Modelling carbon and water exchange from a grazed pasture in New Zealand. Parameterising and testing a model and its use for scenario analysis.

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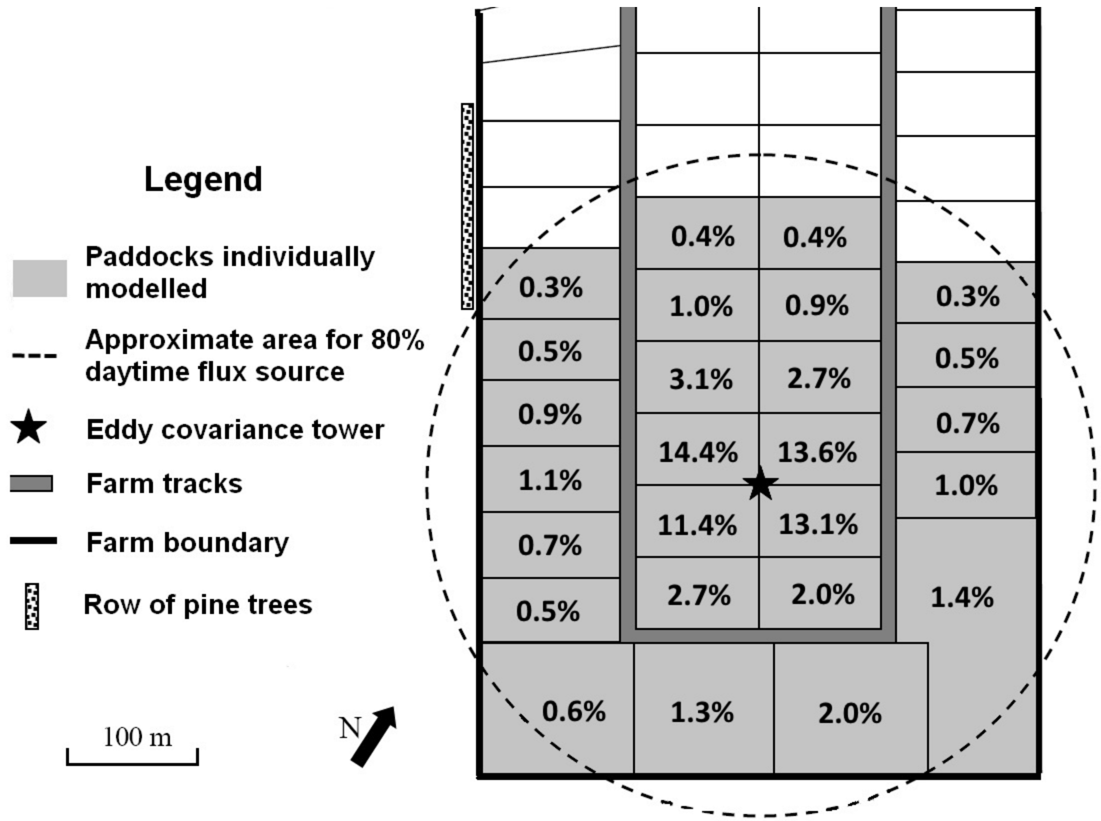
The work

- Simulations with detailed mechanistic model CenW vers 4.1 (daily version)
- Tested against eddy covariance data
- Intensively grazed dairy farm / Waikato region
- Tested scenarios of the effects of management & environmental changes on soil carbon stocks and milk production

Model-data comparison

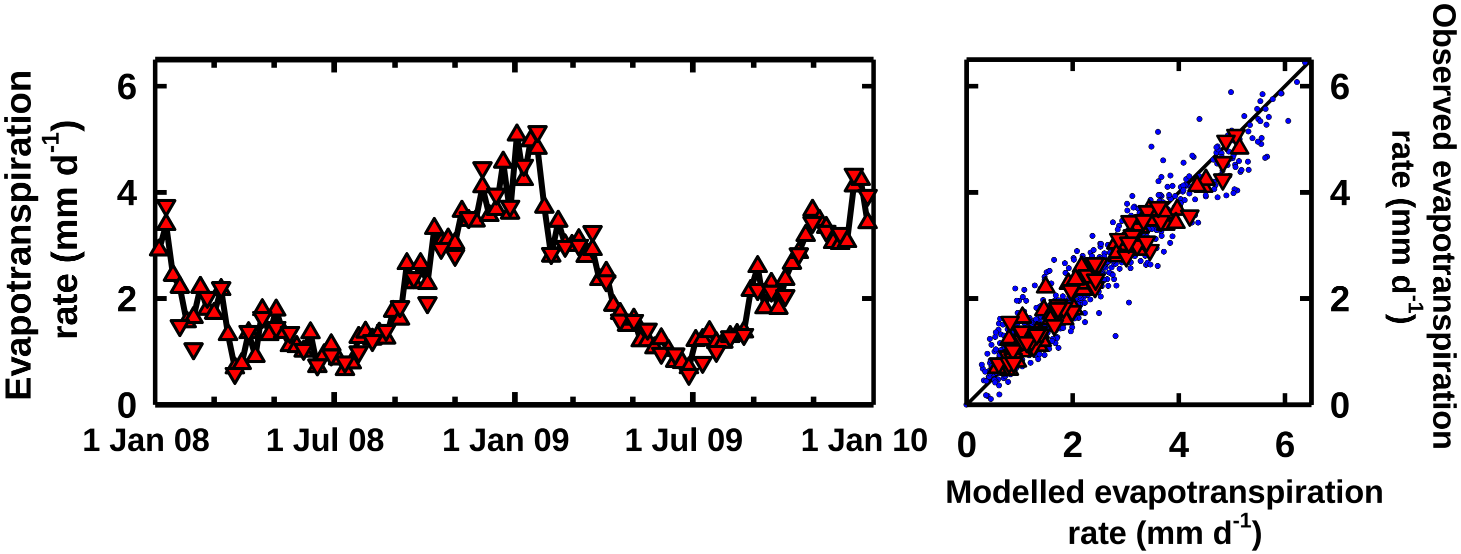
Diverse grazing routines by paddock



Key points:
The experimental site consists of small individual mini-paddocks (usually 0.5 ha) that were individually managed. The modelling separately modelled gas exchange from 26 individual paddocks and used a foot-print model to combine those to generate expected fluxes at the tower that were compared with eddy-flux observations.
The numbers here give the percentages of fluxes over two years originating from respective paddocks.

Model-data comparison

Evapotranspiration rates



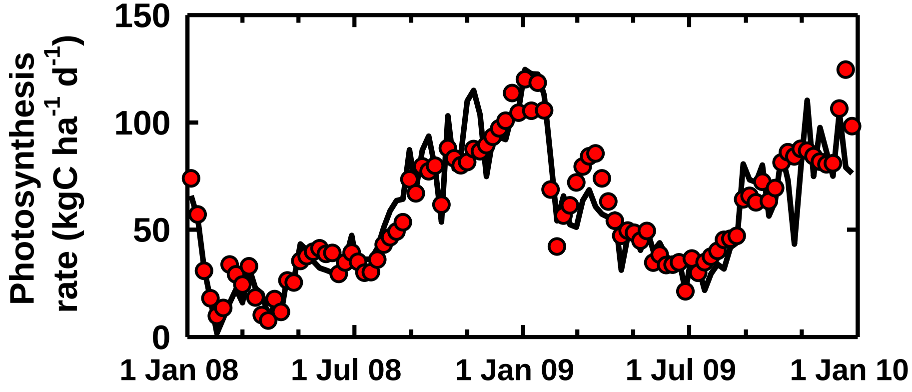
$EF_d = 0.91$ $EF_w = 0.96$

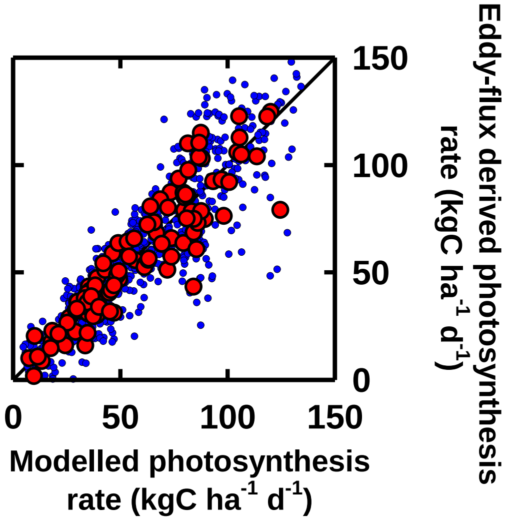
Key points:

