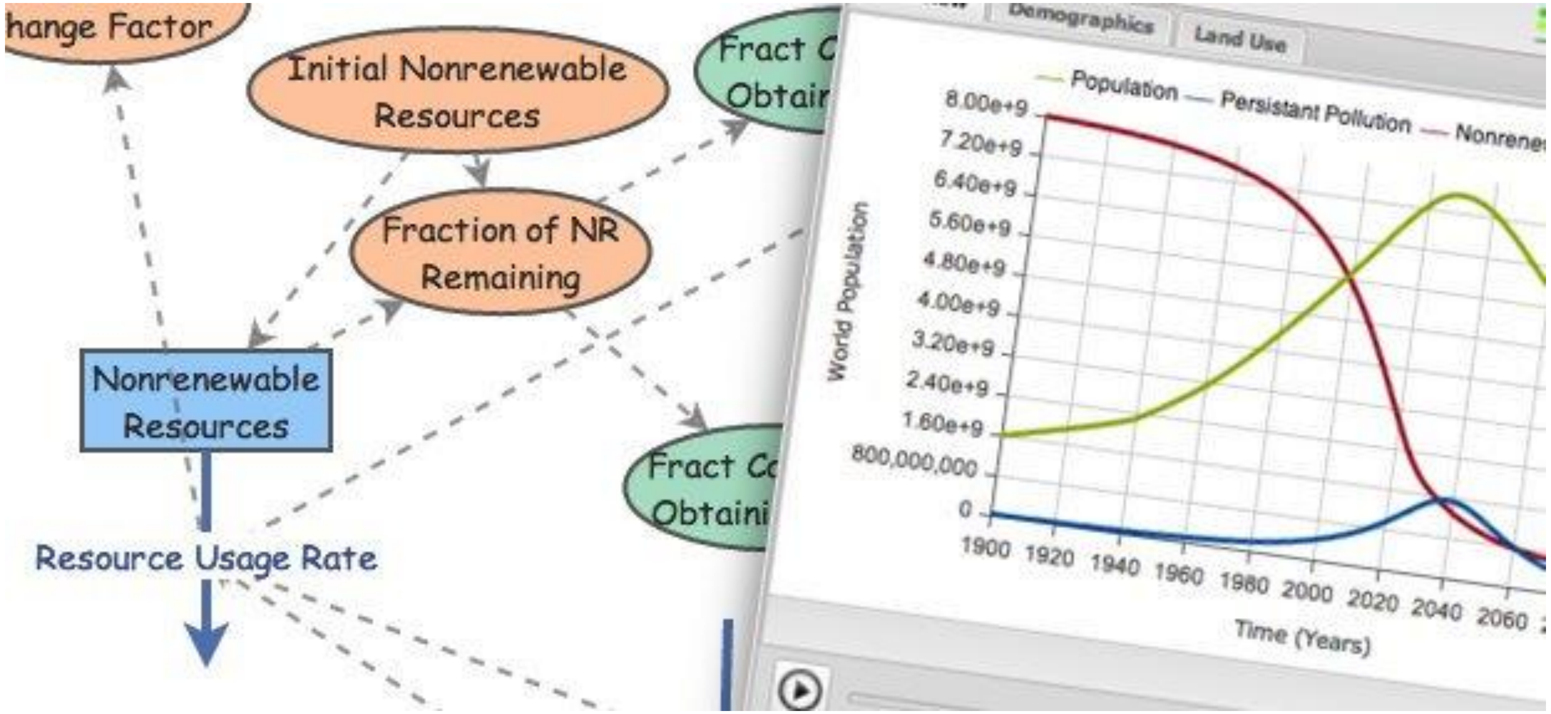
Percentage of land area in each slope and aspect combination

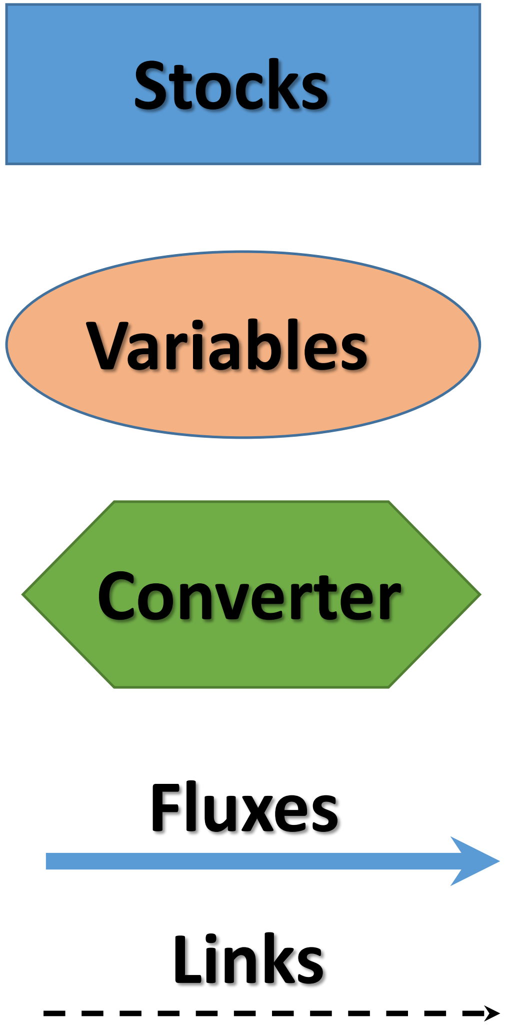
	Aspects		
Farmlet	**East**	**N.West**	**S.West**
LFLF	18.5%	51.8%	29.6%
LFNF	60.0%	23.1%	16.9%
HFHF	18.1%	58.8%	23.1%

	Slopes		
Farmlet	**Low**	**Medium**	**High**
LFLF	27.5%	45.5%	27.0%
LFNF	19.8%	51.5%	28.7%
HFHF	32.9%	50.3%	16.9%

Model development

INSIGHT MAKER





Fortmann-Roe, 2014

https://insightmaker.com

Pasture production

New Zealand Journal of Agricultural Research, 2014
Vol. 57, No. 3, 149–164, http://dx.doi.org/10.1080/00288233.2014.898663

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RESEARCH ARTICLE

Responses of grazed New Zealand hill pastures to rates of superphosphate application

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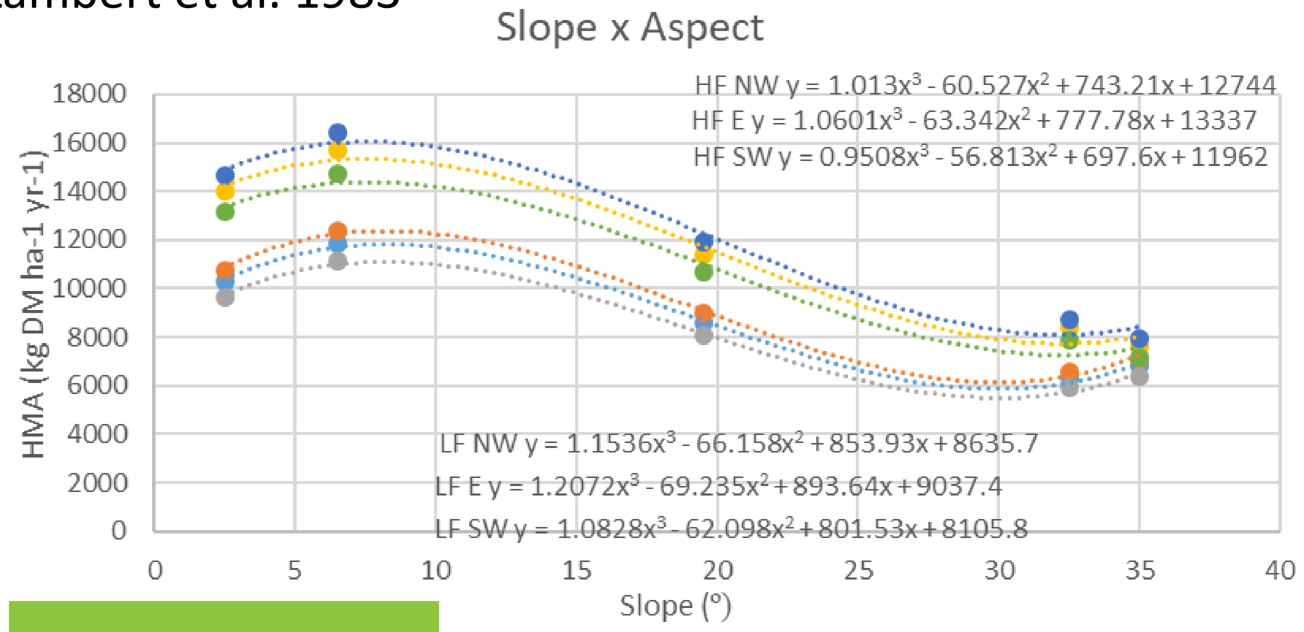
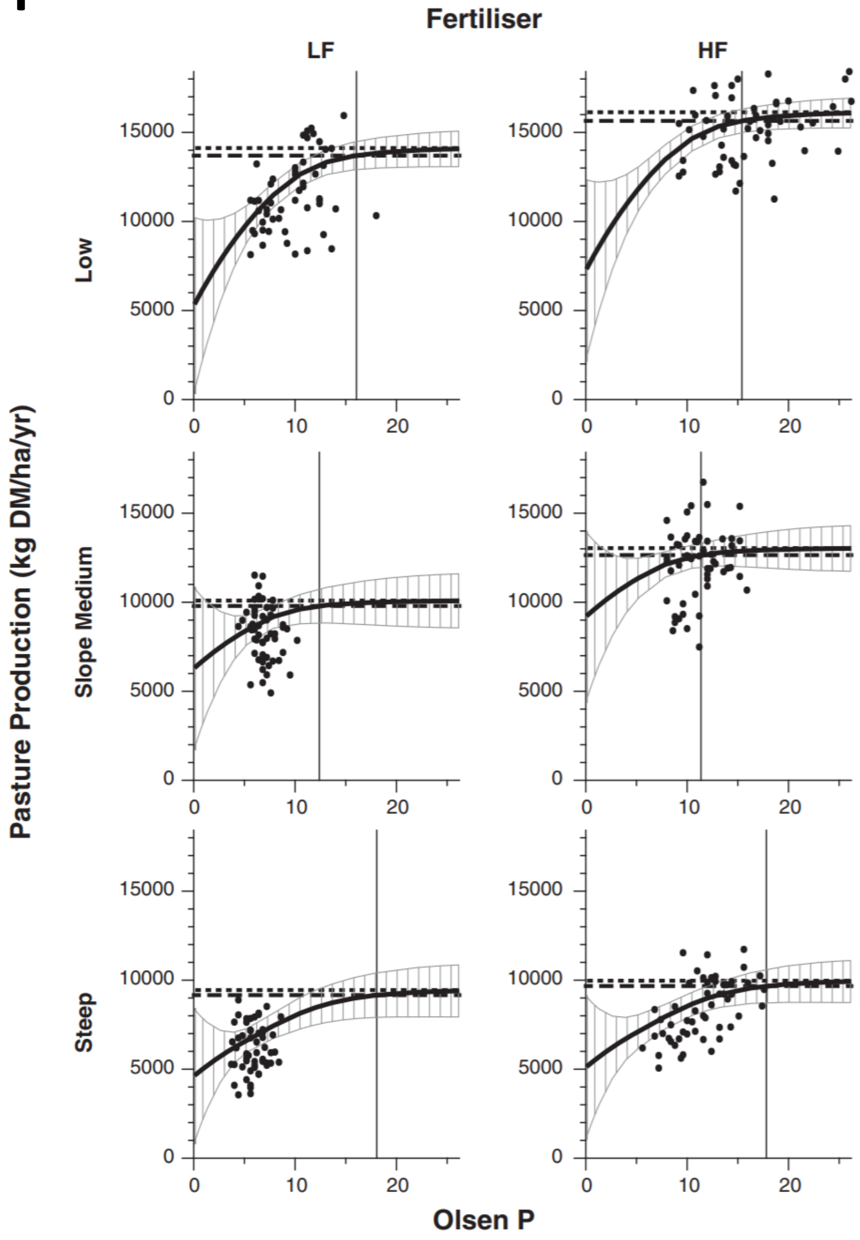
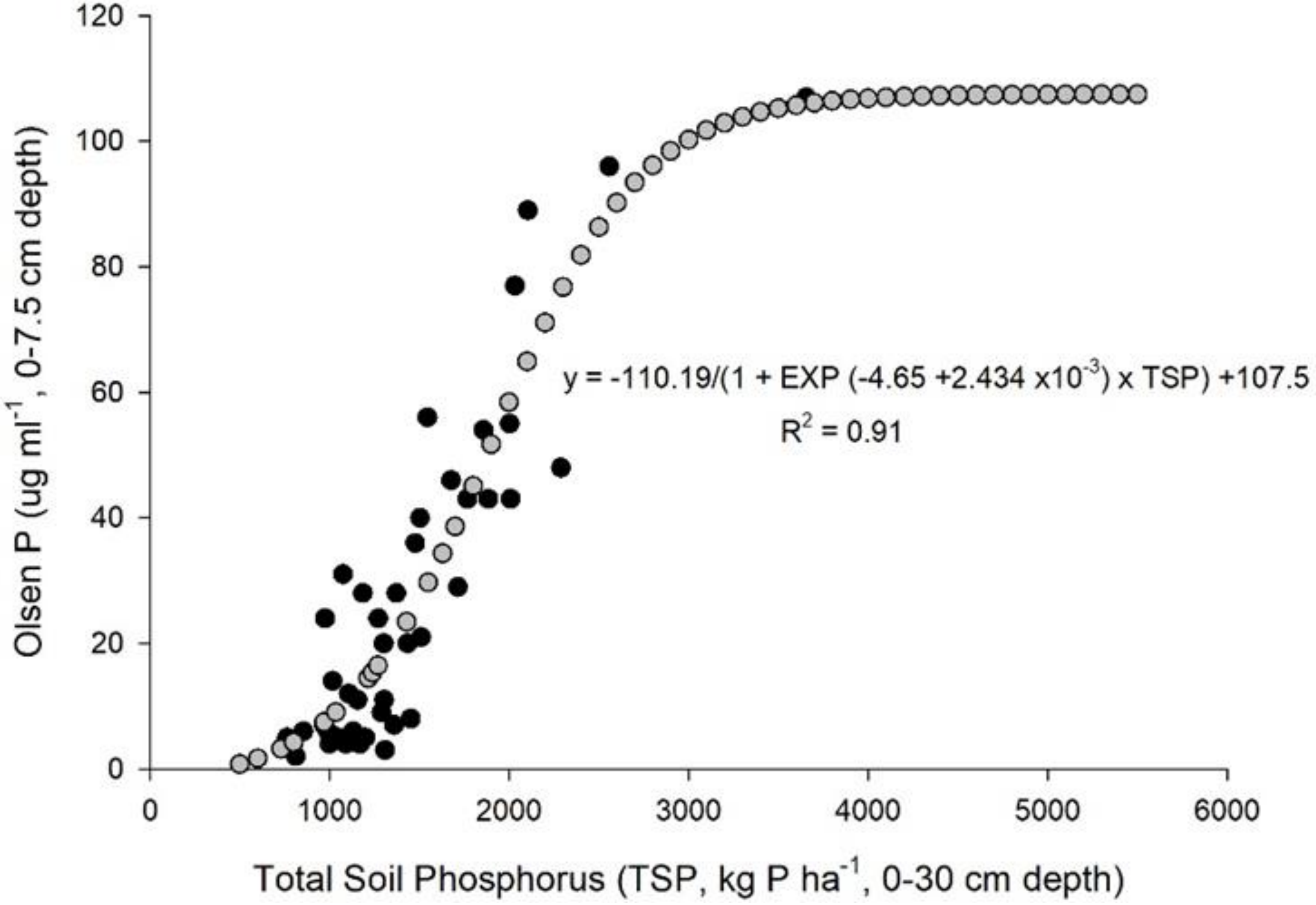
(*Received 22 November 2013; accepted 19 February 2014*)

