Effects of long-term inputs of fertiliser and irrigation on soil carbon under grazed pasture

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Abstract
Soils constitute the largest pool of terrestrial carbon, and the development and adoption of methods designed to increase storage of carbon is an effective means of reducing atmospheric carbon dioxide. The main objective of this research project was to assess the effects of long-term irrigation and fertiliser inputs on carbon in stony soils developed under intensively grazed pasture in New Zealand. Replicated field trials were established at Winchmore in 1949-1952 to assess the input requirements of pasture under flood irrigation, and are the longest running of their type in New Zealand. Results revealed that despite substantial increases in pasture production in response to inputs of fertiliser and irrigation over 60 years, there was no significant sequestration of organic carbon in the soil profile to 1m, and soil profile carbon actually decreased with increased irrigation.

Key Words
Climate change, carbon sequestration, mitigation.

Introduction
Appropriately managing the ongoing and predicted impacts of climate change is widely recognized as the most important challenge facing New Zealand's future. Sequestration of atmospheric carbon dioxide as organic carbon in soil is widely acknowledged as a viable mechanism for climate change mitigation. Recent publications have suggested that declines in soil organic carbon in temperate agricultural regions over the past 20-30 years may be partly attributed to climate change (Bellamy *et al*. 2005; Schipper *et al*. 2007). In light of these research findings, and the significant role that organic matter plays in maintaining and promoting the sustainability of New Zealand's primary industries, it is critical that the effects of long-term pasture management on soil organic carbon be resolved and quantified. The objective of this project is to quantify the effects of long-term irrigation and fertiliser application on the distribution of organic carbon in stoney soils developed under intensively grazed permanent pasture in New Zealand.

Materials and methods
A total of 24 plots comprising of 4 replicate plots of three treatments from the long-term fertiliser and irrigation field trials located at Winchmore in mid-Canterbury were selected for this study (Figure 1). The fertiliser trial was initiated in 1952, and the treatments selected were the control (nil P), 188kg superphosphate /ha.yr (188PA) and 376kg superphosphate ha.yr (376PA). The fertiliser trial received rainfall (740mm) plus 500mm irrigation per annum. The irrigation trial was established in 1949, and the treatments selected were the dryland (rainfall), irrigated at 10% soil moisture (rainfall + 250mm irrigation/yr) and 20% soil moisture (rainfall + 500mm irrigation/yr), and all treatments received 250 kg superphosphate/ha.yr. Lime was applied to both trials at establishment, and in 1965 (irrigation trial) and 1972 (fertiliser trial) to maintain pH above 6. Sampling sites were selected at the same location within each plot. In addition, a single site was selected within the 'wilderness area', which is currently under broom (*Cytisus scoparius*). This area has never received irrigation or fertiliser, and therefore provided an unimproved reference.

The soil sampling at Winchmore was carried out in April 2009 when the fertiliser and irrigation trials had been running for 57 and 60 years, respectively. Twenty five pits were excavated using a mechanical backhoe to a depth of 1.5 meters. Each pit was approximately 1 m wide by 2m long. The exposed vertical soil profile was horizontally levelled using a 40 x 40 x 25cm (0.04 m^3) steel frame as a guide and each sampling depth (0-7.5, 7.5-15, 15-25, 25-50, 50-75 and 75-100cm) soil and stones were removed. The soil and stones from each depth were transported to a laboratory where they were weighed and then separated using a combination of sieves (2cm to 10cm). Approximately 3kg of fresh soil was taken from each depth for analysis, and the residual soil and stones were then returned to the pits before refilling. A total of 150 soil samples were taken, and soils were air dried and ground prior to determination of total carbon by mass spectrometry. The soil weight for each depth increment was combined with the carbon content (%) to determine the total quantity of carbon (t/ha). Statistical analysis of differences in soil carbon content and quantity between depths and treatments within each trial was carried out using Genstat v.11.

Figure 1. The Winchmore long-term filed trials, including the 'wilderness area' (bottom left).

Results

The available average annual dry matter yield (t/ha) data for the fertiliser (1952-1979) and irrigation (1960-2000) trials showed that relative productivity for the 376PA, 188PA and control treatments in the fertiliser trial were 100, 90 and 40%, respectively. The corresponding values for the 20% moisture, 10% moisture and dryland treatments in the irrigation trial were 100, 85 and 60%, respectively. Soil carbon concentrations (%) and quantities (t/ha) determined in soil taken form the fertiliser trial, irrigation trial and wilderness plots are shown in Tables 1 and 2, respectively. As expected, the concentrations and corresponding quantities of carbon in soil decreased significantly with depth on all treatments from averages of 4.22% and 28.96t/ha and 0.67% and 7.43t/ha in the 0-7.5cm and 75-100cm soil depths, respectively. In the fertiliser trial plots there were no significant differences determined in either carbon concentration or amount between treatments at all soil depths, except for the 25-50 cm soil layer where the amount of carbon was greater in the 376PA treatment (28.56 t/ha) compared with the 188PA (19.06 t/ha) and nil P (21.33 t/ha) treatments.