Data were divided into weekly intervals, with one set of weekly data used for model parameterisation (up-arrows) and the other set for model validation (down-arrows). Small symbols show daily data and larger symbols weekly averages. Evapotranspiration rates were very well modelled, with Nash-Sutcliffe model efficiencies (EF) showing that 91% of daily (Ef_d) and 96% of weekly variation (Ef_w) was explained by the model.

Model-data comparison

Photosynthesis rates (Gross Primary Production)





$EF_d = 0.79$ $EF_w = 0.84$

Key points:

Symbols similar to the previous slide except that photosynthesis observations were not used for model parameterisation, so requiring no separation between parameterisation and validation data sets. Agreement was also very good, with 79% of daily and 84% of weekly variation explained by the model.

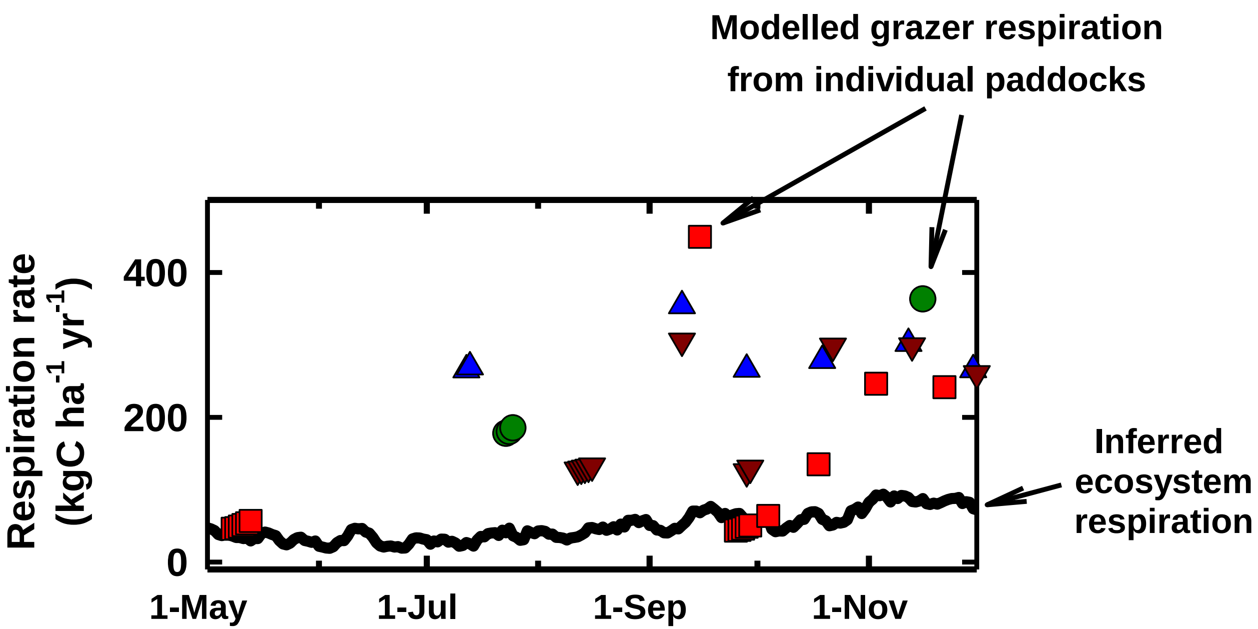
Model-data comparison

Grazer respiration – lots of cows

Key points:
Modelling grazer respiration was a challenge. During grazing events, animal respiration completely dominated overall site fluxes, especially at night time.

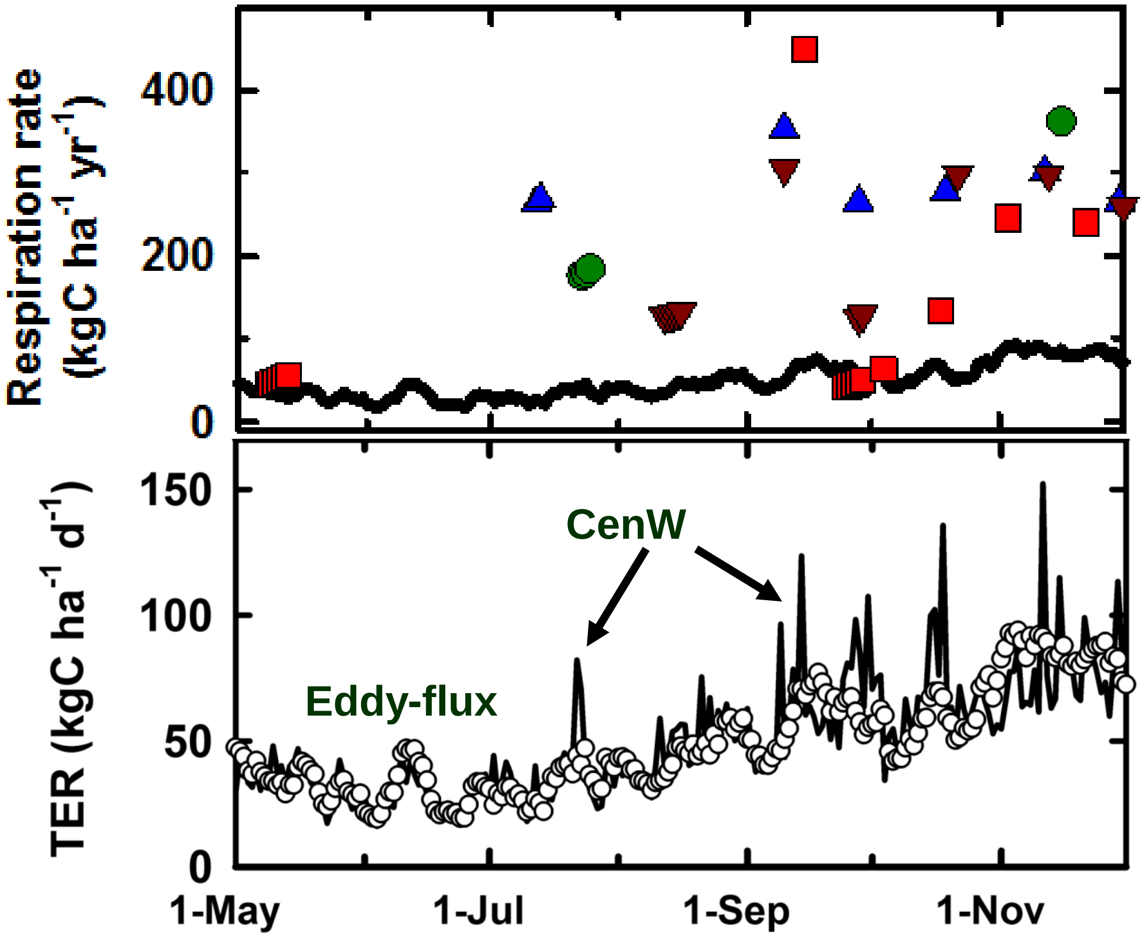
Model-data comparison

Respiration rates – dealing with grazer respiration



Key points:
The irregular line shows model ecosystem respiration rates over a 7-month period. The symbols show modelled grazer respiration from the four inner paddocks around the tower, with different symbols representing different paddocks. Highest rates were found when a large herd of cattle grazed a whole paddock in a single day. Rates could exceed background respiration rates 10-fold.