Lambert et al. 1983





Total soil P and Olsen P



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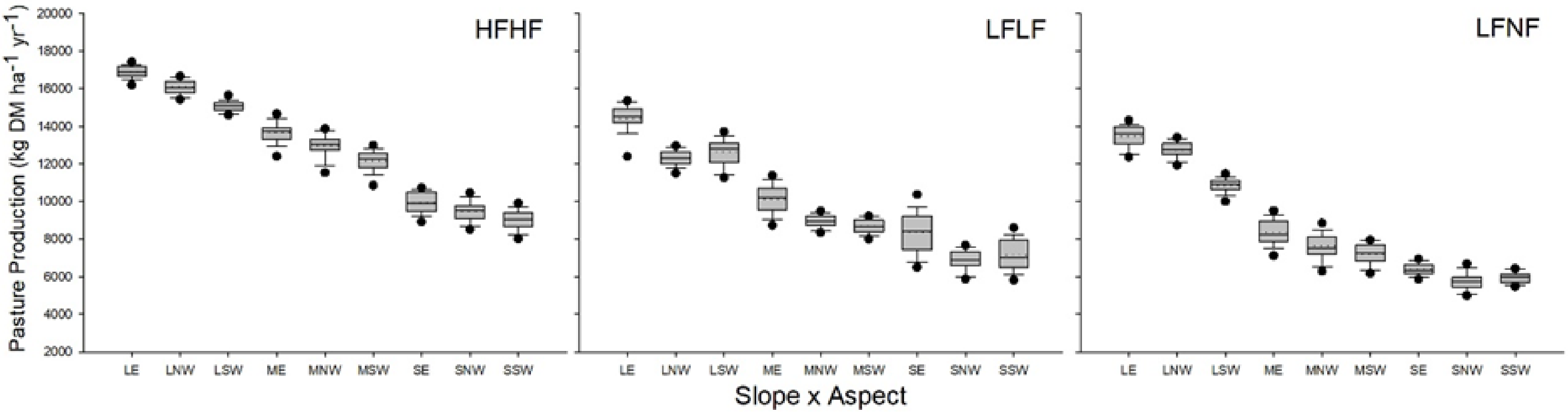
Pasture production and grazing behavior



Long term pasture production (1975-2015) simulated for each slope and aspect combination

Selective defoliation by sheep according to slope and plant species in the hill country of New Zealand

I. F. López*, J. Hodgson*, D. I. Hedderley†, I. Valentine* and M. G. Lambert‡

*Institute of Natural Resources, Massey University, Palmerston North, New Zealand, †Institute of Information Sciences and Technology, Massey University, Palmerston North, New Zealand, and ‡AgResearch Grasslands, Palmerston North, New Zealand

 Grass and Forage Science, **58**, 339–349

Redistribution of nutrients in animal excreta

Allocation to low slopes		
% area of low land	Fraction faecal deposition	Fraction urine deposition
<1%	30*x*	27*x*
1-5%	0.30	0.27
5-9%	0.45	0.405
9-35%	0.61	0.55
35-85%	(0.5*x* + 0.5)	(0.45*x* + 0.45)
>85%	(0.5*x* + 0.5)	(0.5x + 0.5)

Allocation to high slopes		
% area of low land	Fraction faecal deposition	Fraction urine deposition
<1%	7.5*x*	10*x*
1-20%	0.075	0.10
20-40%	0.10	0.14
40-60%	0.15	0.21
60-85%	0.20	0.28
>85%	(16*x* – 13)/3	4.8*x* – 3.8

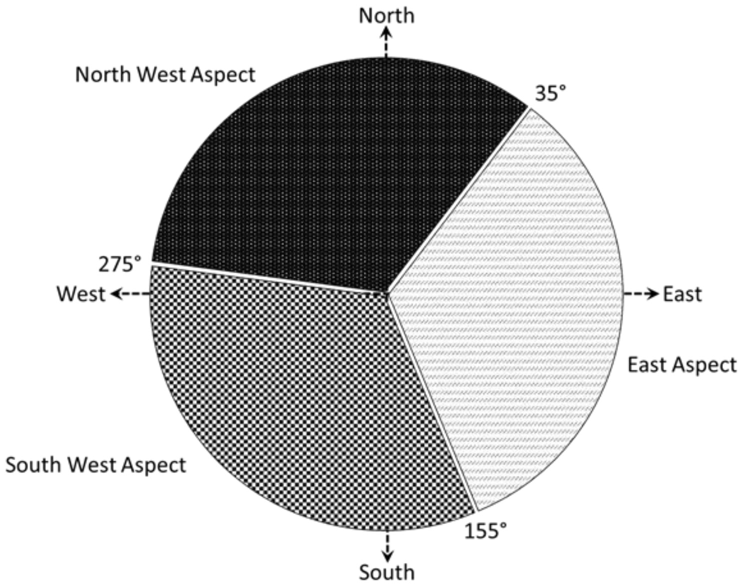
Saggar et al. 2015

N.Z. Journal of Agricultural Research 21 (1978): 255–60

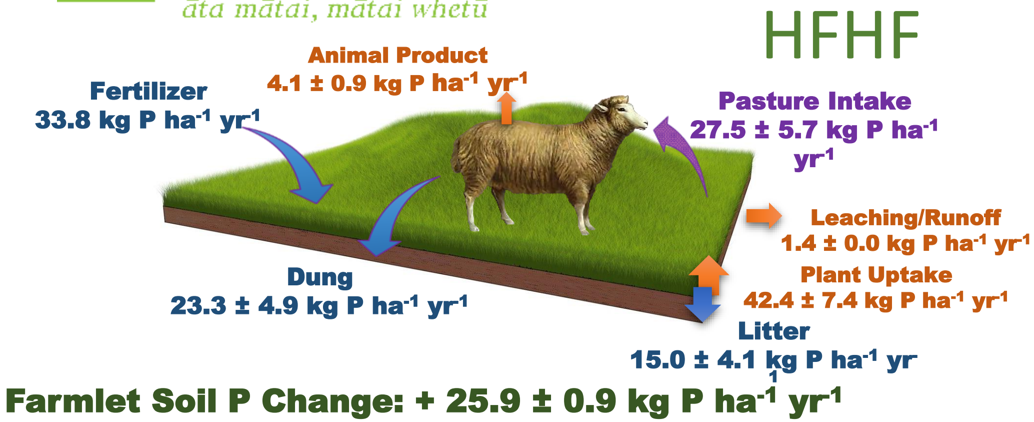
Aspect differences in an unimproved hill country pasture

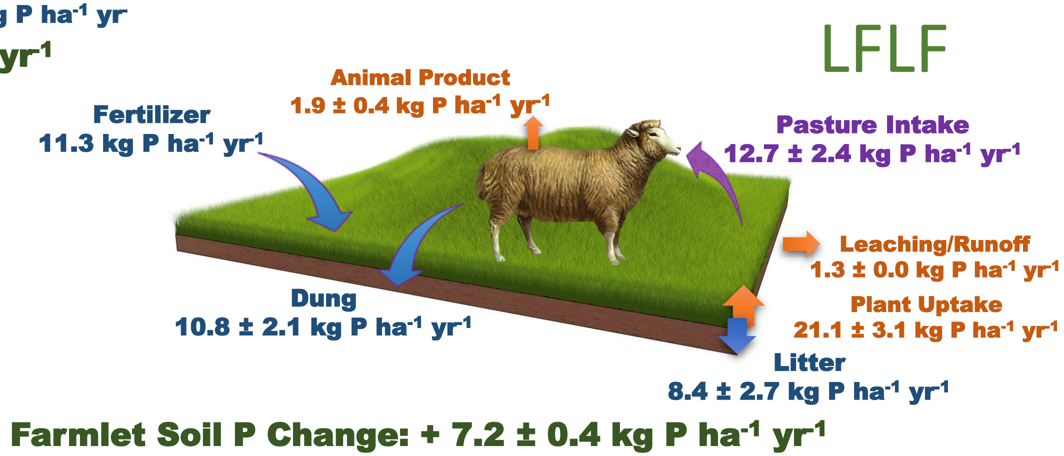
II. Edaphic and biotic differences

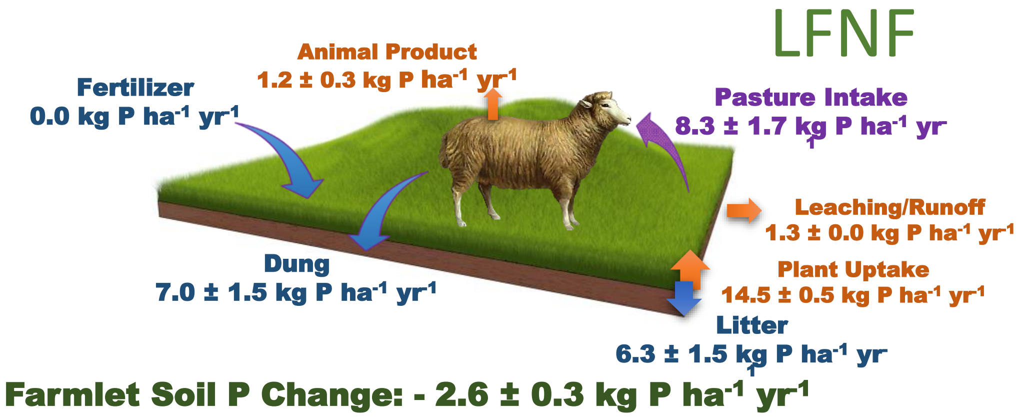
M. G. Lambert* and E. Roberts



P cycle



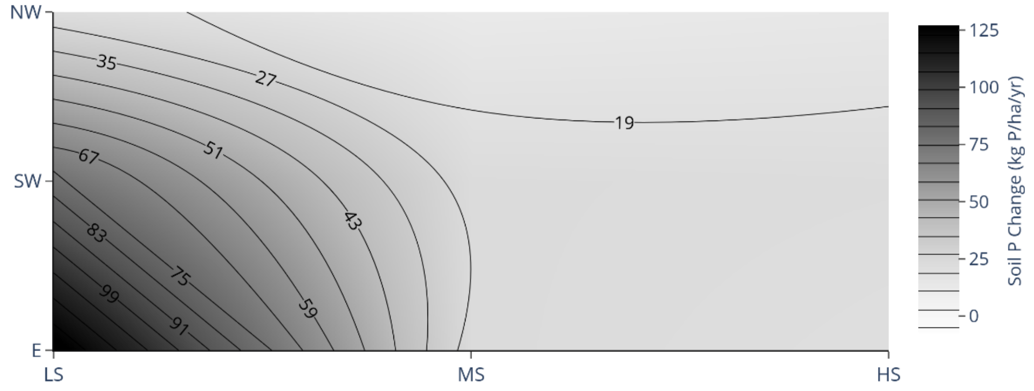




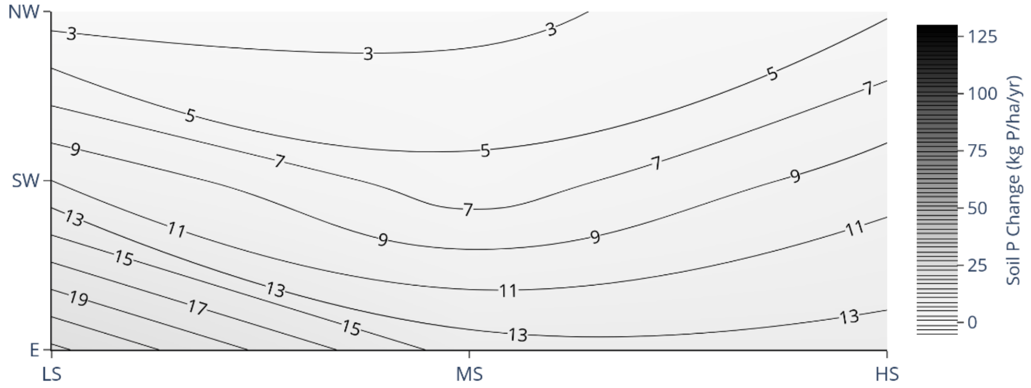
Lambert et al., 1985;
Rowarth 1987;
Rowarth and Gillingham 1990;
Saggar et al. 1990;
McDowell et al., 2004

P distribution

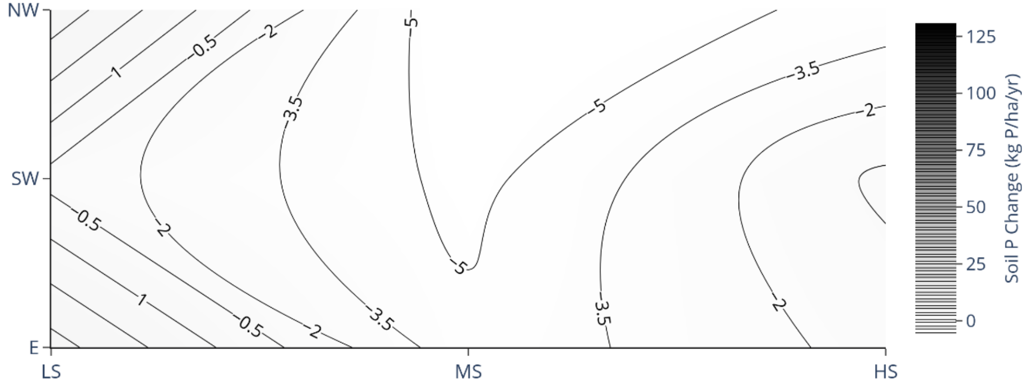
HFHF



LFLF



LFNF



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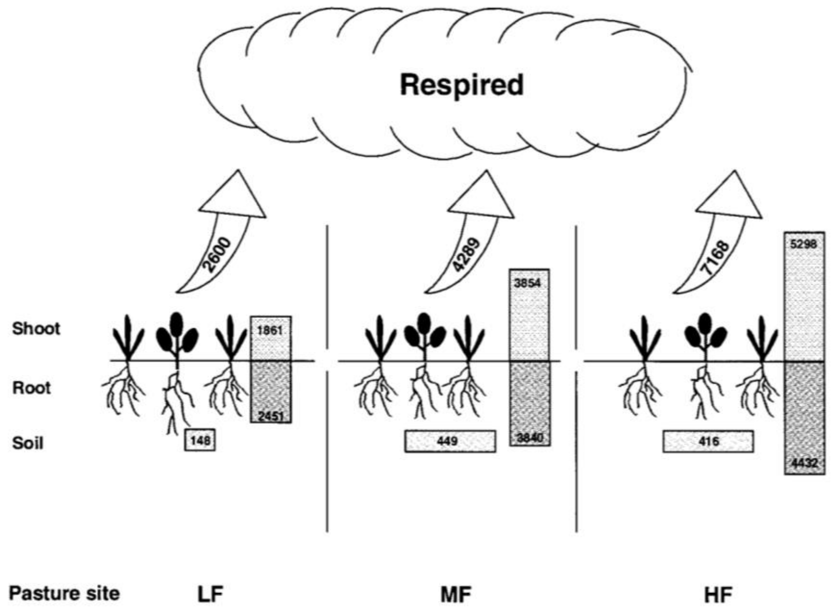
C Partitioning

Fig. 1 Schematic representation of annual carbon fluxes (kg C ha^{-1}) in varying fertility pastures estimated from ^{14}C distribution 35 days after pulse labelling and annual above-ground plant growth



Saggar et al. 1997

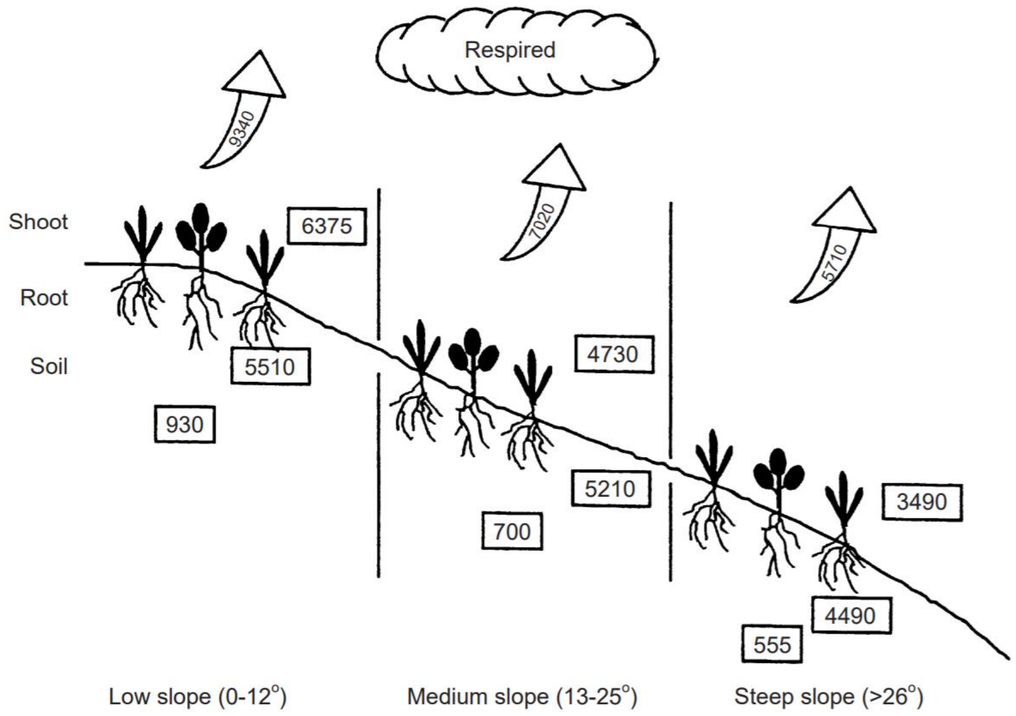


Fig. 2. Schematic representation of annual C fluxes (kg C/ha) estimated from annual pasture production data at each slope category.

