Soil organic matter loss following land use change from long-term pasture to arable cropping: Pool size changes and effects on some biological and chemical functions

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Abstract
Effects of tillage on soil organic matter (SOM) and soil functions dependent on SOM (C and N minerization, cation retention) were examined in trial that was established (in 2000) to identify practices that conserve SOM following cultivation of pasture to grow annual crops. During the 2000-07 period, soil C stocks declined by about 12 Mg/ha (a decrease of ~14% compared with pasture). Total soil C stocks were not affected by tillage type (intensive, minimum, no tillage) after seven years of continuous cropping.
The results confirm that mineralization potential can decline by about 50% within a few years of pasture cultivation. This reduction in mineralization potential is large relative to the decline in total C and N (~20%), indicating labile part of SOM depleted. There was little difference in mineralization between tillage treatments or between disturbed and intact soil cores. The results suggest that changes in total and mineralizable organic matter following change in land use were mainly due to change in plant type from perennial grass returning large amounts of OM to the soil in above ground resideues and roots to an annual crop with smaller inputs. The effects of soil disturbance associated with the establishment of the annual crops appear to have only a small effect on toatla and mineralizable OM.

Key Words
Tillage, pasture, carbon, nitrogen, mineralization, disturbance

Introduction
Soil organic matter (SOM) generally makes up a small fraction of the mass of mineral soil, but it can have a profound influence on soil biological and chemical functions. Most of the N in soil is in organic form and the rate at which it mineralizes has a strong influence on N availability to plants. Because SOM has a high density of negatively charged sites compared with mineral material, it makes a disproportionately large contribution to soil cation exchange capacity (CEC). Management-induced changes in SOM could, therefore, have a significant effect on the retention and leaching of cations such as K, Ca, and Mg. The Millenium Tillage Trial was initiated in 2000 at Lincoln, Canterbury, New Zealand to identify tillage and cover crop practices that maintain SOM following the conversion of long-term pasture to arable cropping. The objectives of this paper are to: (1) examine effects of these management practices on total C and N stocks; (2) identify SOM fractions depleted under arable cropping; and (3) quantify effects of management-induced changes in SOM on key soil biological and chemical functions.

Materials and methods
Trial description
Trial was established in spring 2000 on a Wakanui silt loam (immature Pallic soil or Orthic Tenosol) that had been under sheep-grazed ryegrass/clover pasture for >14 years. The trial was designed as a split plot experiment with tillage as main-plot and cover crop (+/- winter forage crops) as sub-plot treatment. Each treatment was replicated three times in an incomplete Latin square. Main plot size was 28 m x 18 m (sub-plots 28 m x 9 m). The tillage treatments were (1) intensive tillage (mouldboard plough to ~20 cm, maxi-till, grub, harrow, roll); (2) minimum tillage (maxi-till, grub, harrow, roll (tillage depth ~ 10 cm)); and (3) no-tillage. All tillage operations were carried out using standard commercial equipment.

Spring-sown main crops (the crop sequence was barley, wheat, pea, barley, pea, barley, barley, barley) were followed by winter cover crops (oats or forage brassicas) or winter fallow (minus cover crop sub-plot). All crops were sown using a Great Plains Direct Drill. Fertiliser (N and P) was applied to the spring crops to ensure these nutrients were not limiting. The spring crops were irrigated using a sprinkler that applied water at approximately 6 mm/h. Irrigation was not usually required for the winter cover crops, but it was occasionally applied at sowing to improve plant establishment. Spring-sown crops were harvested at grain maturity (late summer-early autumn; late January to early March).

Each autumn, a winter forage crop (oat in 2001; forage rape in other years) was sown on the plus cover crop sub-plots with either intensive, minimum, or no-tillage, as described above for the spring crops. The minus cover crop subplots were also cultivated, but no crop was sown (i.e., plots remained fallow over winter). Cover crops were grazed using sheep in spring (prior to spring cultivation). Plots representing the previous land use (i.e., pasture) were included in the trial as a control. To maintain consistency with the trial design, these plots were split into pasture and fallow sub-plots. The fallow sub-plots were maintained plant-free during the experiment using herbicides (i.e., not cultivated) (hereafter this treatment is referred to as "permanent fallow"). The pasture sub-plots were grazed by sheep (typically 10 times per year and 20 sheep per plot), with all animal dung and urine returned to the plots. The pasture and fallow sub-plots were irrigated in summer (water application rate was the same as for the arable crops). Management (irrigation, fertilizer, grazing regime) of the pasture plots remained essentially the same as before the trial.