Respiration rates – dealing with grazer respiration

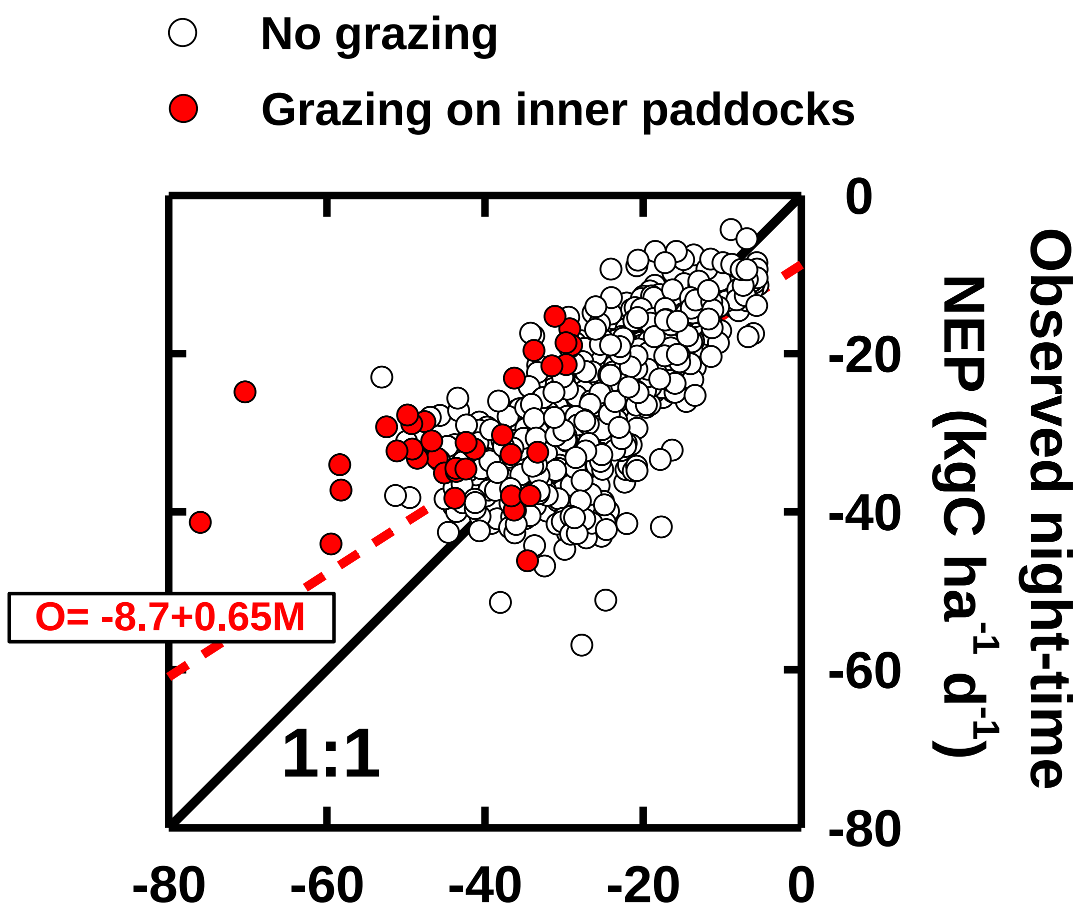


Key points:

The top graph is the same as on the previous slide. The bottom graph gives estimates of system respiration derived either from eddy-flux data (symbols) or modelled by CenW (solid line). Eddy-flux data and CenW agree over periods without grazing, but eddy-flux data did not show the expected peaks associated with grazing events. Modelled respiration peaks mostly coincided with times of grazing events, but not always as it also depended on wind speed and direction. The lack of agreement between the estimates was likely due to eddy-flux derived respiration estimates missing the peaks during grazing events, especially during times when daily flux estimates heavily relied on gap-filling.

Model-data comparison

Dealing with paddock-to-paddock variability



Key points:
Open symbols show data when there was no grazing on the inner paddocks. There was good agreement between eddy-flux data and CenW simulations, especially no systematic bias, well approximated by the 1:1 line. However, on days, when the inner paddocks were grazed, CenW simulated significant C losses that were no observed (the red symbols). A line fitted to the combined data (red dashed line) had a much lower slope (0.65) than the 1:1 line. It is suggested that the observations did not pick up the large negative fluxes that were occurring, and fitting the model to all data would bias parameter fitting. Data obtained on days with grazing on the inner paddocks were therefore excluded.