Saggar et al. 1999

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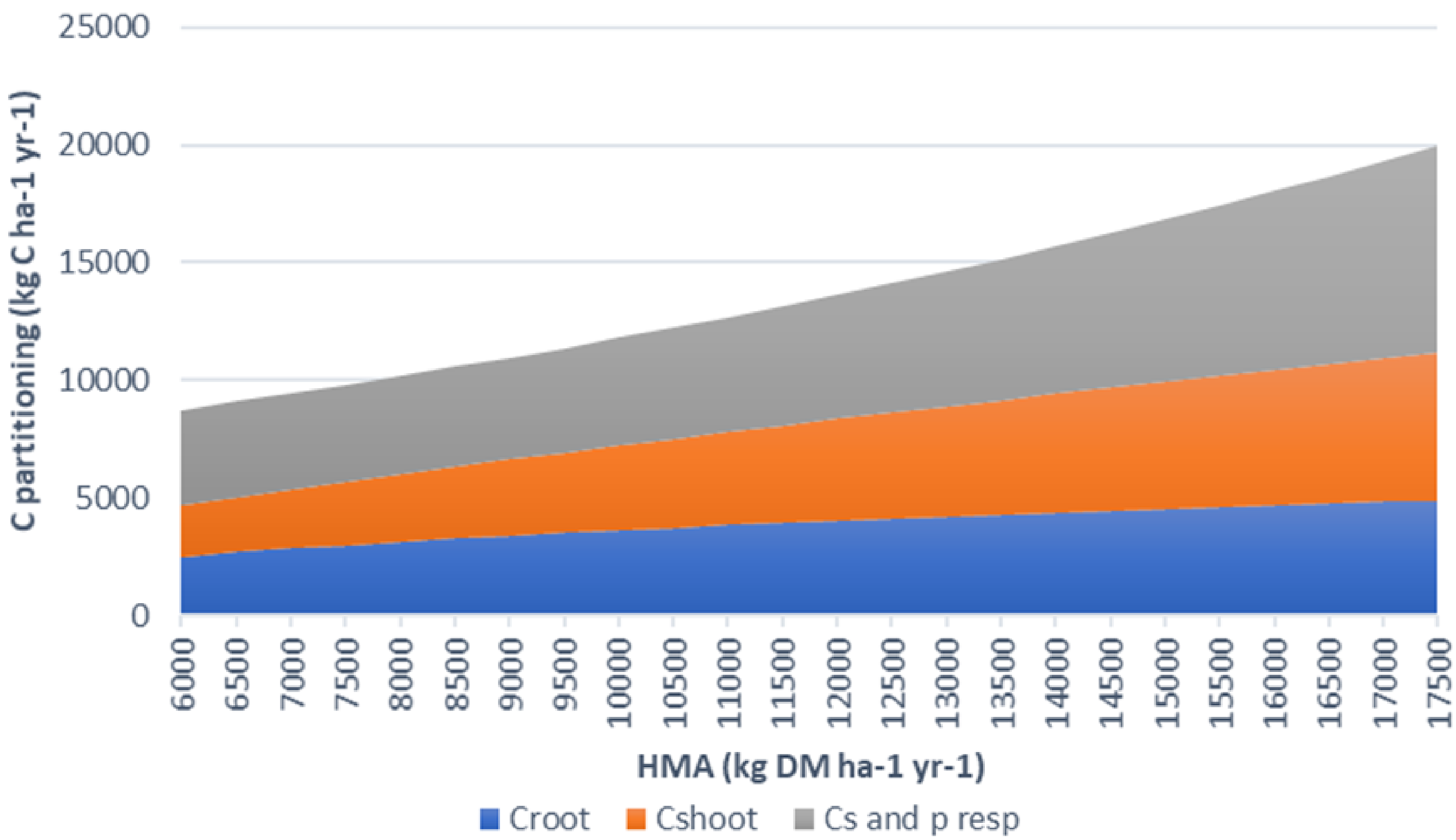
C Partitioning



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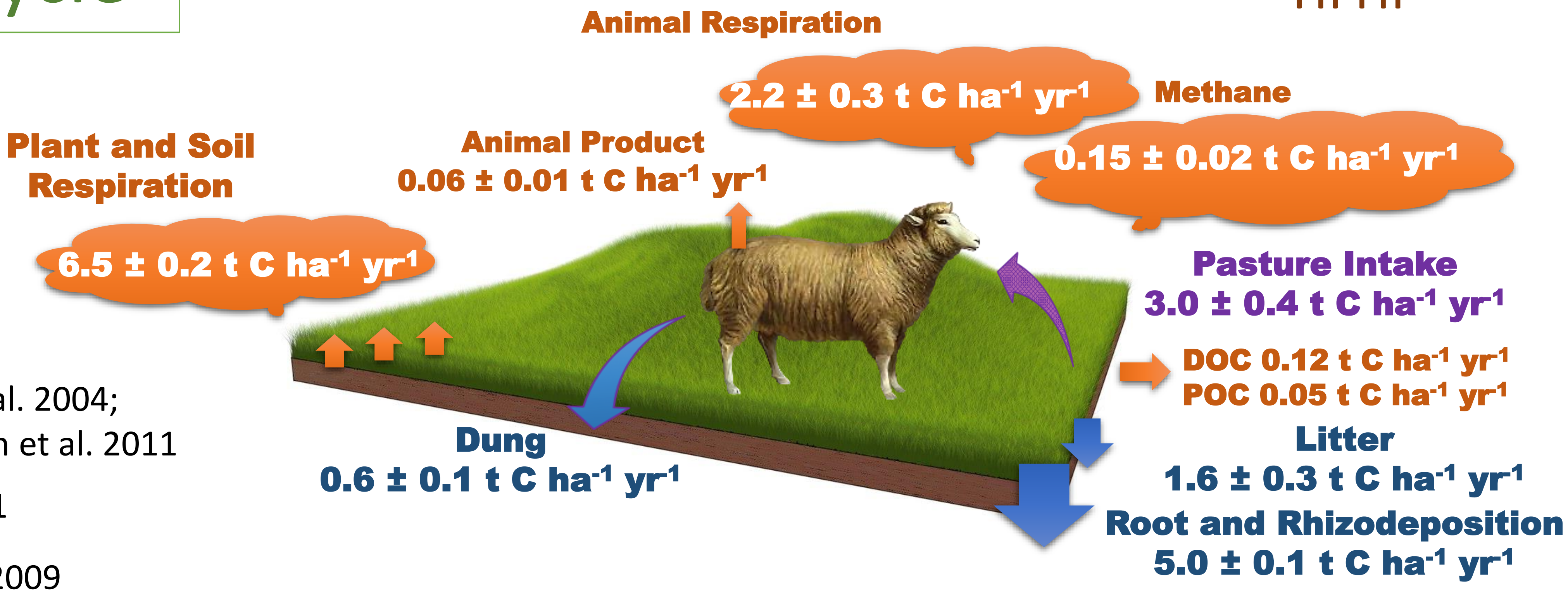
C cycle

HFHF



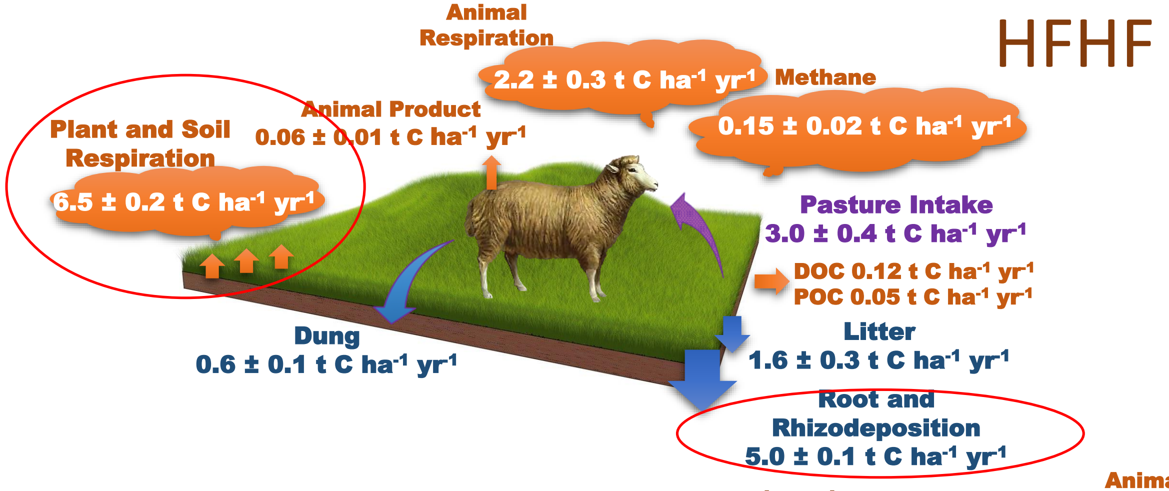
Soussana et al. 2004;
Hoogendoorn et al. 2011

Muetzel 2011

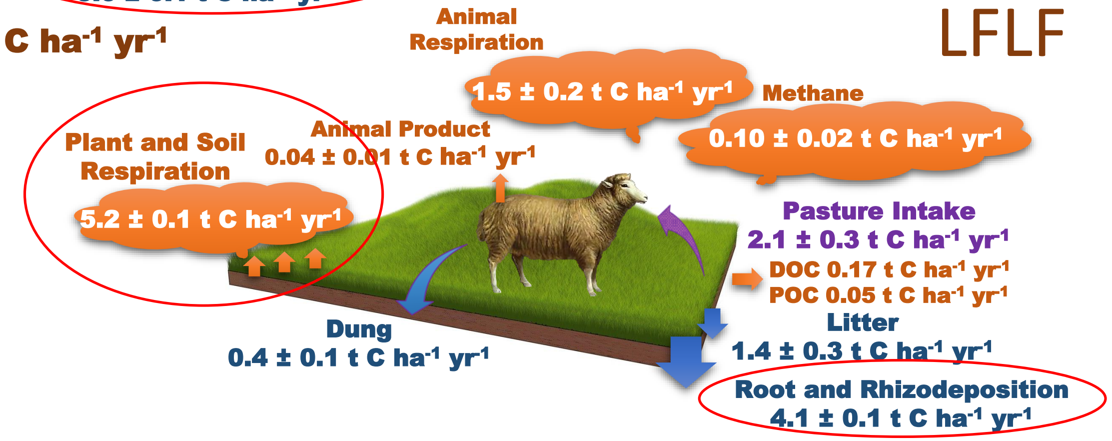
Parfitt et al. 2009

Farmlet Soil C Change: + 0.56 ± 0.3 t C ha^{-1} yr^{-1}

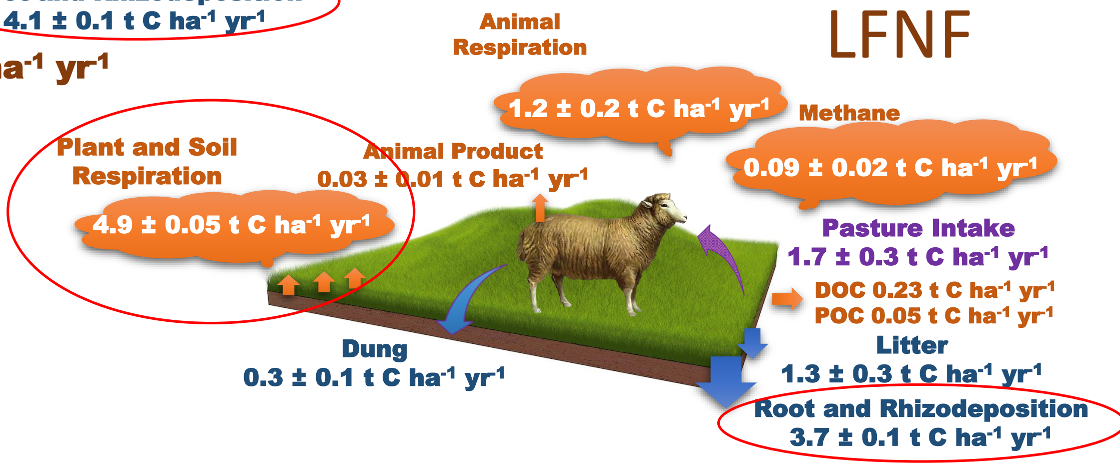
C cycle



Farmlet Soil C Change: + 0.56 ± 0.3 t C ha^{-1} yr^{-1}



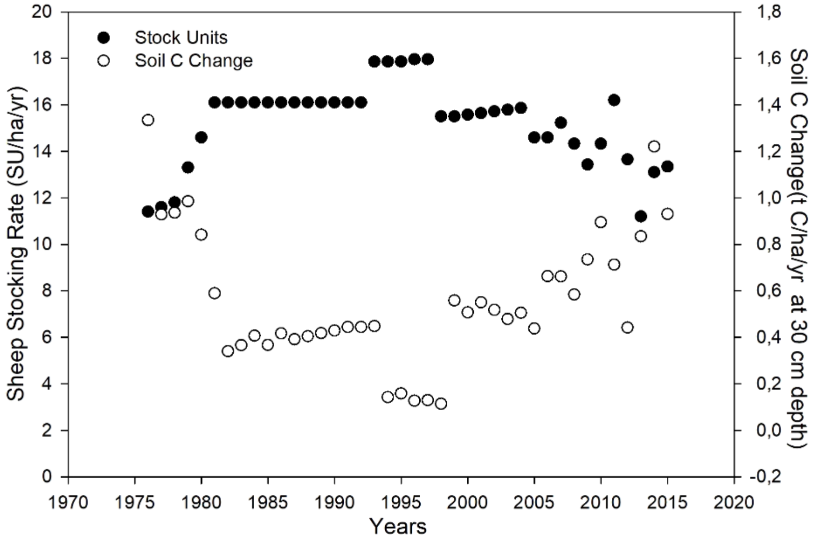
Farmlet Soil C Change: + 0.47 ± 0.3 t C ha^{-1} yr^{-1}



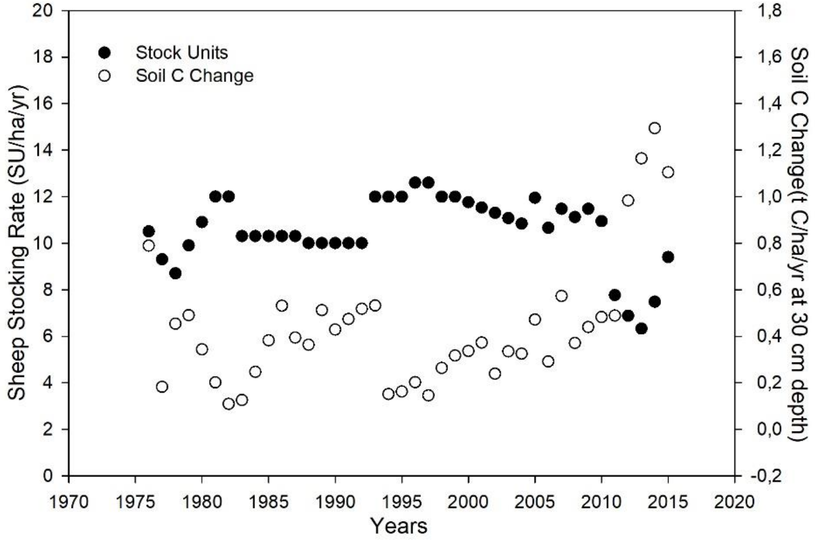
Farmlet Soil C Change: + 0.21 ± 0.2 t C ha^{-1} yr^{-1}