Changes in soil C and N
Soil samples were collected before initiation of the trial in 2000 and again in 2007 (0-7.5, 7.5-15, 15-25, and 15-30 cm). A total of 7 cores (5 cm diameter) were taken per plot. Bulk density and soil C and N (Leco TruSpec C/N analyzer) were determined in each depth increment. Total stocks of C and N were estimated by the equivalent mass method (Ellert *et al*. 2001) based on a 3500 Mg/ha soil mass (i.e., ~ pasture soil mass to 25 cm depth at the start of the trial). The particle size distribution of C and N in soil samples from the 0-7.5, 7.5-15, and 15-25 cm layers was measured after soil dispersion by ultrasonic vibration. The sand fraction (>50 µm) was separated by sieving and the 20-50, 5-20, and <5 µm fractions were obtained using standard sedimentation methods. The size separates were analyzed for total C and N (Leco TruSpec C/N analyzer).

Exchangeable cations and CEC
Exchangeable cations and CEC were determined using the ammonium acetate method. Exchangeable cations (Ca, Mg, K, Na) extracted in 1 *M* NH_4OAc were measured by inductively coupled plasma spectroscopy. Effective CEC was estimated by summing the exchangeable cations.

Carbon and N mineralization
Intact soil cores (0-15 cm depth; 5 cm diameter) were extracted in spring 2005 when the soil was close to field capacity. Half of the cores were maintained intact while the other half was disturbed by passing the soil through a 4 mm sieve. These disturbed cores were then refilled to the original bulk density (all material retained on the sieve was returned to the soil). The soil cores were incubated in 5.5 L air-tight plastic containers (3 cores per container) for 100 days at 20^{o}C. Carbon dioxide evolution was measured periodically (usually every 2 to 3 days) by determining the concentration of CO_2 in air samples removed from the containers using a syringe. After each measurement, the headspace was flushed with air to return the CO_2 concentration to ambient levels. Nitrogen mineralized during the 100 day incubation was determined as the difference between post- and pre-incubation mineral N.

Results and discussion
Average-to-good yields of spring-sown main crops were obtained during the experiment with generally little difference between the tillage treatments (data not shown). Although in some years winter cover crop yields were somewhat less under no-tillage (partly due to slug damage), inputs of organic matter to the soil in crop residues are unlikely to have differed much between tillage treatments. As cover crop yields and, by extension, organic matter returns in plant residues and sheep dung were low in many years, there was usually no difference in SOM between the plus and minus cover crop treatments (not shown).

The total mass of C (top 3500 Mg/ha of soil) under pasture in 2007 was 87 Mg/ha (Table 1), slightly higher than the initial value (84 Mg/ha) in 2000. Alter 7 years of continuous cropping, loss of SOM was similar for all tillage treatments (average 12 Mg C/ha). The tillage treatments had lower C concentrations than pasture soil in the top 7.5 cm. Re-distribution of SOM was evident under intensive tillage. This treatment had lower C levels in the top layer but higher levels deeper in the profile compared with minimum and no tillage. Greatest SOM loss was observed in the permanent fallow (~17 Mg C/ha less than pasture in 2007), emphasizing the importance of plant inputs in maintaining SOM. Our results show that, while soil under no tillage may have more organic matter near the soil surface than intensively cultivated land, the total quantity of SOM in the profile may be similar regardless of tillage intensity.

Table 1. Effect of management treatments on C concentrations in the top 25 cm and on total C stocks in 3500 Mg/ha soil mass in 2007. Standard deviations are in parentheses.