Table 1. Average concentrations (%) of carbon determined in soils taken from the Winchmore long-term trials and the adjacent 'wilderness area'.

	Fertiliser Trial			Irrigation Trial			*Wilderness*
Depth (cm)	*Nil P*	*188PA*	*376PA*	*Dryland*	*10%*	*20%*	
0-7.5	4.12	4.35	4.25	4.42	4.25	3.92*	*4.50*
7.5-15	3.10	3.01	2.91	3.20	3.13	2.66*	*3.23*
15-25	2.14	2.04	2.22	2.09	2.18	1.84	*2.39*
25-50	1.35	1.22	1.38	1.20	1.35	0.90*	*0.87*
50-75	1.10	1.07	1.05	1.00	0.85	0.89	*0.62*
75-100	0.76	0.76	0.73	0.64	0.56	0.58	*0.95*

*indicates that means for 20% treatment were significantly different (P <0.05) compared with dryland and 10% treatments

Table 2. Average amounts (t/ha) of carbon determined in soils taken from the Winchmore long-term trials and the adjacent 'wilderness area'.

	Fertiliser Trial			Irrigation Trial			*Wilderness*
Depth (cm)	*Nil P*	*188PA*	*376PA*	*Dryland*	*10%*	*20%*	
0-7.5	27.96	30.84	29.25	29.94	28.99	26.77	*24.94*
7.5-15	20.54	17.77	17.91	27.81	17.49*	13.59*	*15.63*
15-25	20.63	17.26	20.13	25.27	22.35	23.03	*22.10*
25-50	21.33	19.06	28.53*	21.45	24.31	15.69*	*25.06*
50-75	9.07	10.49	10.09	12.28	16.21	7.76*	*14.79*
75-100	7.48	5.48	8.32	8.78	8.37	6.14	*11.27*
Profile	107.01	100.90	114.23	125.53	117.72	92.98*	113.73

*indicates that means for indicated treatment were significantly different ($P < 0.05$) compared with other trial treatments

Conversely, consistent significant differences in the amounts and distribution of carbon in soil were observed between treatments in the irrigation trial plots. In particular, levels of carbon were consistently lower in soils under the 20% irrigation treatment compared with the 10% irrigation and dryland treatments at most depths. Carbon concentrations in the 0-7.5, 7.5-15 and 25-50 cm soil depths under 20% irrigation (3.92, 2.66, 0.90) were significantly lower compared with either the 10% irrigation (4.25, 3.13, 1.35) or dryland (4.42, 3.20, 1.20) treatments. The corresponding data for carbon quantities revealed significantly lower levels under the 20% irrigation treatment in the 7.5-15, 25-50 and 50-75cm soil depths. In the 7.5-15cm soil, amounts of carbon were lower in both the 20% irrigation (13.59 t/ha) and 10% irrigation (17.49 t/ha) treatments compared with dryland (27.81t/ha). Only 15.69 t/ha of carbon was present in the 25-50cm soil under the 20% irrigation treatment compared with 24.31t/ha and 21.45 t/ha under the 10% irrigation and dryland treatments, respectively. Concentrations and amounts of carbon present in the wilderness site soil to 50cm were generally similar to the values determined in corresponding soils in the fertiliser and irrigation trials (except for the 20% irrigation treatment). However, quantities of carbon in the 50-100cm soils were higher in the wilderness area compared with the trial plots, especially in the 75-100 cm soil depth. Differences in carbon determined in various soil depths described above were reflected in the derived data for total soil profile carbon (Table 2). There were no significant differences observed in soil profile carbon levels between the treatments included in the fertiliser trial (100.90-114.23 t/ha). However, the amount of carbon determined in the soil profile under the 20% irrigation treatment (92.98 t/ha) was significantly lower compared with either the 10% irrigation (117.72 t/ha) or dryland (125.53 t/ha) treatments. Thus soil profile carbon to 1m under the 20% irrigation treatment was 21 and 26% lower than the corresponding amounts determined under the 10% irrigation and dryland treatments, respectively.

Conclusions

The findings of this study showed that despite significant increases in pasture production over 60 years there was no significant accumulation of organic carbon in the soil profile to 1 metre on the Winchmore plots. This was surprising given the magnitude of the response to inputs, where yields on the control treatments were only 40-60% compared with the corresponding fertiliser and irrigation treatments. Results from the irrigation trial revealed that profile soil carbon was significantly lower under the higher irrigation rate compared with the lower irrigation and dryland treatments. It is likely that soil carbon dynamics were influenced by the quality of organic carbon inputs rather than quantity, which in turn may be related to differences in pasture composition related to fertiliser and irrigation inputs. Ongoing studies are investigating this further.

References

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