Changes in soil C and stocking rate

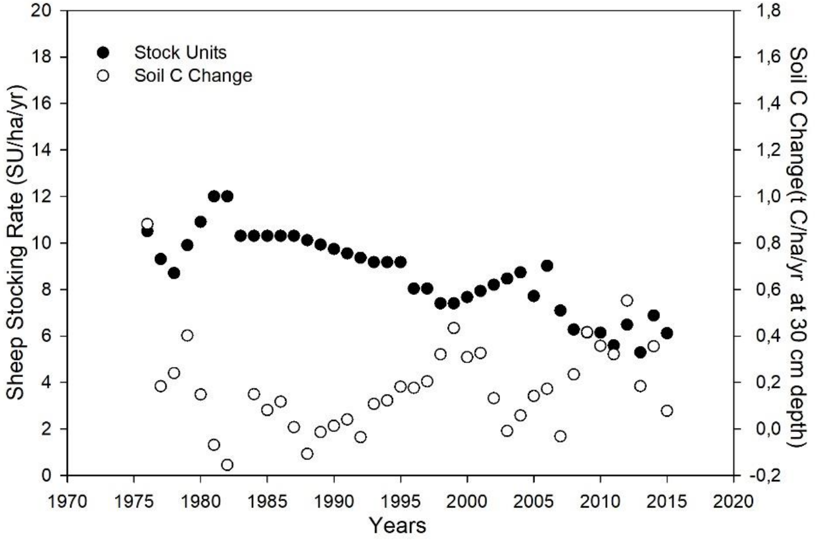
HFHF



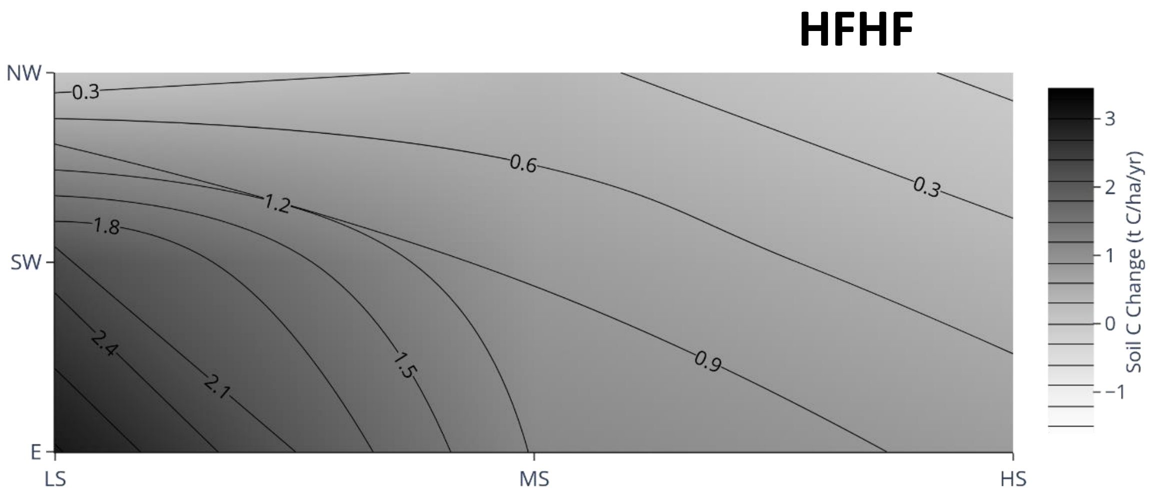
LFLF

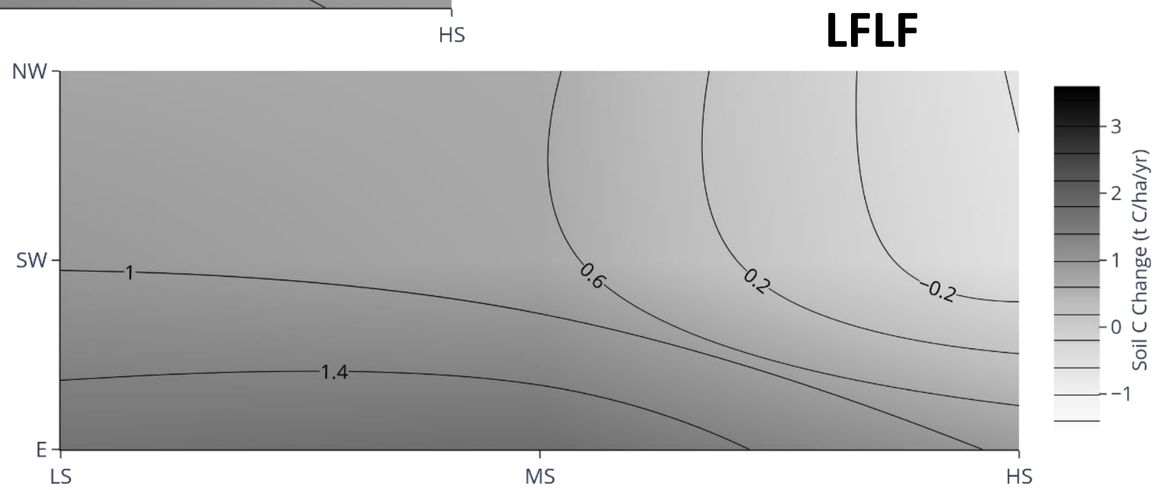


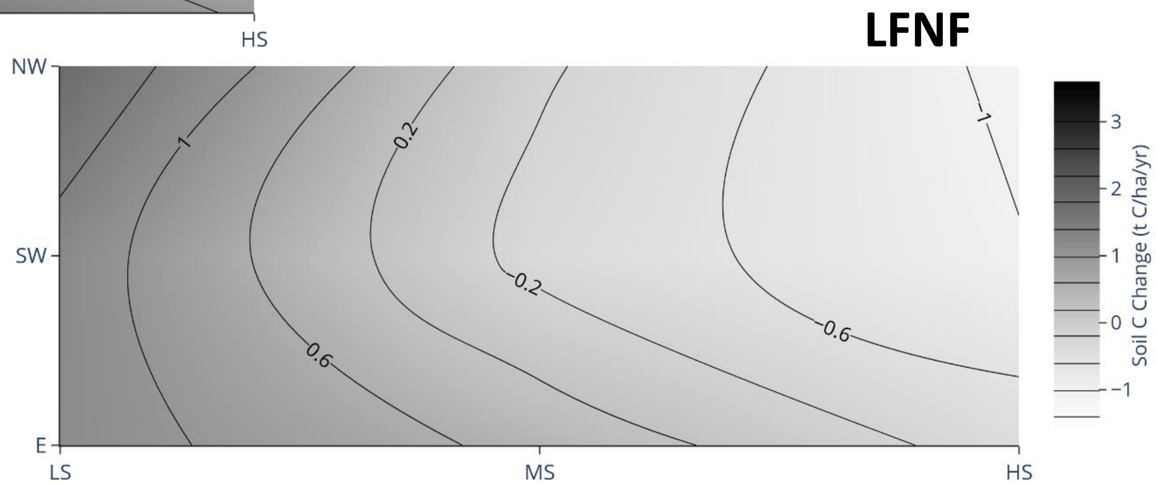
LFNF



Carbon distribution



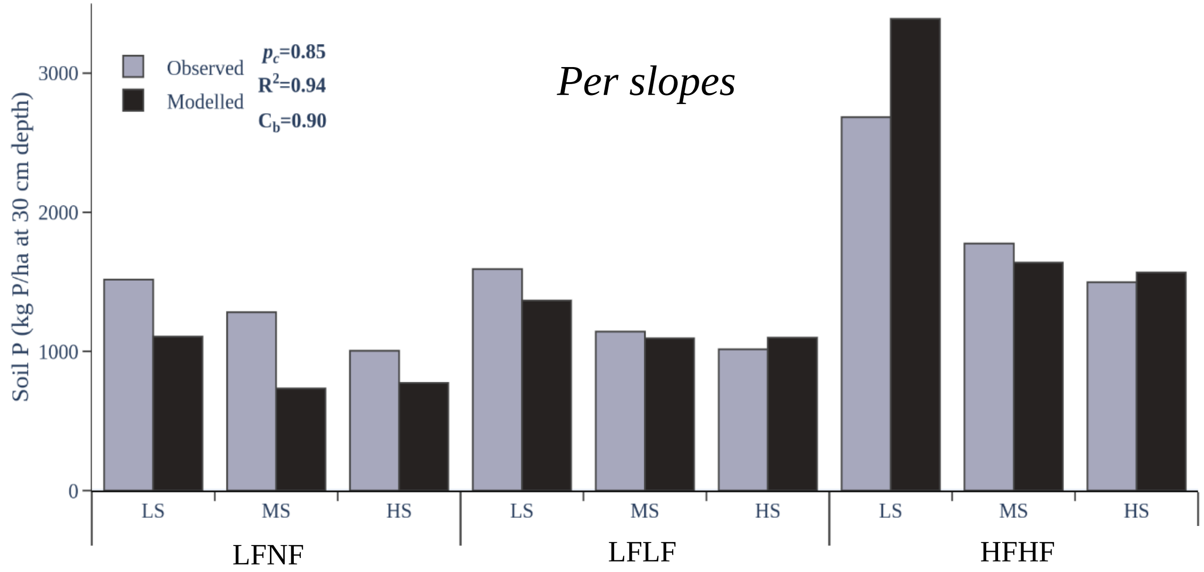




Soil P stocks – Observed vs Predicted

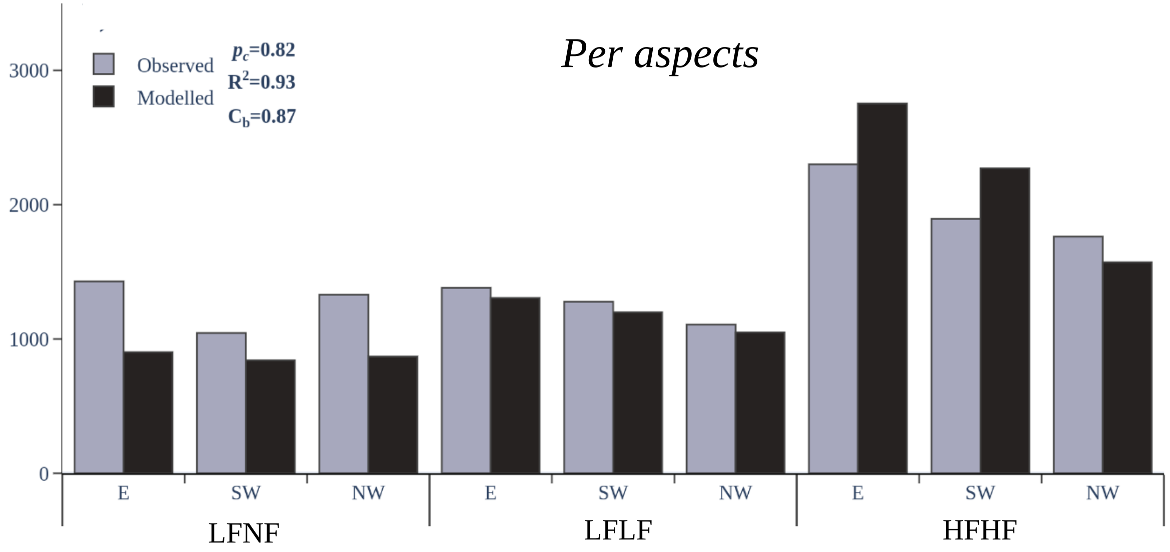
Data from 2003, 0 – 300 mm

CCC = 0.80
R^2 = 0.84
C_b = 0.93



Pearson correlation for ***slope*** = 0.94
Underestimation of soil P across all slopes in LFNF, and overestimation on LS in HFHF

Pearson correlation for ***aspect*** = 0.93
Underestimation of soil P in LFNF and LFLF, and overestimation in HFHF