Treatment	C concentration (g/kg)			Total C stock (Mg/ha)
	0-7.5 cm	7.5-15 cm	15-25 cm	
Pasture	36 (2.2)	27 (2.2)	19 (1.8)	87.3
Permanent fallow	24 (1.6)	21 (1.3)	16 (0.8)	70.5
Intensive tillage	24 (1.4)	24 (1.4)	22 (1.4)	76.6
Minimum tillage	29 (1.5)	26 (0.7)	17 (1.9)	75.6
No tillage	29 (1.6)	22 (1.2)	16 (2.6)	73.9

Size fractionation data confirmed that SOM was concentrated in the colloidal fraction (<5 µm). However, SOM associated with this fine-sized material changed relatively little following cultivation of pasture. Most of the C lost after cultivation was derived from the > 50 µm fraction, which is commonly referred to as particulate organic matter (POM), and from the 5-20 µm size fraction. Changes in POM-C in response to land use change have been shown previously (Skjemstad *et al*. 2004). The nature of the organic matter in the 5-20 µm fraction requires further investigation, but our preliminary results suggest that at least part of it is POM-like in character.

Organic matter mineralization, measured five years after the start of the trial, did not differ significantly between intact and disturbed cores (Table 2), contrary to the common belief that physical disturbance stimulates microbial activity. Over the 100 day incubation period, C mineralization in pasture soil averaged 3120 kg/ha, compared with only 1150 kg/ha in cropped treatments. The decline in mineralizable C following cultivation was large relative to the change in total C. Effects of tillage treatments on C mineralization were small. As observed for total C (Table 1), the permanent fallow had lowest levels of mineralizable C. Nitrogen mineralization also showed a large decline under arable cropping and, again, there was little difference between tillage treatments. Over the 100 day incubation, pasture soil mineralized about 200 kg N/ha, compared with ~100 kg/ha under arable cropping. Mineralization of N was similar for intact and disturbed cores. The results confirm that the mineralizable fraction of SOM is rapidly depleted after pasture is cultivated. The decline in SOM may, on a large extent, be due to lower organic matter inputs from arable crops vs perennial pasture species. Based on our observations, physical disturbance (cultivation) does not appear to accelerate the decomposition of SOM.

Table 2. Effects of the management treatments on C and N mineralization, measured using intact and disturbed soil cores.

Treatment	C mineralized (kg/ha)		N mineralized (kg/ha)	
	Intact	Disturbed	Intact	Disturbed
Pasture	3015	3221	203	191
Permanent fallow	861	848	76	74
Intensive tillage	1048	1058	88	77
Minimum tillage	1155	1233	93	99
No tillage	1273	1111	111	91
LSD (0.05)	226		28	

The decline in SOM under permanent fallow and arable cropping had a detectable effect on effective CEC and exchangeable cation composition (Table 3). In permanent fallow (C loss of ~17 Mg/ha), there was a decline in total exchangeable cation (Ca + Mg + K + Na) equivalents of 47 $kmol_c$/ha (0-25 cm depth), a decrease of 20% compared with pasture. Loss of cation exchange capacity resulted in selective release of cations with lower affinity for SOM (K, Na, Mg).

Table 3. Effect of management treatments on total amounts of exchangeable cations in the top 0-25 cm soil layer.

Variable	Pasture	Permanent fallow	Intensive tillage	Minimum tillage	No-tillage	LSD (0.05)
Exch. Ca (kg/ha)	3410	2935	3259	3226	3320	449
Exch. Mg (kg/ha)	377	246	290	268	289	55
Exch. K (kg/ha)	836	536	366	357	375	242
Exch. Na (kg/ha)	256	135	164	174	164	46
ΣCa+Mg+K+Na ($kmol_c$/ha)	234	186	203	200	206	

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References

Ellert BH, Janzen HH, McConkey BG (2001) Measuring and comparing soil carbon storage. In 'Assessment methods for soil carbon'. (Eds R. Lal, JM Kimble, RF Follett, BA Stewart) pp. 131-146. (Lewis Publishers: Boca Raton: FL).

Skjemstad JO, Spouncer LR, Cowie B, Swift RS (2004) Calibration of the Rothamsted organic carbon turnover model (RothC ver. 26.3) using measurable soil organic carbon pools. *Australian Journal of Soil Research* **42**, 79-88.