Model-data comparison

Dealing with paddock-to-paddock variability

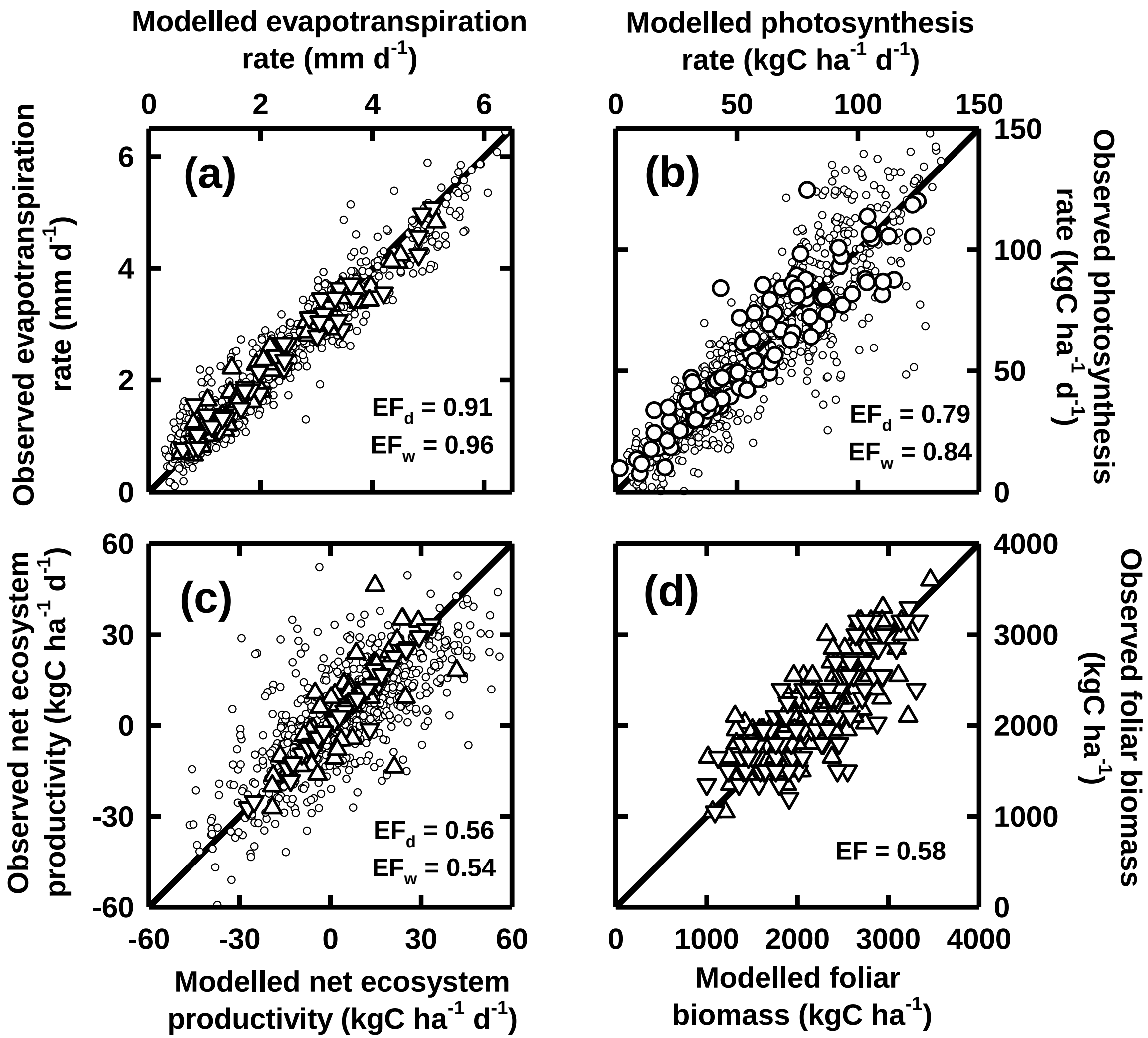
Final model efficiencies

	Averaged	Generic	Weighted
24-hr NEP	0.39	0.44	0.52
Daytime NEP	0.60	0.63	0.69
Night-time NEP	0.37	0.48	0.50

Key points:

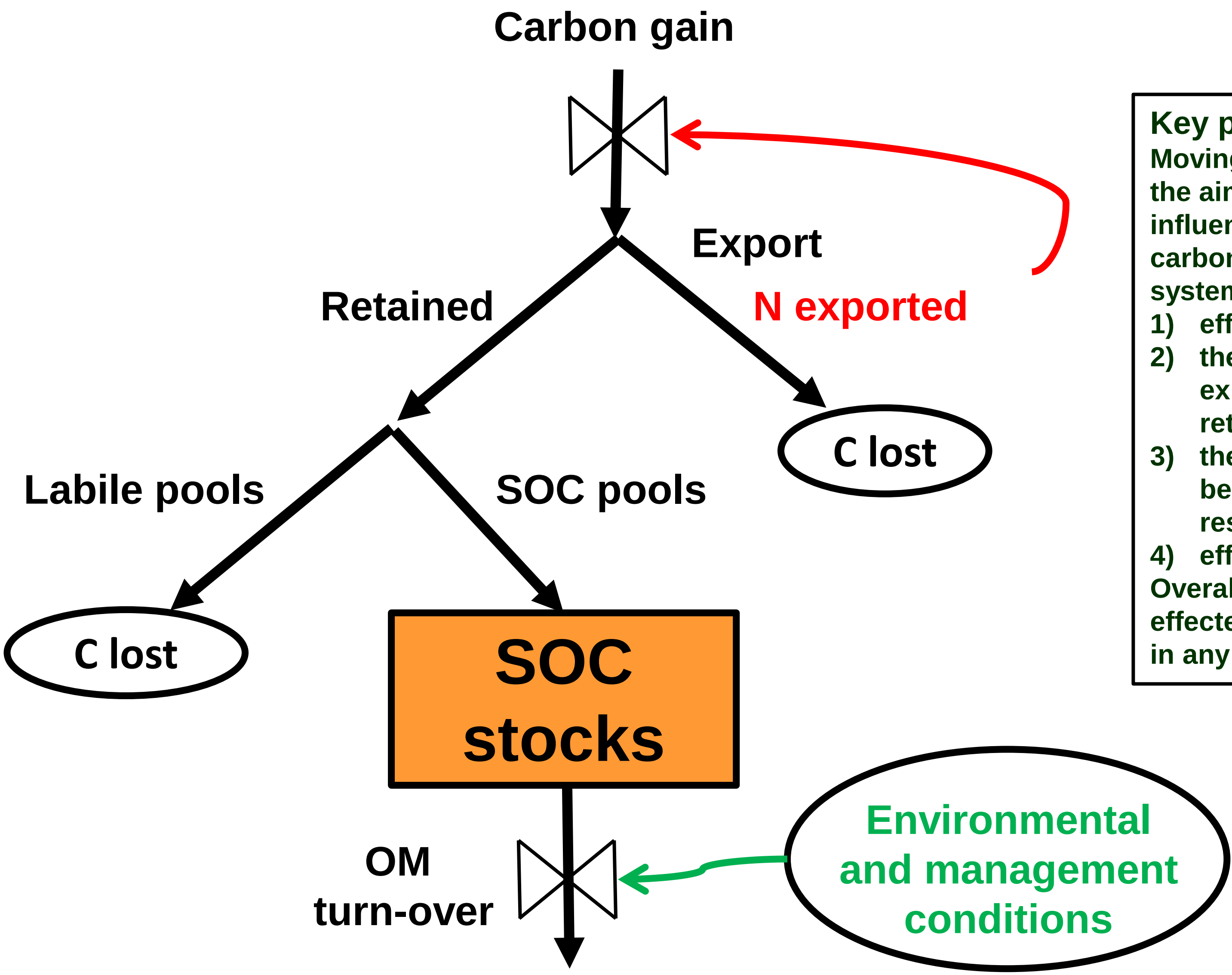
We separately modelled the gas exchange of 26 paddocks within the tower footprint. Options were to take the average of all paddocks, or weight them based on a source distribution from a footprint model to generate integrated fluxes that could be compared with tower observations. A third alternative was to ignore the discrete timing of specific grazing events and emulate grazing by a small daily grazing rate on all paddocks. Compared to the measurements, taking the average of all paddocks was worst – even worse than the generic model. It meant that ignoring the discrete timing of grazing events was better than incorrectly assigning it to the wrong paddocks. But best results were obtained when the heterogeneity of grazing events was combined with the best estimates of paddock origin of fluxes that reached the tower.

Model-data comparison



Key points:

Overall data comparisons between observations and CenW simulations were good. Agreement was excellent for water fluxes and very good for photosynthesis. There were more problems with modelling carbon losses, mainly related to grazer respiration, but more 50% of NEP could still be explained. Changes in foliar biomass were also adequately modelled.



Key points:
Moving on to scenario analysis – the aim was understanding the influence of various factors on soil carbon stocks. In a grazing systems, that needs to include:

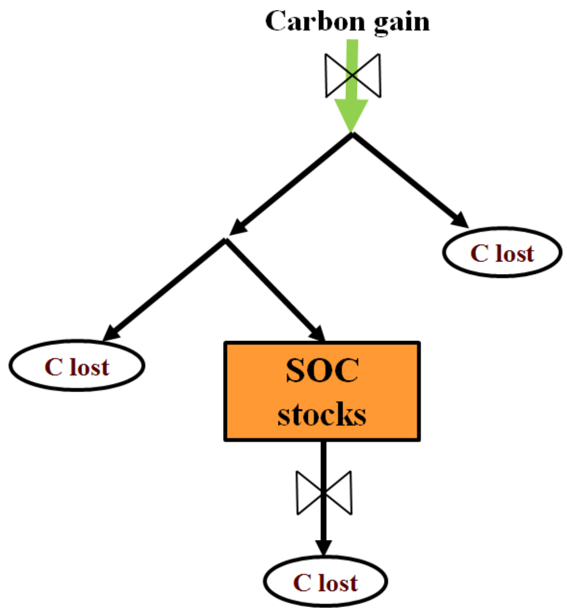
1) effects on NPP;
2) the partition between C exported and C and nutrients retained on site;
3) the partition of retained C between labile and more resistant pools;
4) effects on OM turn-over.