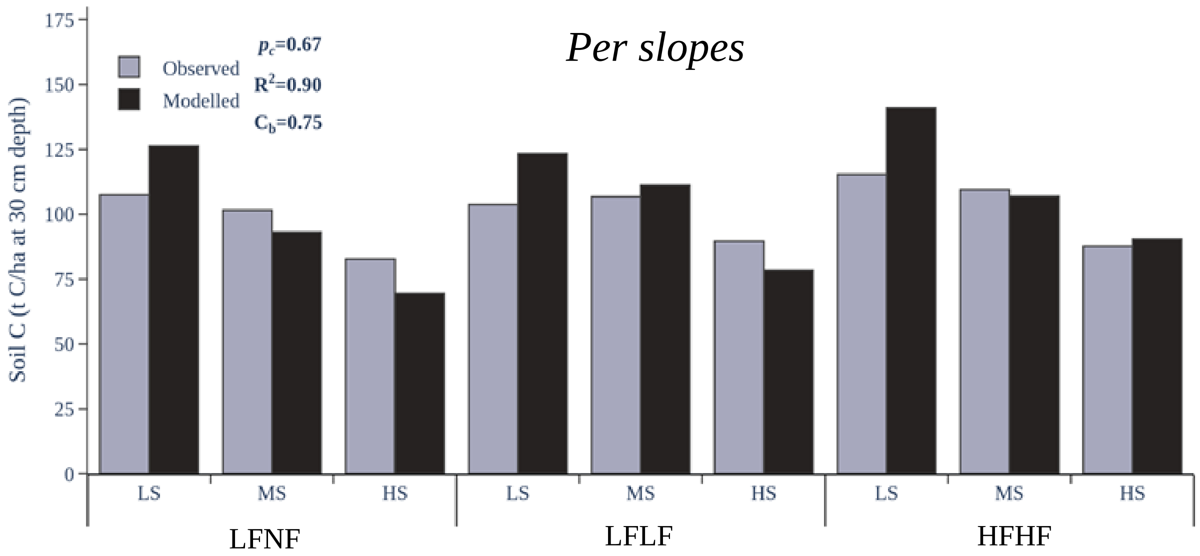
Soil C stocks – Observed vs Predicted

Data from 2003, 0 – 300 mm

CCC = 0.57

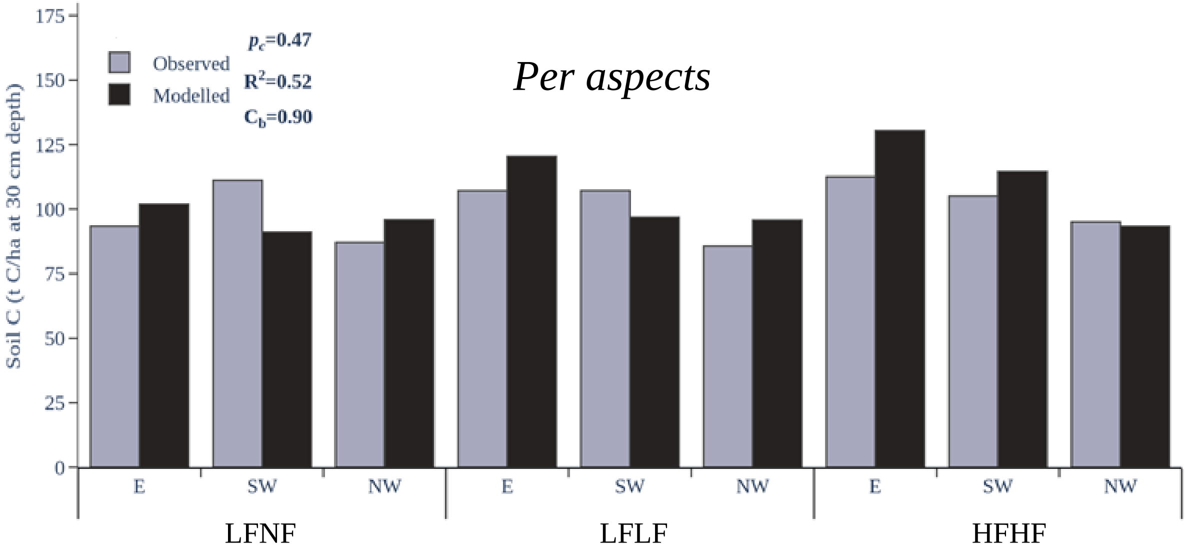
R^2 = 0.64

C_b = 0.89



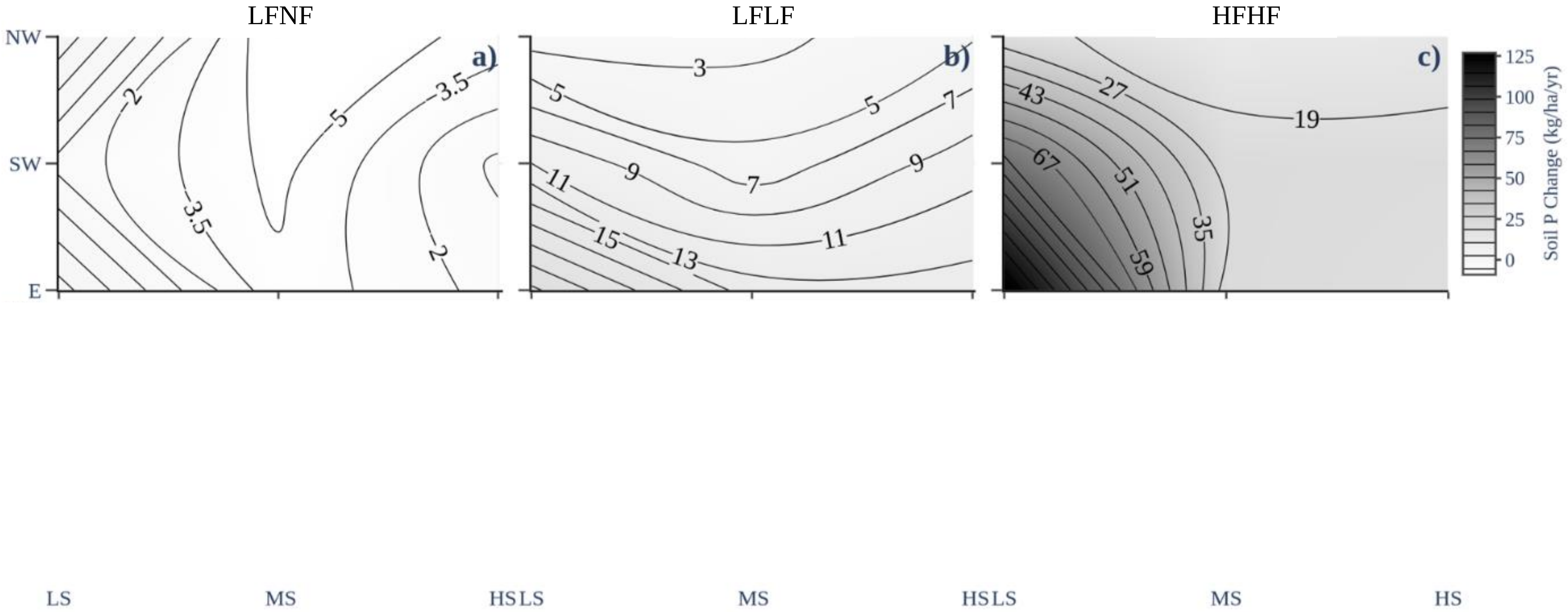
Pearson correlation for ***slope*** = 0.90
Underestimation of soil C on MS and HS in LFNF, and overestimation on LS across farmlets

Pearson correlation for ***aspect*** = 0.52
Underestimation of soil C in LFLF and LFNF, and overestimation in HFHF



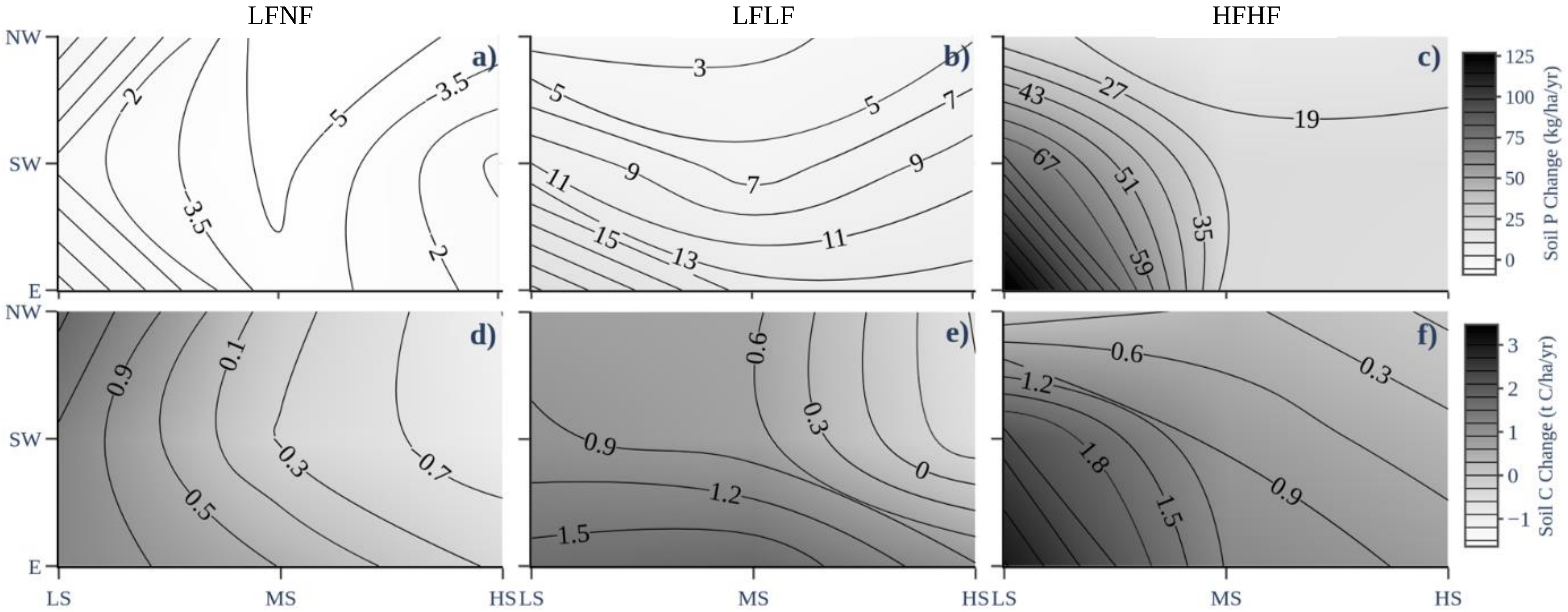
Modelled annual changes in soil P and C

Slopes and Aspects



Modelled annual changes in soil P and C

Slopes and Aspects



Summary – Soil P Model

Reasonable approximation of P dynamics and associated amounts of P distributed across the landscape

i) Amounts of pasture (and P) consumed by the grazing animal

ii) Amount of ungrazed pasture and P returned in litter

iii) Amounts of dung on the slope and aspect combinations

iv) Amount of P incorporated into the soil to a depth of 30 cm

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āta mātai, mātai whetū

Summary – Assumptions of the C model

a) 20% of C from pasture intake ends in soil (i.e., 80% OMd)

b) Pasture utilisation based on grazing behaviour (70% utilisation)

c) 30% of HMA to soils as litter

d) Soil and plant C respiration rates (Saggar et al. 1997; Saggar et al. 1999)

The model predicted C accumulation vs. measured values of soil C stocks in the 3 farmlets (minimal change over the last 40 years) (Lambert et al. 2000; Mackay et al. 2018)

Take-home messages

- Slope and Aspect are valuable in spatially modelling nutrient distribution in hill country grazed by livestock
- Understanding spatial patterns of soil C across the farmlets is a key element in the design of any soil C-stock monitoring regime
- Future changes in C inventories should highlight the spatial and temporal effects of topography and animal behaviour on soil C

Acknowledgements

All the science, technical and farm staff and service staff involved with the AgResearch Hill Country Research Station, Ballantrae since its establishment in 1972

Funding from the Sustainable Land Management and Climate Change fund of the Ministry for Primary Industries and the AgResearch Strategic Science Investment Fund

Thank you!

Manaaki Whenua
Landcare Research

A balanced sampling method to monitor soil organic carbon stocks

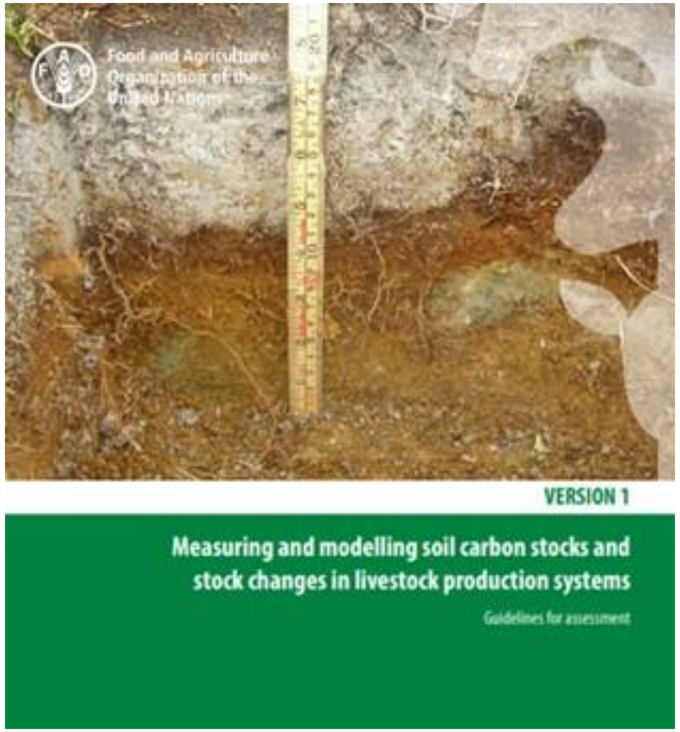
Carolyn Hedley, Stephen McNeill, Pierre Roudier, Matteo Poggio, Paul Mudge
Scott Fraser, Nadia Laubscher, Gerard Grealish, Andre Eger
Manaaki Whenua Landcare Research

Louis Schipper
University of Waikato

SLMACC Project

Why do we need to monitor soil carbon stocks?

- Need improved, reliable, cost-efficient methods to assess, monitor and verify SOC changes
  - *FAO Soil C Forum, 2017*
  - *FAO Guidelines 2018*
- Soil resilience and climate change mitigation
- National monitoring needs
- Harmonised international efforts
  - e.g. FAO, VERRA Verified Carbon Standard

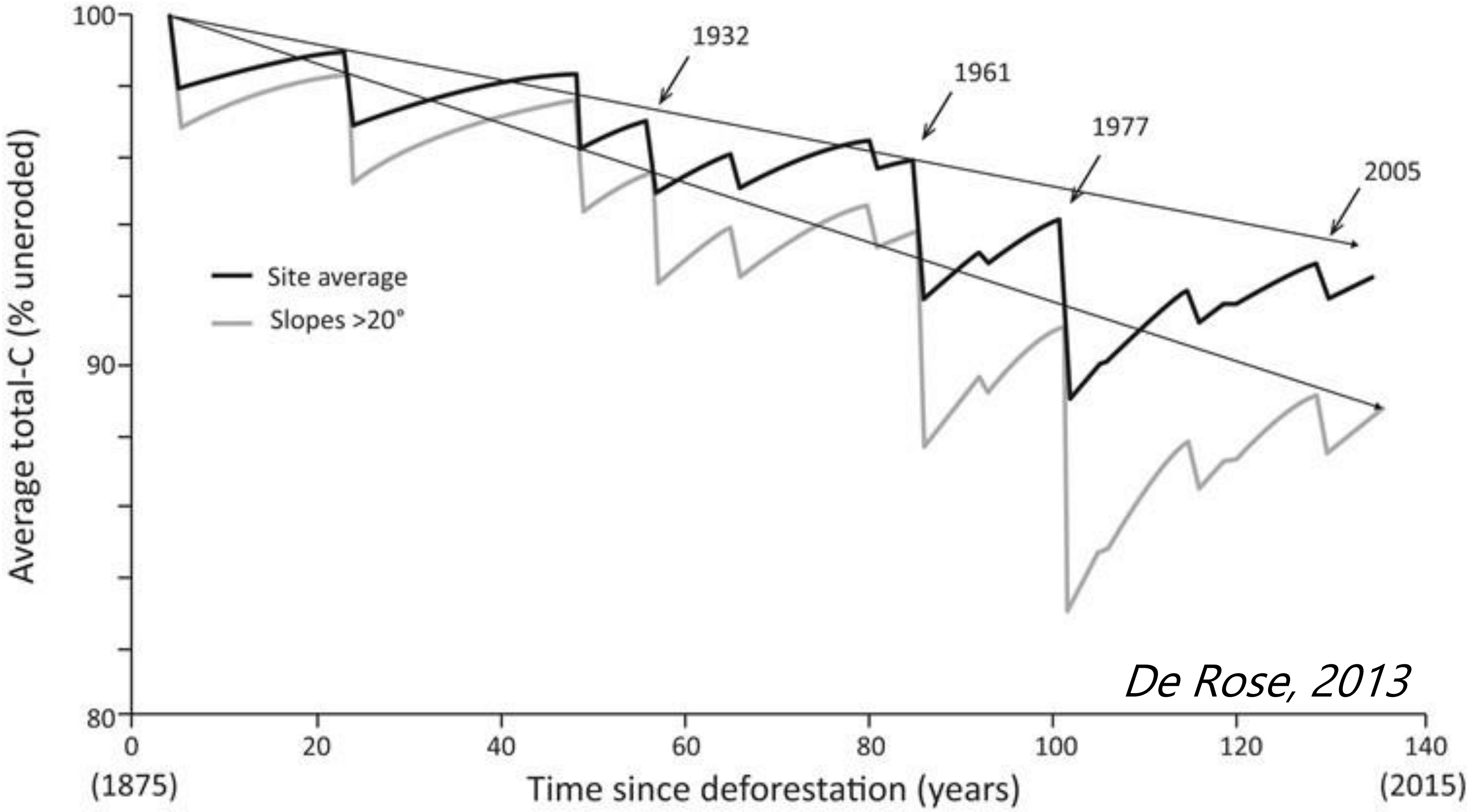


Why balanced sampling?

…because it proportionally samples the range of soil carbon stocks

If spatial variability is not considered then it is likely to be the major source of uncertainty in stock estimations

Soil carbon stock changes



…rates of change vary through time so long term monitoring is needed

Develop a SOCS monitoring system for managed grasslands in hill country

- **Managed grasslands** >50% NZ; 38% in hill country
- **Hill country**: 37% of NZ; slopes >15°, elevation < 1000m ASL
- **LCDB Managed Grassland Classes**: high producing, low producing, grassland with woody biomass, tall tussock, depleted

Project Method

- Spatially delineate ‘managed grasslands in hill country’
- Estimate quantity and frequency of sampling to meet specified rate of change
- Derive ‘balanced’ sampling positions
- Field campaign = baseline SOCS
- Report baseline SOCS and recommendations for on-going monitoring

Spatially delineate the target area

Resources:

Landcare Research LCDB v4.1 – Land Cover Database version 4.1, Mainland New Zealand. Available at: [*https://lris.scinfo.org.nz/layer/423-lcdb-v41-land-cover-database-version-41-mainland-new-zealand/*](https://lris.scinfo.org.nz/layer/423-lcdb-v41-land-cover-database-version-41-mainland-new-zealand/)

Landcare Research Hill Country datalayer for New Zealand.

Intersect hill country layer with LCDB 2012 grassland classes.

Managed grasslands in hill country

What level of change are we interested in?

- Calculate the number of sites required to detect a change of **2**, **5** & **10** t ha^{-1} between samplings for the specified target areas.
- For the **5** t ha^{-1} scenario:
  - a change of 1 t ha^{-1} y^{-1} detectable after 5 years
  - a change of 0.5 ha^{-1} y^{-1} detectable after 10 years

- For context, a change of 5 t ha^{-1} on the 10.7 million hectares of managed grassland would be a total change of **53** million tonnes of carbon, equivalent to**196** million tonnes of CO_2, with a total value of **$4.9 billion** (at $25 per tonne of CO_2).

- NZ's annual agricultural GHG emissions are equivalent to **38.7** million tonnes of CO_2

- On average, SOCS in New Zealand's managed grasslands are approximately 100 Mg ha^{-1} in the top 30 cm, so a change of 5 Mg ha^{-1} would be a change of about 5%.

McNeill, S, Mudge P, Hedley C, Roudier P, Schipper L 2019 Statistical Design of a National Soil Carbon Monitoring Programme for New Zealand. MWLR Contract Report LC3459, 59p.

Estimate how many samples required to meet specified aims?

- Estimate expected mean and variance (downscale national model, existing SOC data or pilot study)
- Use mean and variance in a power analysis to estimate no. sites to determine baseline and specified change for given level of statistical certainty

Estimated sample size to detect ΔSOCS for target area over 5 years

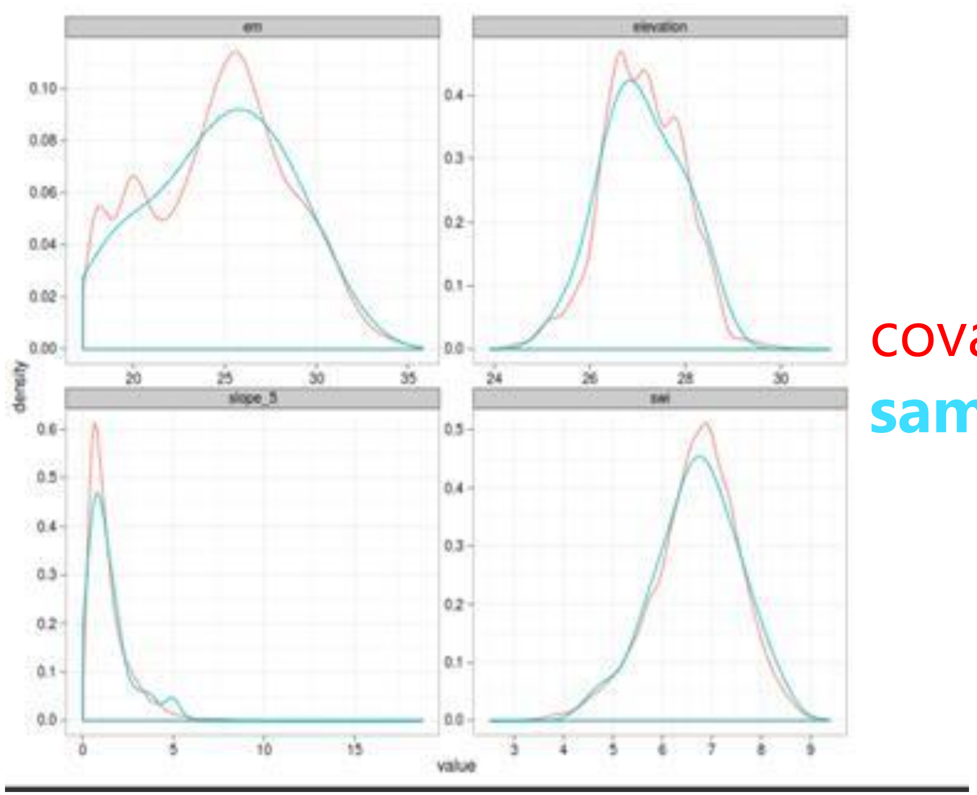
	longitudinal variance		
ΔSOCS	SD 1 t C/ha/y	SD 2 t C/ha/y	SD 5 t C/ha/y
0.5 t C/ha/y	63	251	1570
1.0 t C/ha/y	16	62	392
2.0 t C/ha/y	4	16	98

Hedley C, McNeill S, Roudier P, Mudge P, Eger A, Schipper L. 2019 A Balanced Sampling Method for Monitoring SOC in Managed Grasslands of NZ’s Hill Country. MWLR Contract Report LC3558, 86p.

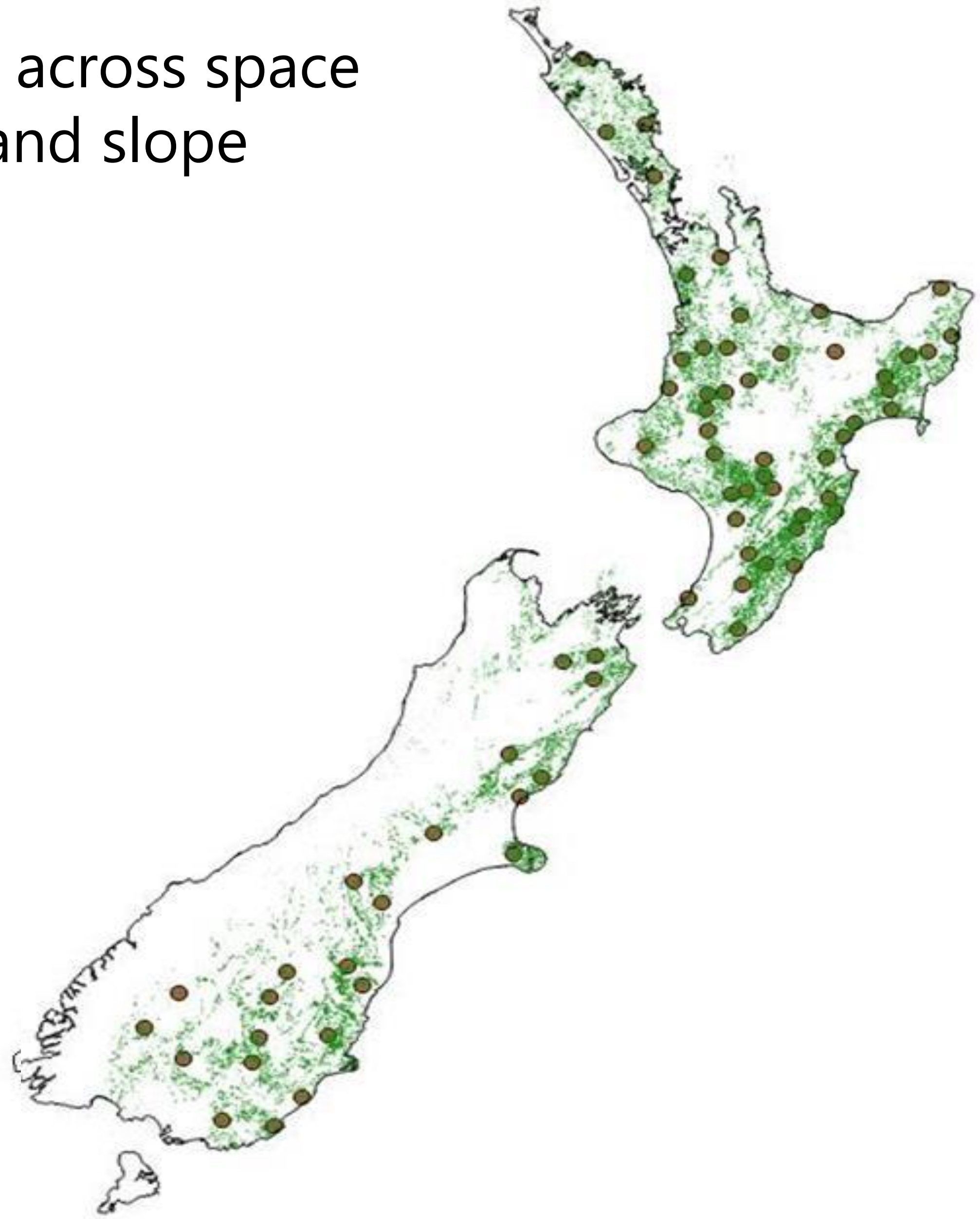
Balanced sampling method

- R code is used to derive 60 positions spread across space and environmental covariates: C stock, rain and slope *(nominal 1,000 realisations)*

- ‘balanced covariate sampling’

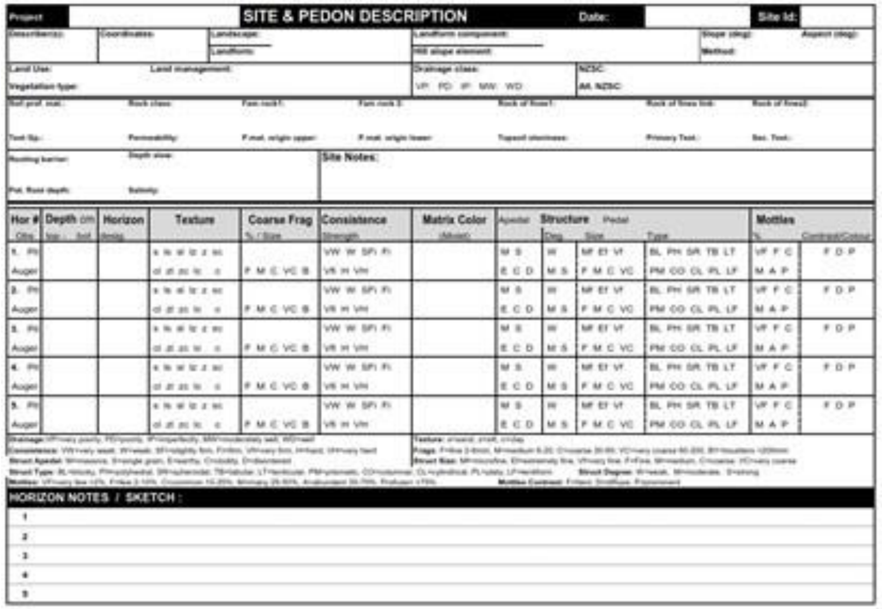


covariates
samples



Field campaign

- Mark out 20 x 20 m plot
- Record site and soil details
- Non-stony soils: soil coring (50)
- Stony soils: pit excavation (10)


Project | SITE & PEDON DESCRIPTION | Date: | Site Id:

Site Notes:

Hor #	Depth cm	Horizon	Texture	Coarse Frag	Consistence	Matrix Color	Structure	Mottles

HORIZON NOTES / SKETCH :

1
2
3
4
5

Field campaign

Northland to Southland

MAR:
570 – 2576 mm

Slope:
3° - 45°

Aspect:
10° - 355°

Soil orders:
Raw, Recent, Gley, Pumice, Allophanic, Brown, Pallic, Semi-arid, Ultic, Melanic

Soil organic carbon stocks - results

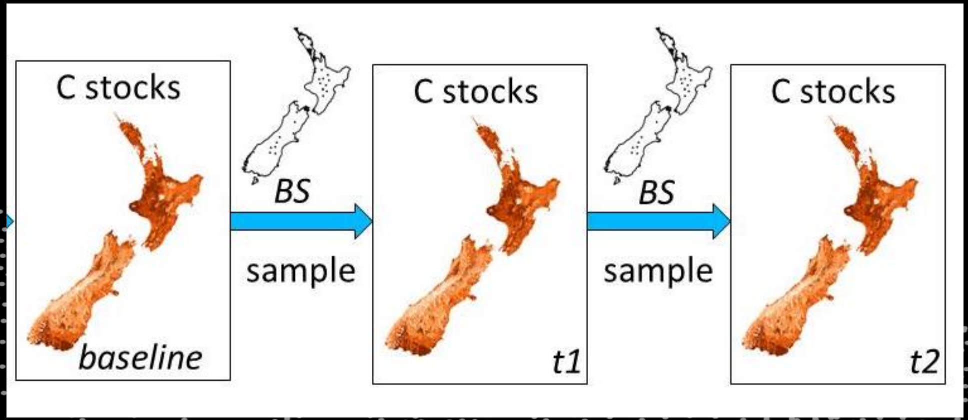
	SOCS_30	C:N
Mean	90.29	12.17
st.dev	*3.51*	*0.24*
Range	27 - 150	9.76 – 16.87

Allophanic, 150tC/ha to 0.3m 1952 mm

Semi-arid, 27tC/ha to 0.3m, 628 mm

Summary

- A balanced sampling method devised that unbiasedly selects sampling positions from a target area to measure and monitor SOCS.
- Time 1 provides a baseline SOCS estimate within defined confidence intervals
- Repeated samplings (Time 1, Time 2, Time 3 …) monitor change through time.



Impact of irrigation on soil carbon & nitrogen stocks

Paul Mudge, Jack Pronger, Alesha Roulston, Scott Fraser, Andre Eger, Veronica Penny, Thomas Caspari, Danny Thornburrow, Jamie Millar and Louis Schipper

Manaaki Whenua
Landcare Research

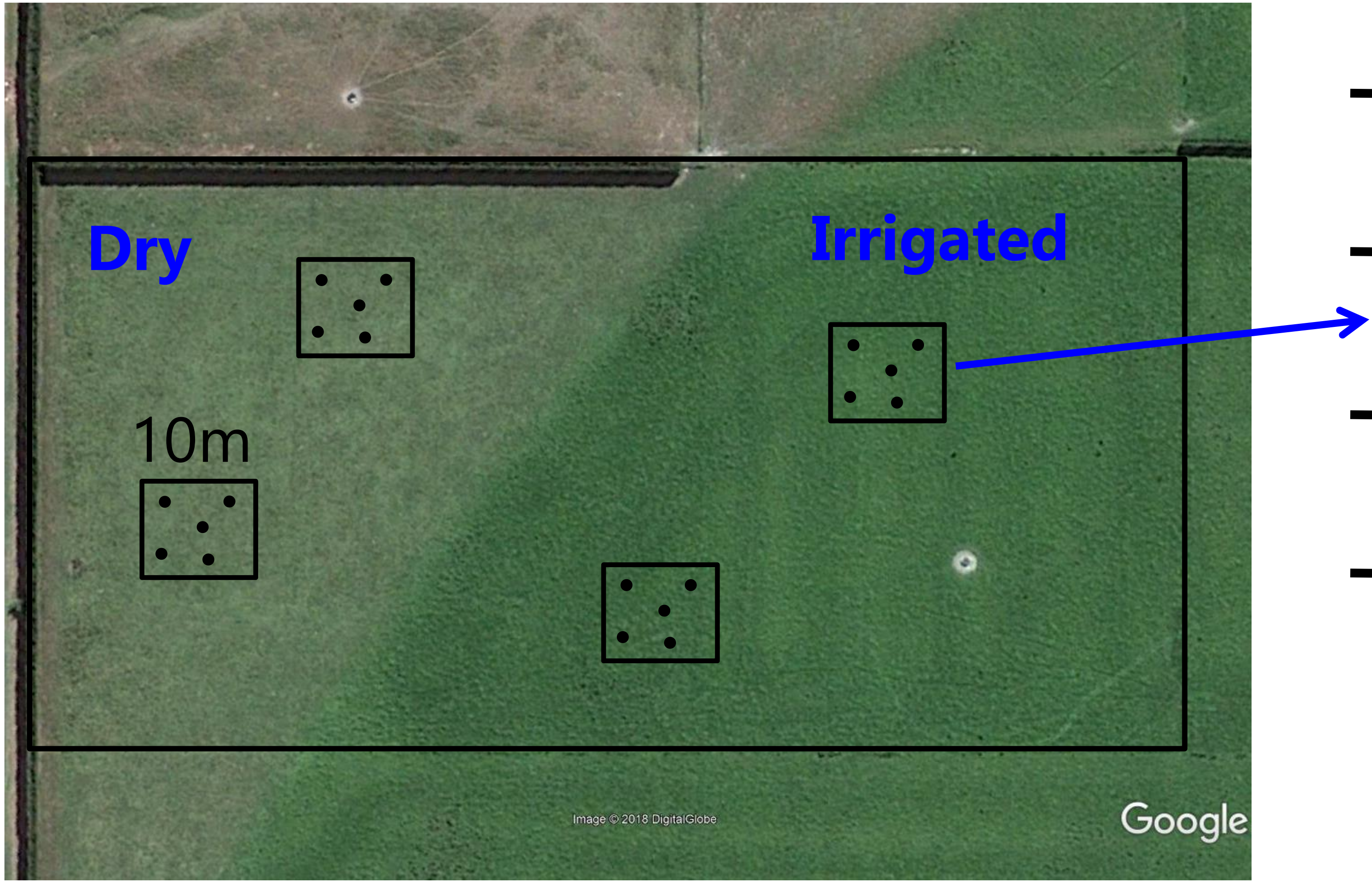
THE UNIVERSITY OF
WAIKATO
Te Whare Wānanga o Waikato