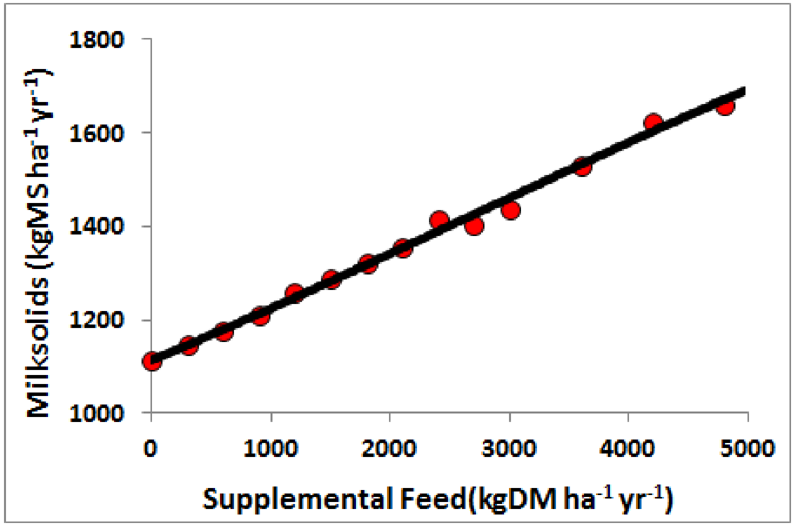
Overall effects on SOC can be effected by the combined changes in any or all of these factors.

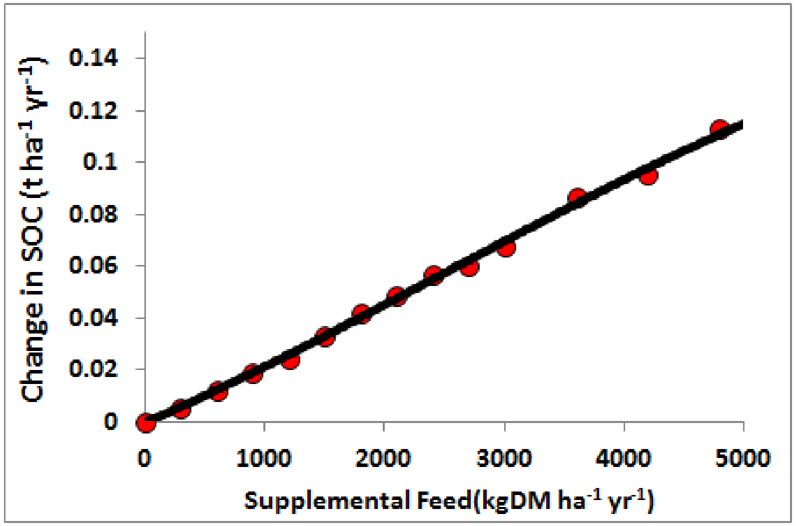
The scenarios

- The system was run for 50 years under standard conditions
- Changed a specified management or environmental factor
- Ran the system for another 50 years
- Show activity data (net primary production or milk production) at the end of the 50 years
- Show average rates of soil carbon change over the 50 years

Supplemental feed



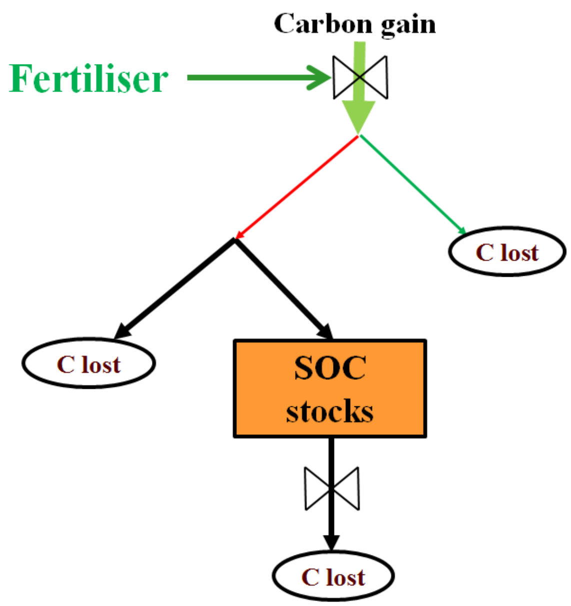


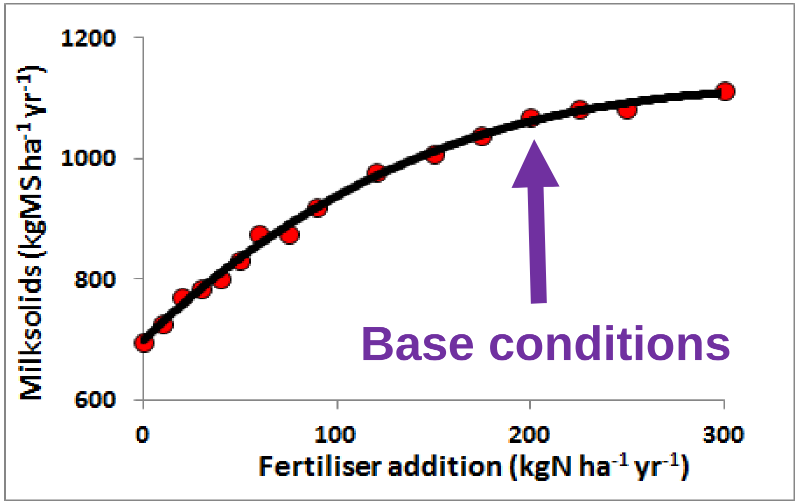


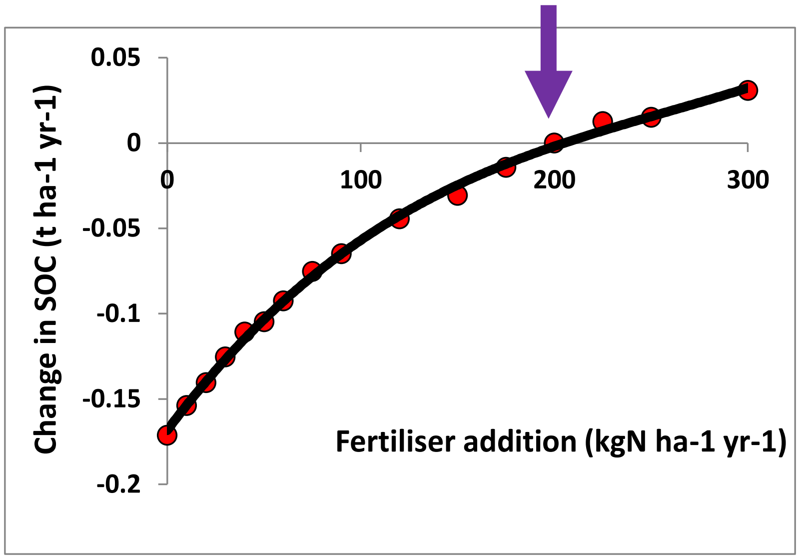
Key points:

The simplest system change was one where extra C was brought onto the site in extra feed. The model predicted a positive effect on milk production and SOC storage. Extra C storage was, however, only a small fraction of added C with more than 4 tDM addition needed to sequester an additional 0.1 tC in SOC. Most C was respired by cattle or micro-organisms to leave only a small fraction for formation of more resistant SOC.