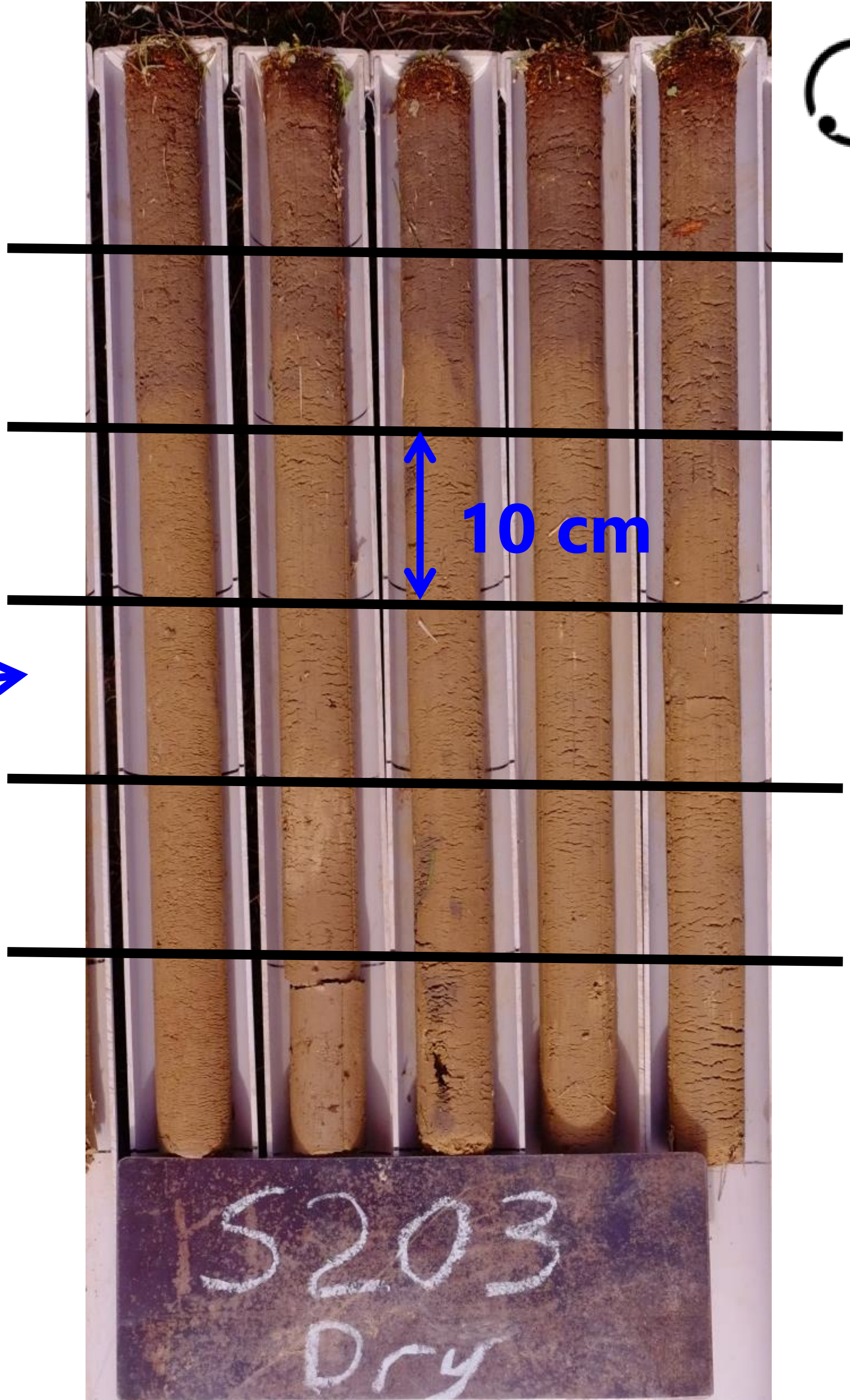
Context – why we initially started this research

- Irrigation globally and in New Zealand is increasing
  - NZ ~3 fold increase in irrigated land area since 1950s
  - 33% of global food from irrigated crops
- Little known about impact of irrigation on soil C & N stocks
- At a 50 year old trial in NZ, soil C stocks were **32** t ha^{-1} lower in well irrigated c.f. non-irrigated treatment (Condron et al., 2013)
  - **One** site – and out-dated boarder-dyke method

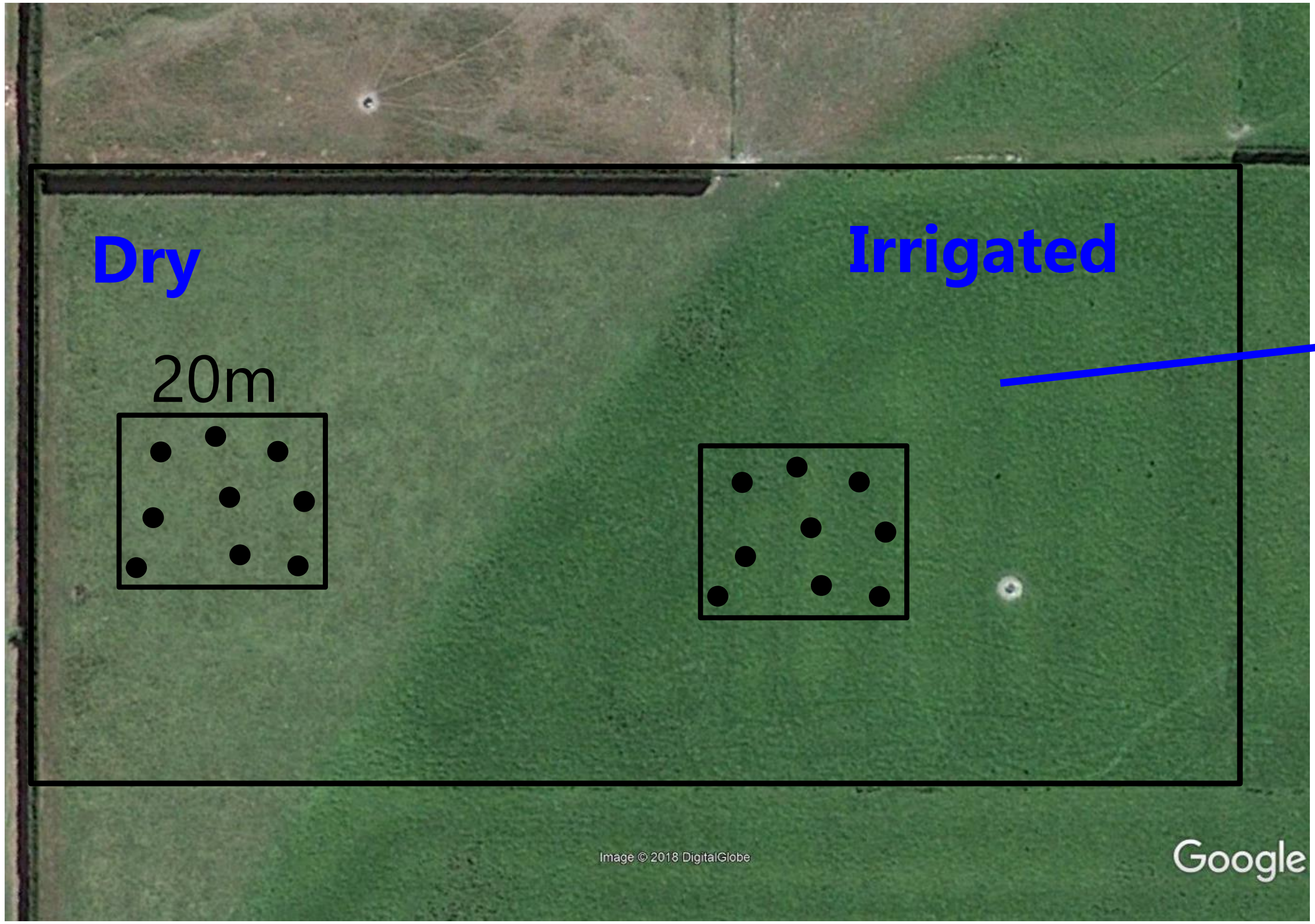
Was the negative effect of irrigation on soil C & N stocks more widespread?

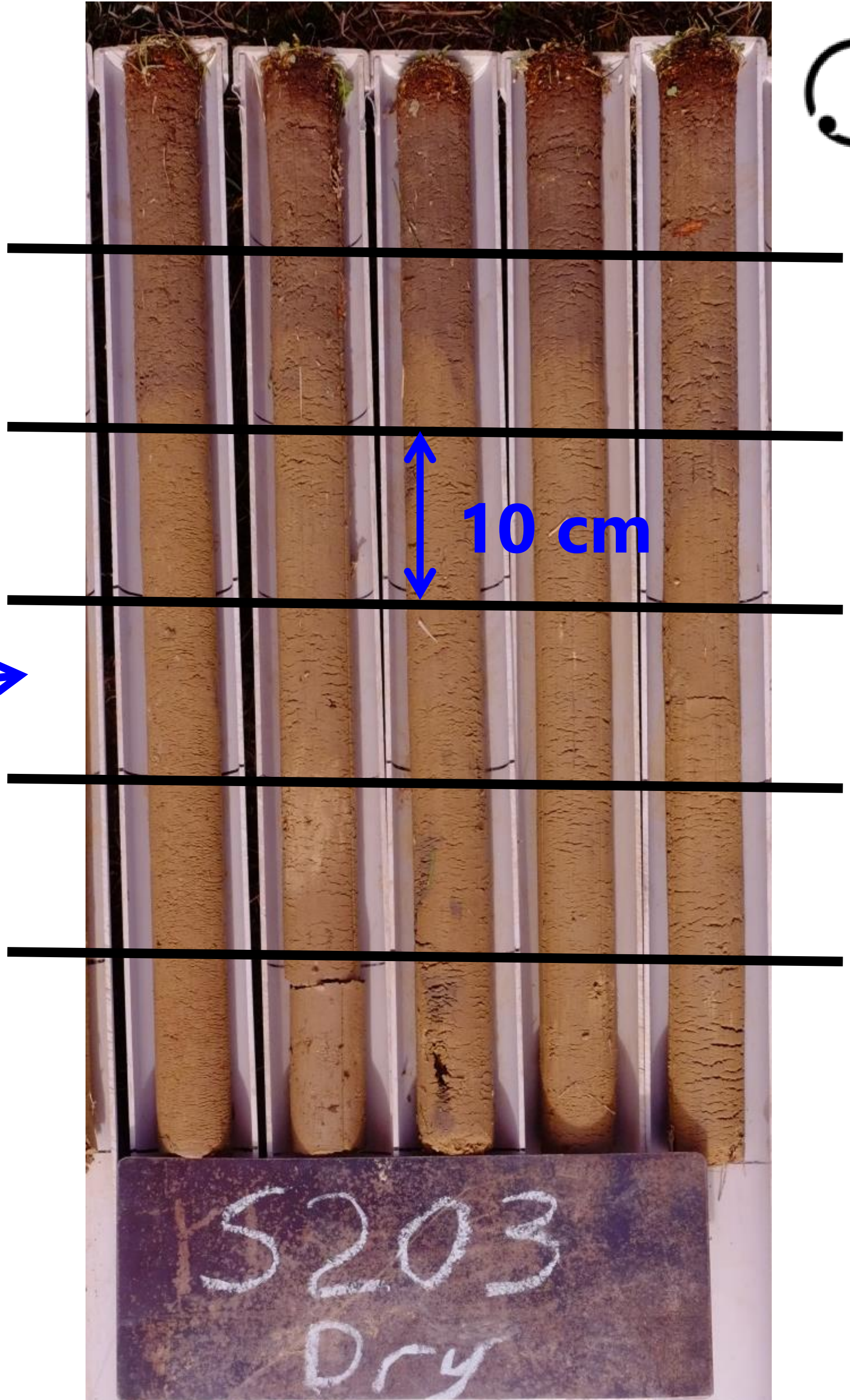
Study design & sampling





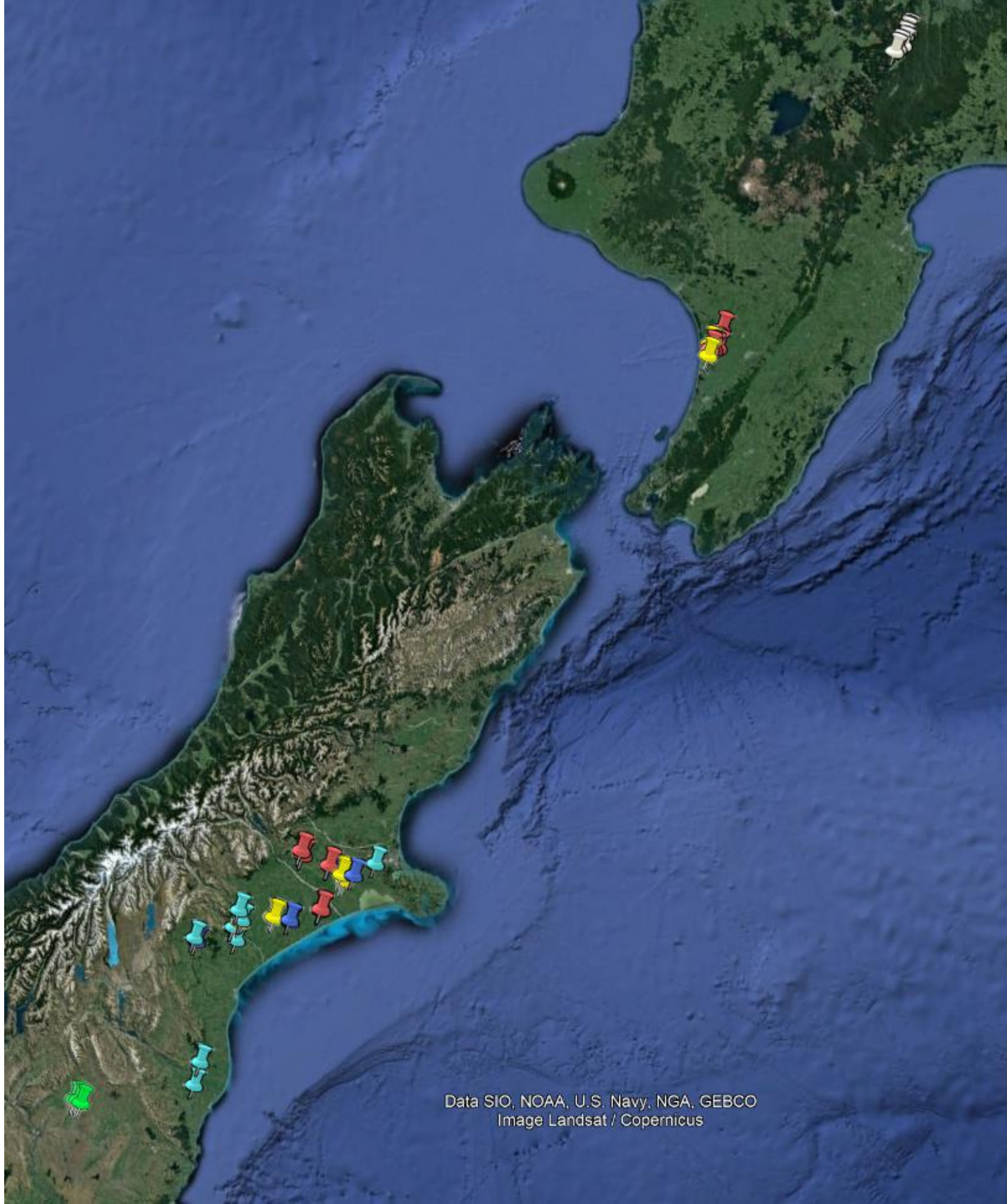
Study design & sampling





Study 1

- 34 <u>paired</u> irrigated and un-irrigated pastures in 4 regions
- Mostly centre pivot irrigation
  - Ave duration was 19 y (3-90 y)
- A range of soils
  - Pumice in BOP
  - Recent sands in the Manawatu
  - Brown/Pallic/Recent/Gley Canterbury
  - Semi-arid in Otago



Study 1 – results

Significantly less soil C and N under irrigated pastures

Depth	Number of paired sites	Cumulative differences Irrig-Dry (t ha^{-1})	
cm		Carbon	Nitrogen
0-30	30	-7.0***	-0.6**
0-60	15	-9.6*	-0.8

No clear effect of **Region**, **Soil Order** or **Irrigation duration**

Mudge PL, Kelliher FM, Knight TL, O'Connell D, Fraser S, Schipper LA 2017. **Irrigating grazed pasture decreases soil carbon and nitrogen stocks**. Global Change Biology 23: 945-954.