Fertiliser addition



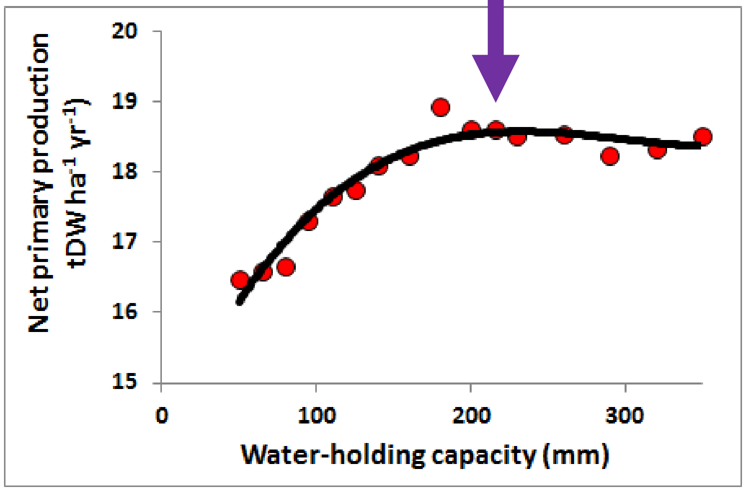


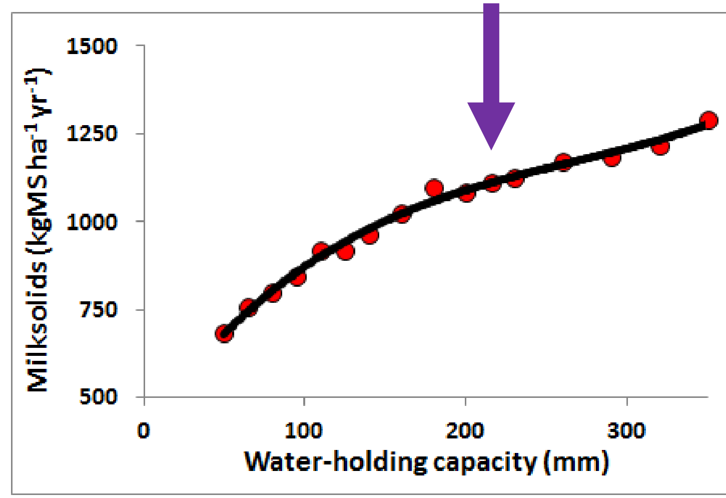


Key points:

Addition of fertiliser was also a fairly simple change, with fertiliser addition stimulating NPP thus bringing more C on-site. Its effect on SOC was positive but muted by fertiliser addition also increasing the proportion of C taken off-site so that the full benefit of increased C fixation did not flow through to SOC formation. Typical fertiliser additions in New Zealand are also so high already that there is more scope for losing C than enhancing the already high SOC.

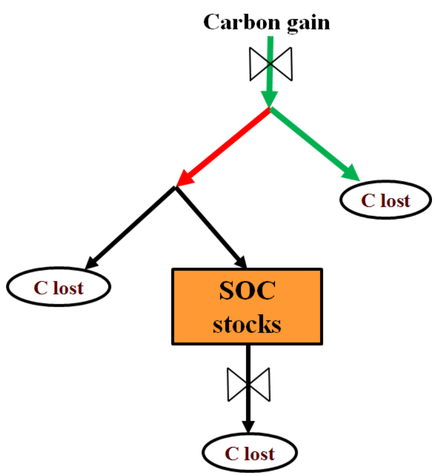
Rooting depth (soil water holding capacity)

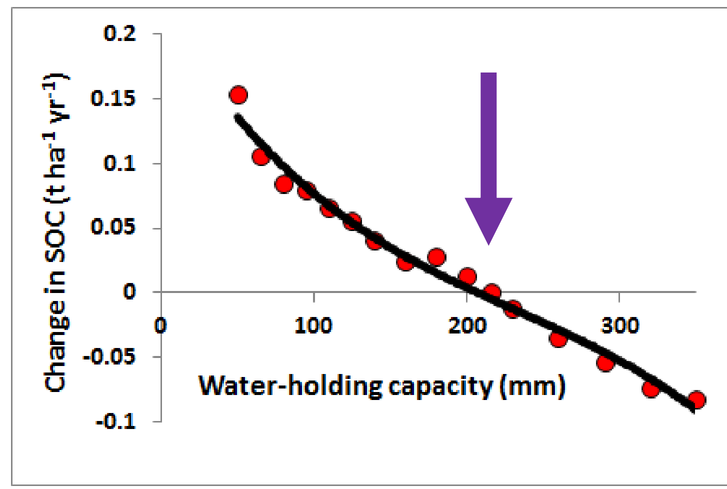




Key points:

The effect of plant rooting depth was emulated through changes in soil water holding capacity, thus assuming that greater rooting depth means a change in root architecture instead of an increase in C allocated to roots. It suggested a positive effect on milk production, but negative effect on SOC, mainly because the enhanced C uptake was preferentially exported in milk.





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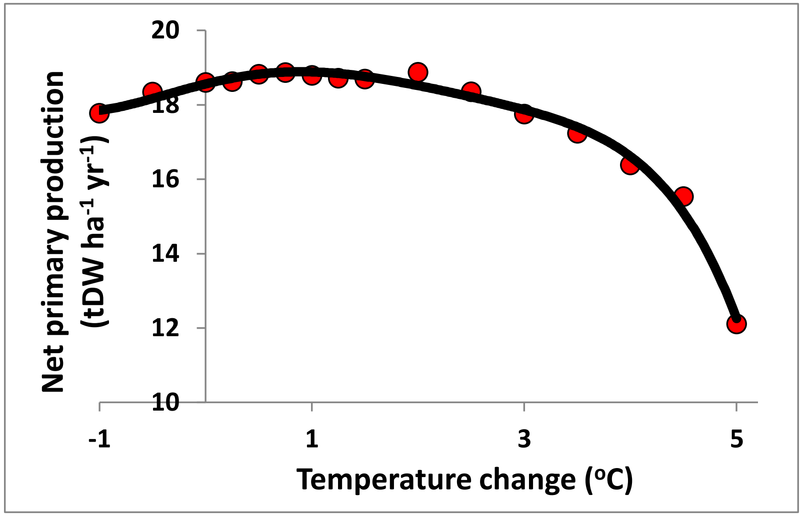
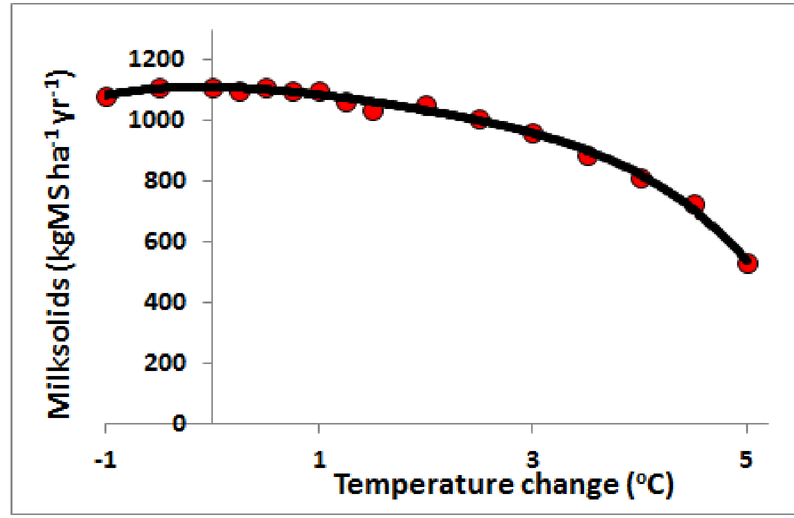
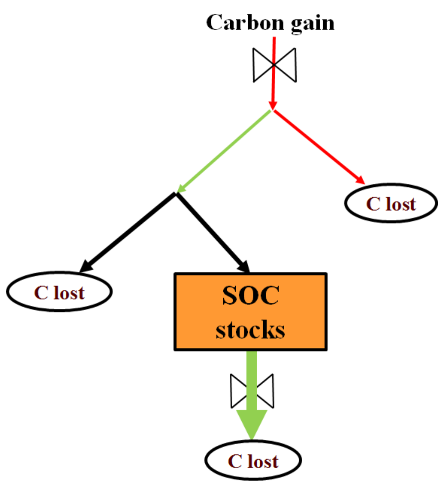
Changing temperature

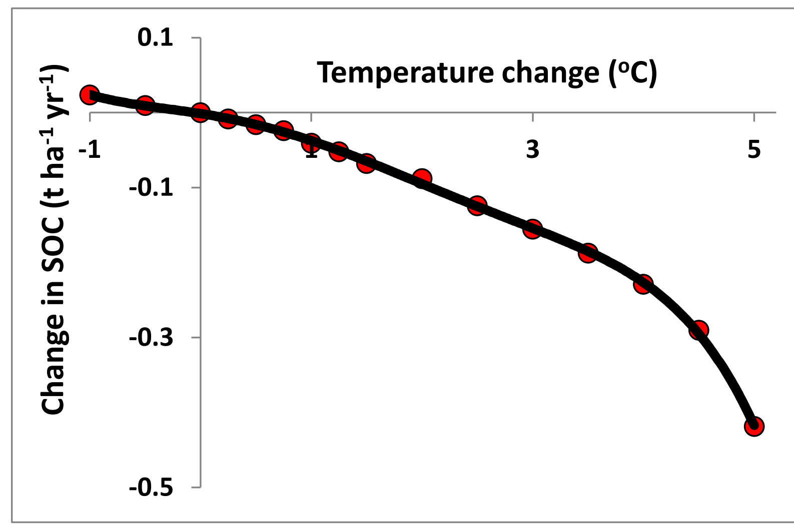




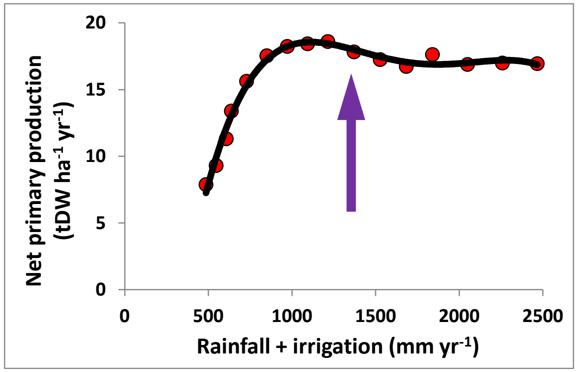
Key points:

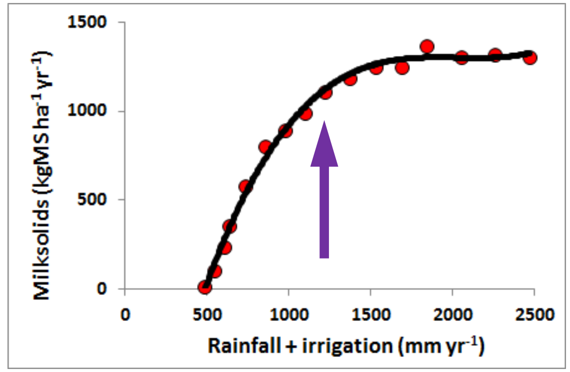
Moderate temperature changes had little effects on NPP or milk production but led to large SOC losses. It was due to small losses in NPP, even though a greater proportion was retained on-site, but a consistent and over-riding stimulation of the specific SOC decomposition rate.