Study 2

Check results from study 1 AND determine whether the impact of irrigation differed depending on:

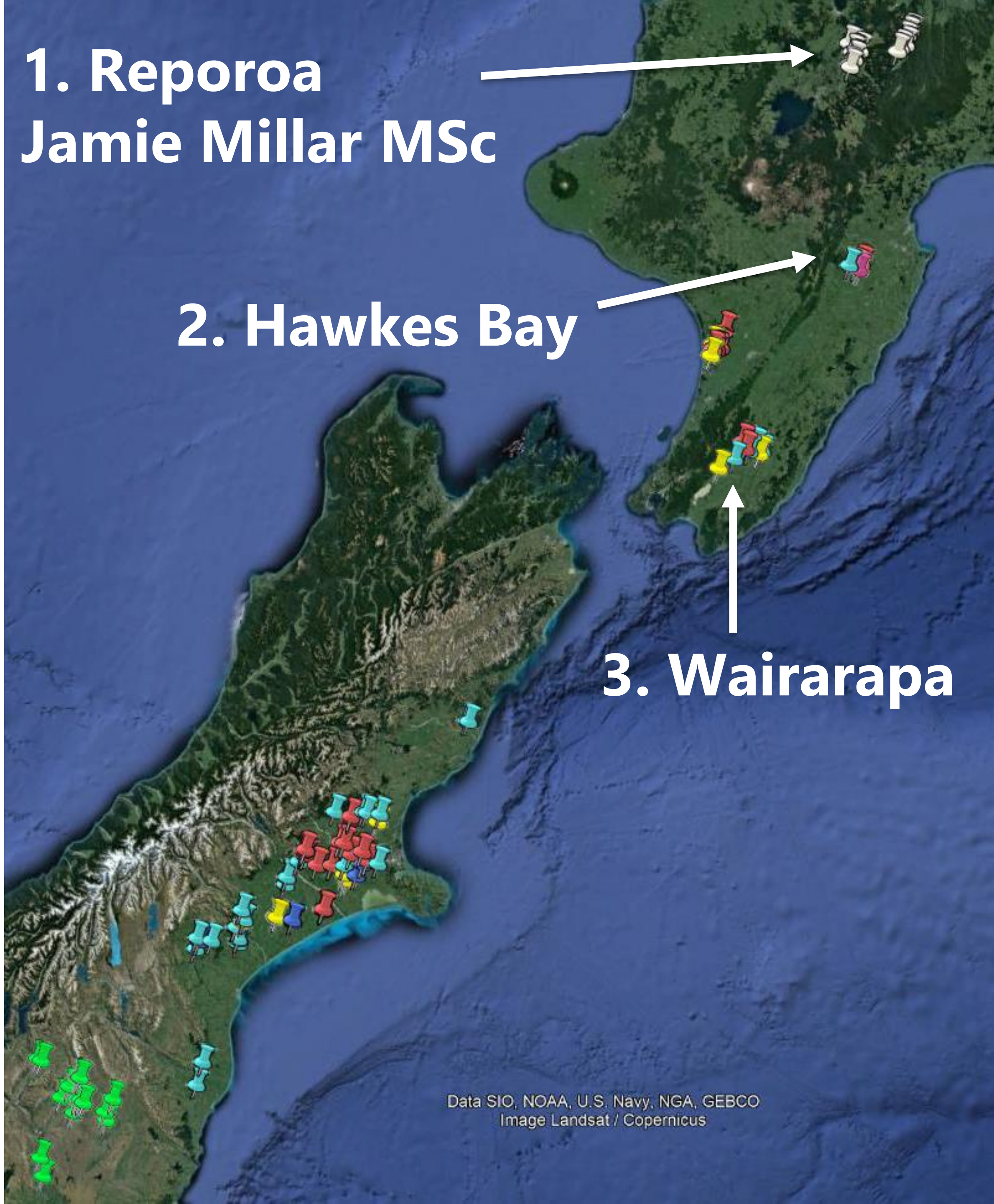
1. Region
2. Soil Order
3. Irrigation duration

Power analysis showed 15 paired sites required to detect differences of ~5 t ha^{-1} for any ‘grouping’

Study 2

- Extension of the first study
- Three more regions
- Additional sampling in:
  - Canterbury
    - aligned with SFF project
  - Otago
    - aligned with Soil Health MBIE

Total of 118 paired sites sampled to 0.3 m depth



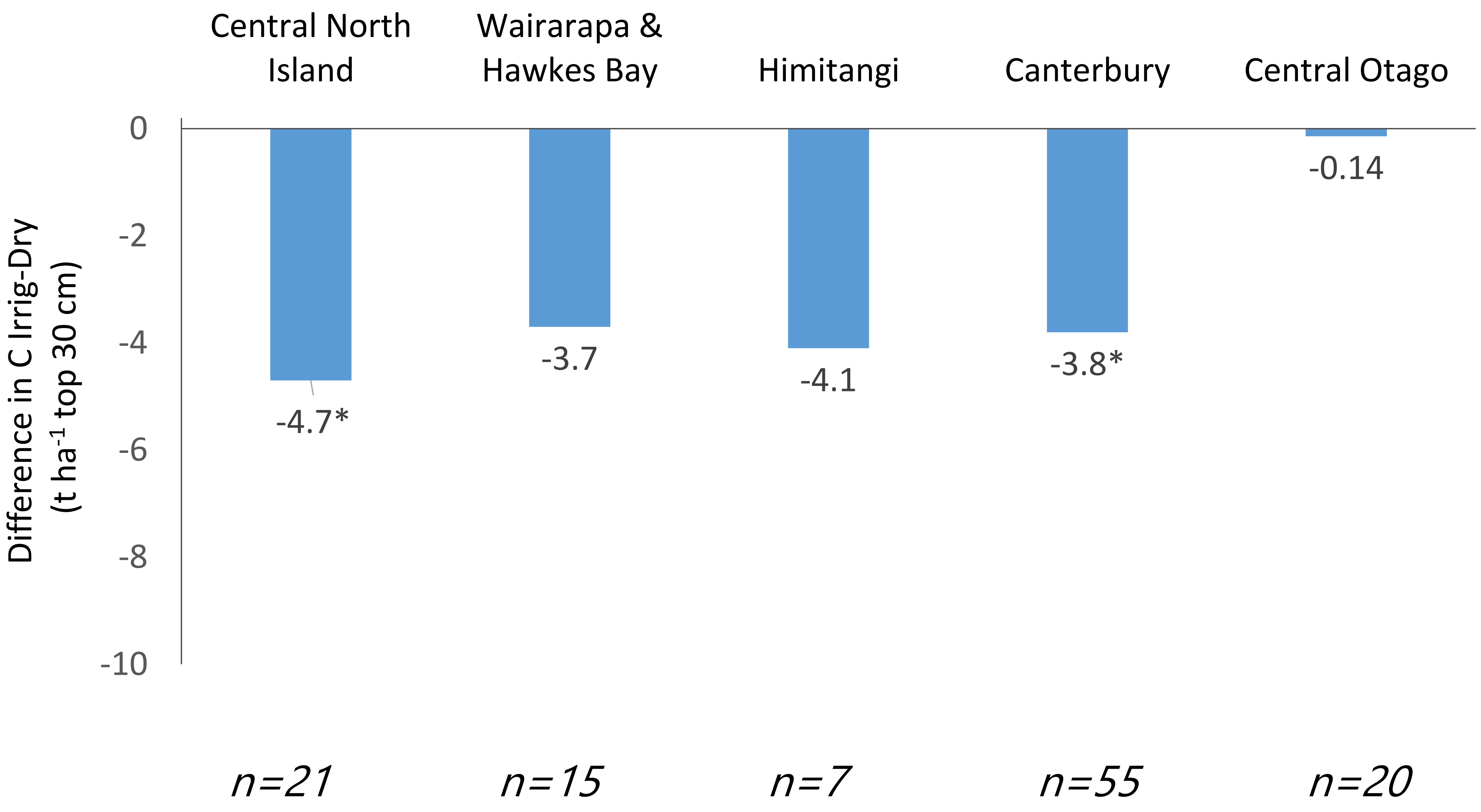
Overall results (not finalized)

Significantly less soil C under irrigated pastures.
No difference in N stocks

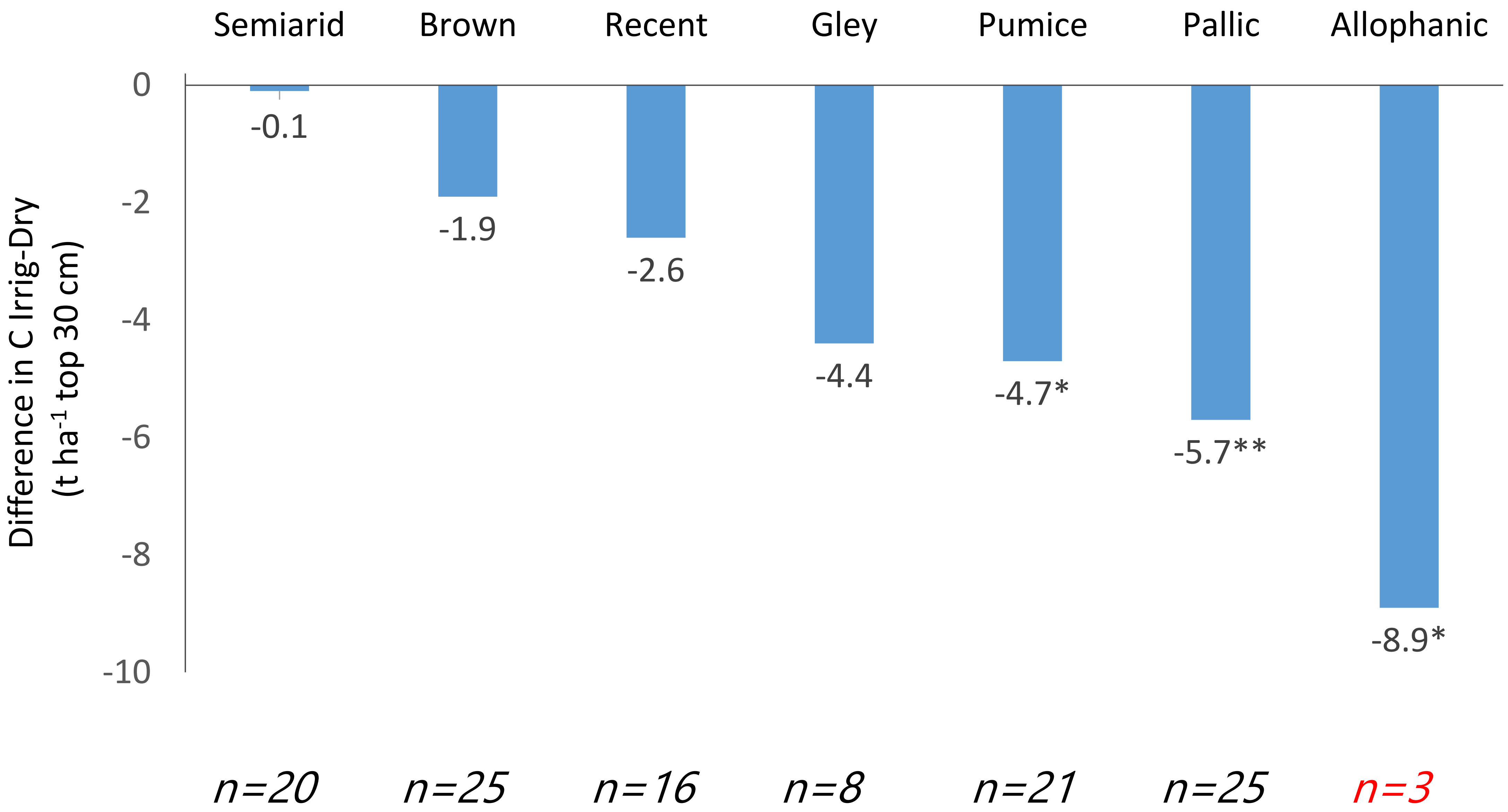
Depth	**Number of paired sites**	**Cumulative differences Irrig-Dry (t ha^{-1})**	
cm		Carbon	Nitrogen
0-30	118	-3.3***	-0.13
0-60	74	-3.6**	-0.09

C:N ratio significantly lower under irrigation (10.4 vs. 10.2 in top 30 cm)

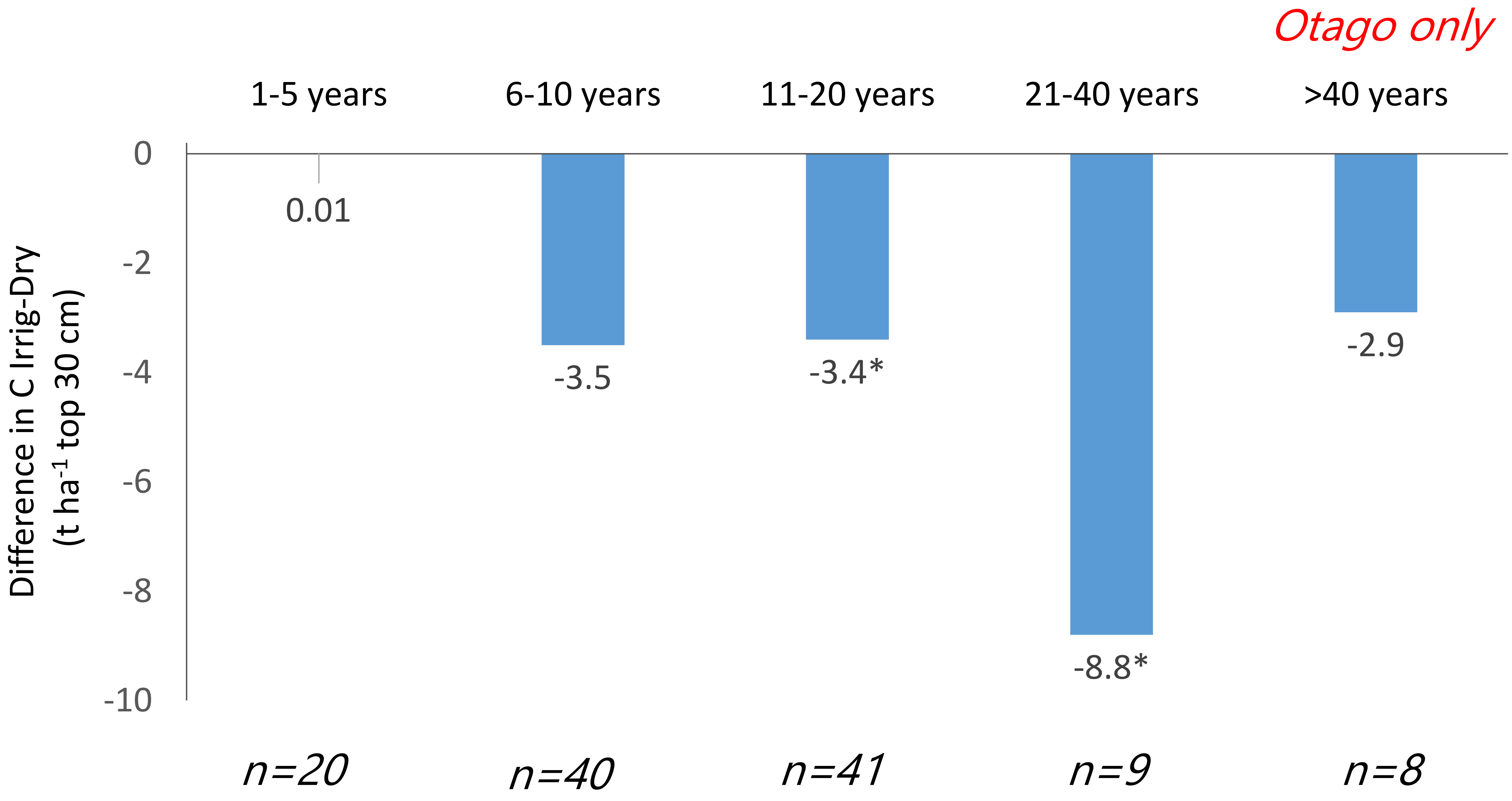
Regional effects



Soil Order effects



Irrigation duration effects



Summary

- Expanded dataset still showed soil C significantly <u>lower</u> under irrigated than adjacent non-irrigated pastures.
  - Average difference of 3.3 t C ha^{-1} in top 30 cm (~half study 1)
- Soil N stocks not significantly different
- Soil C:N ratio consistently lower under irrigation

- Size of difference relatively consistent across regions (3.7-4.7 t C ha^{-1}),
  - Except Otago (0.14 t C ha^{-1}).
- Impact of irrigation greatest in Pallic and Pumice Soils (5.7 & 4.7 t C ha^{-1}),
  - Except Allophanic 8.8 t C ha^{-1} but *n*=3
- Impact of irrigation on soil C tended to increase with duration
  - No significant effect for first 5-10 years
  - Greatest effect (8.8 t C ha-1) between 20 & 40 years but *n*=9

Acknowledgements

- **Funding**:
  - Primarily NZ Ministry for Primary Industries (**SLMACC**, SFF)
  - MBIE Endeavour (Soil Health)
- **Balin Robertson** for Canterbury site stone content data
- **Farmers** who allowed us to sample and provided site info