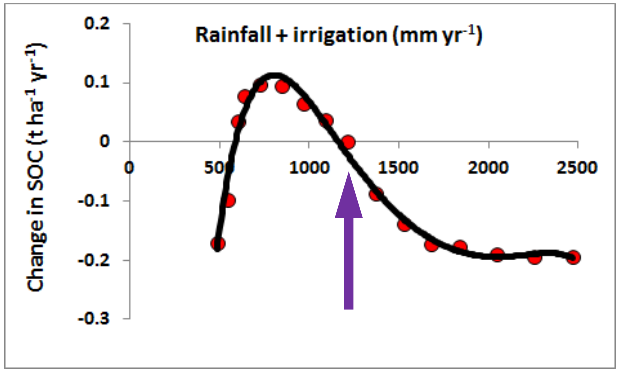


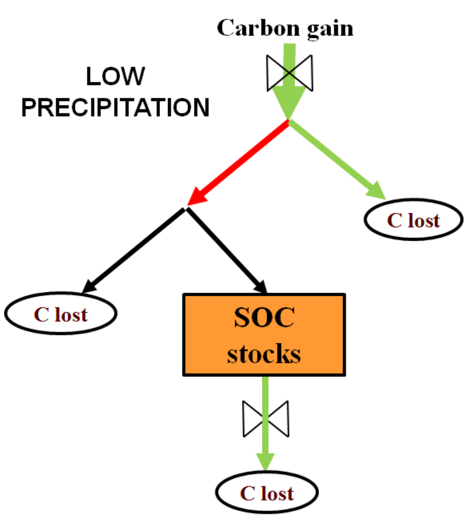


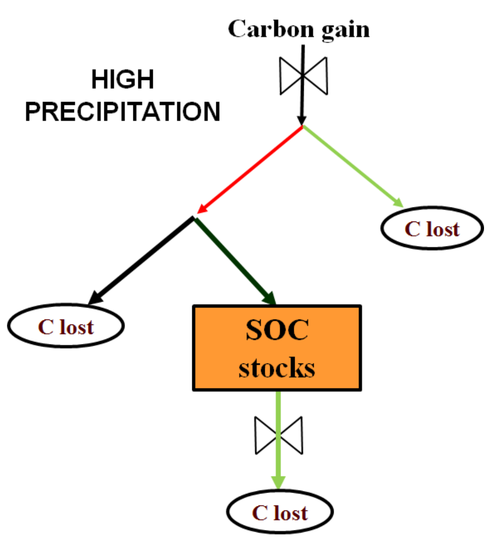
Changing rainfall/ irrigation









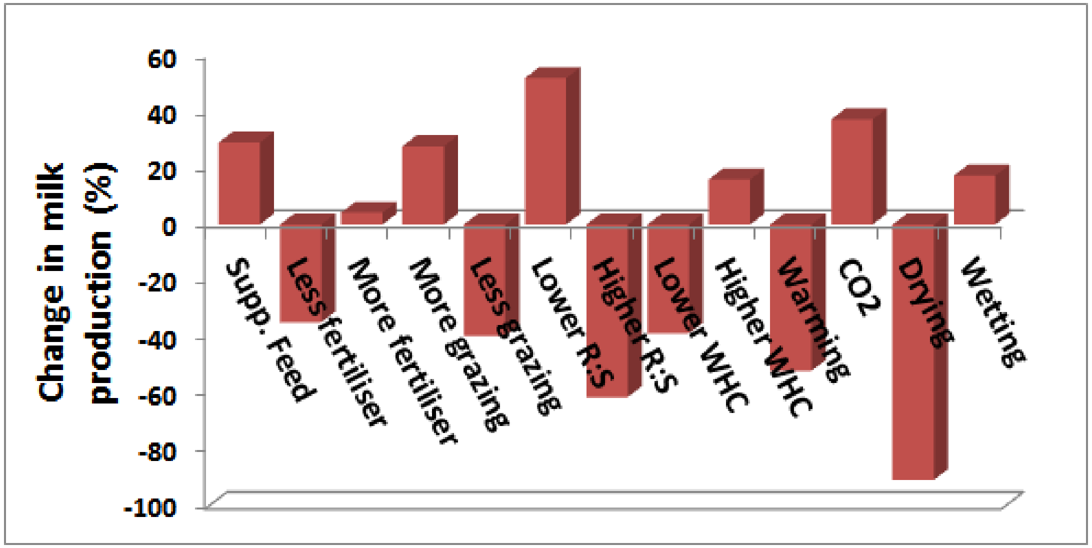


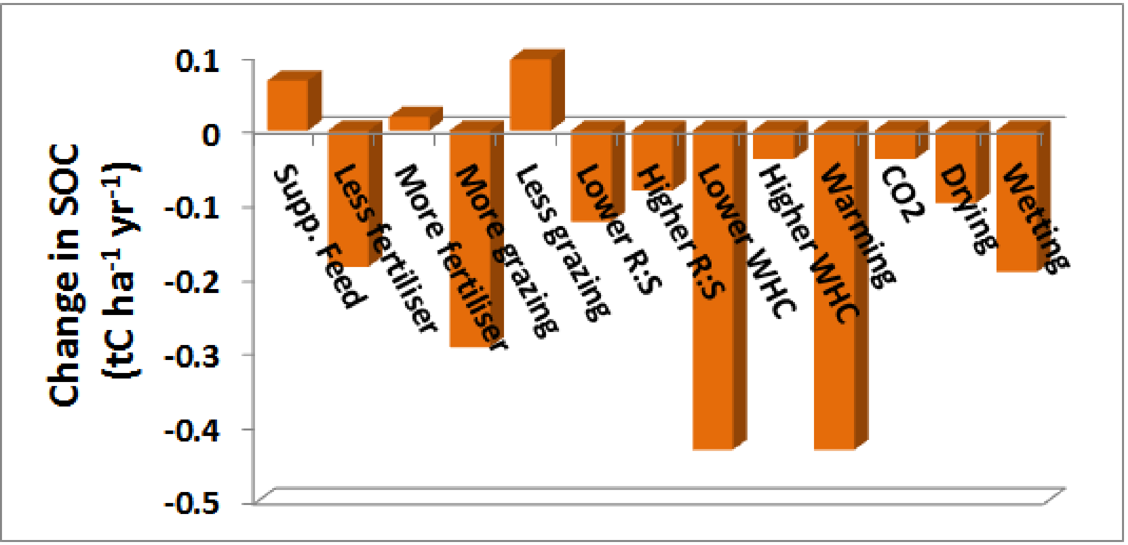
Key points:

Changes in water provision led to complex responses. Under low precipitation, adding water increased NPP, and even though it was preferentially utilised for milk production, it increased SOC despite a stimulation by OM decomposition in wetter soils.

Under higher precipitation, there was little effect on NPP, but still an increase in the fraction exported. That, together with further increased in SOC decomposition rates, led to SOC losses.

Summary of scenarios





Key points:

This slide summarises the findings of all the scenarios we studied. In addition to the ones described above, we also investigated the effect of increasing or decreasing grazing, changing root:shoot ratios and increasing CO_2 concentrations.

Of the various options, only adding supplemental feed or fertiliser, or reducing grazing, could increase SOC. However, reducing grazing would also reduce milk production and is thus unlikely to be acceptable to farmers.

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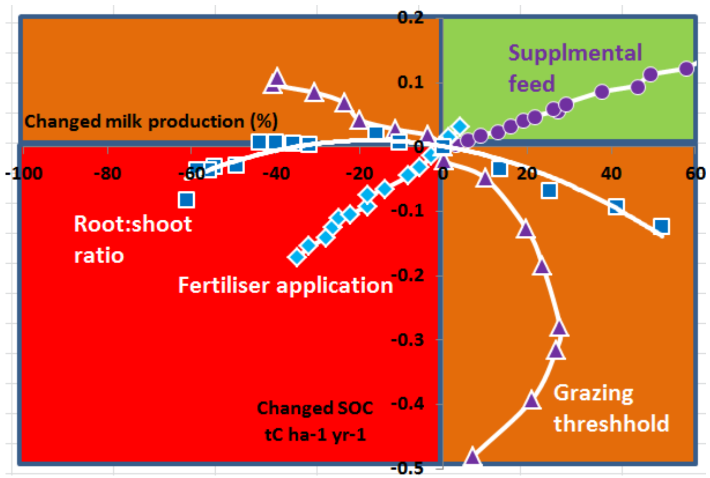
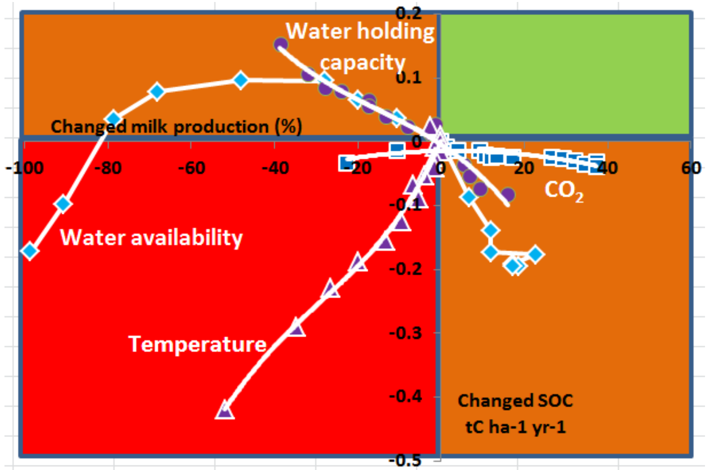
Summary of scenarios





Key points:

It is instructive to plot various scenarios by comparing changes in SOC and changes in milk production. The green sector would provide desirable outcomes, with increased SOC and increased milk production, while the red sector would be bad with reductions in both. The orange sectors represent trade-offs between one desirable outcome and another.

Most scenarios present trade-offs with increases in one desirable outcome being at the expense of losses in the other. The major exception is the provision of supplemental feed, but its overall desirability would need to be assessed with wider system boundaries than just the individual paddocks studied here.

Conclusions

- **CenW simulations provided modelling results that were consistent with observations**
- **ET, photosynthesis worked very well – grazer respiration was more problematic**
- **Footprint weighted modelling reduced residual error**
- **SOC changes depended on C gain, grazing off-take, C stabilisation and SOC turn-over**
- **SOC was increase with supplemental feeding, fertiliser addition, and irrigation on very dry sites**
- **SOC increases could be achieved at the cost of reduced milk production**
- **Anticipated environmental changes (↑T, CO_2, rain) were largely detrimental for SOC, but less so for milk production.**

References:

Kirschbaum, M.U.F., Rutledge, S., Kuijper, I.A., Mudge, P.L., Puche, N., Wall, A.M., Roach, C.G., Schipper, L.A., Campbell, D.I. (2015). Modelling carbon and water exchange of a grazed pasture in New Zealand constrained by eddy covariance measurements. *Science of the Total Environment* 512-513: 273-286.

Kirschbaum, M.U.F., Rutledge, S., Mudge, P.L., Puche, N., Schipper, L.A., Campbell, D.I. (2015). Changes in soil carbon stocks of a New Zealand grazed pasture in response to variations in management and environmental factors. In: Moving farm systems to improved nutrient attenuation. (Currie, L.D., Burkitt, L.L., eds). Occasional Report No. 28. Fertilizer and Lime Research Centre, Massey University, Palmerston North, New Zealand, 19 pp.

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