LONG-TERM INFLUENCE OF MANAGEMENT PRACTICES ON NUTRIENT SUPPLY POTENTIAL OF A SILT LOAM SOIL

Weiwen Qiu, Denis Curtin, Mike Beare, Richard Gillespie, Tina Harrison-Kirk and Trish Fraser

The New Zealand Institute for Plant & Food Research Limited, Private Bag 4704, Lincoln
Email: Weiwen.qiu@plantandfood.co.nz

Abstract
A long term trial was established in 2000 at Lincoln, Canterbury on a Wakanui silt loam to quantify the effects of management (tillage intensity, i.e., intensive, minimum and no-tillage; plus or minus winter cover crops) on soil quality following the conversion of long term pasture to arable cropping. In 2013, soil samples were collected (0-7.5, 7.5-15, 15-25 cm depths) from five treatments. Nitrogen (and C) mineralisation potential were determined by incubating samples for 98 d (25^{o}C, -60 kPa water potential). The effects of the treatments on chemical fertility were evaluated by using standard soil tests (Olsen P, pH, available cations, cation exchange capacity (CEC)). Under arable cropping, N mineralisation potential declined by 22-28% compared with long-term pasture. Tillage type had little effect on total mineralisation in the top 25 cm, but it did affect the vertical distribution of mineralisation (more concentrated near soil surface under no-tillage; uniform depth distribution in intensively tilled plots). Mineralisation was least in the long-term permanent fallow (67% less than in pasture), which had negligible inputs of fresh organic matter in the 2000-2013 period. As a result of a decline in soil organic matter under arable cropping and long-term fallow, there was a decrease in CEC (pH 7) up to 22% at 0-7.5 cm depth. There was substantial decrease in available cations under arable cropping, with K decreasing by 46-73% and Mg by 36-52%. Although most indicators of nutrient availability were low in the fallow treatment, it had highest levels of Olsen P, presumably due to accumulation of mineralised P.

Introduction
Land management practices can influence soil fertility in several important ways (Cole et al., 1990; Thomas et al., 2007). The amounts of nutrient applied in fertiliser and removed in harvested products can differ depending on land use. Land use may also affect soil organic matter content (SOM) which, in turn, can alter the soil's potential to supply nutrients (particularly N) via mineralisation (Curtin and McCallum, 2004). The retention and leaching of nutrient cations (Ca, K, Na) may also change if SOM changes. Changes in soil fertility may occur relatively slowly, and long-term data are often needed to quantify fertility trends. The objective of this work was to evaluate long-term effects of land use (sheep-grazed pasture v. arable cropping) and tillage practices on biological and chemical components of soil fertility.

Materials and Methods

Experimental sites and treatments
Soil samples (0-7.5, 7.5-15, 15-25 cm) were collected in 2013 from selected treatments in the Millennium Tillage Trial at Lincoln, Canterbury (Fig.1). The trial, on a Wakanui silt loam, was established in November 2000 to examine the effects of tillage practices on SOM following conversion of long-term ryegrass (*Lolium perenne* L.)-white clover (*Trifolium repens* L.) pasture to arable cropping. The experiment had a split-plot design with tillage type (intensive, minimum, or no tillage) as main-plot treatment and winter cover crop (plus or minus winter forage crops) as sub-plot treatment. The tillage treatments were:

1. Intensive tillage (IT): Mouldboard plough (top 20 cm), followed by secondary cultivation (one pass with a spring tined implement and then harrowing and rolling twice);
2. Minimum tillage (MT): Shallow cultivation (top 10 cm) using a disk implement, followed by secondary cultivation (harrowing and rolling twice);
3. No-tillage (NT): No soil cultivation, seeds direct drilled.

Figure 1. Aerial view of the experimental plots at the trial site.

Treatments were replicated three times in an incomplete Latin square. Main plot size was 28 m × 18 m (sub-plots 28 m × 9 m). The tillage treatments were applied in both spring (prior to establishing the main crops) and autumn (before establishing the winter cover crops) using standard commercial equipment. Crops (the arable rotation included barley, wheat, peas, and grass seed crops) were sown using a Great Plains direct drill. Irrigation and fertiliser were applied to ensure that water and nutrients were not limiting. Further trial details can be obtained from Fraser et al. (2013).

Replicated plots representing the original ryegrass-clover pasture were maintained within the trial design as a control treatment. Half of the pasture main plot was chemically fallowed (maintained plant free using herbicide, glyphosate and not cultivated) throughout the experiment (i.e. permanent fallow). The permanent pasture sub-plots were grazed using sheep (typically 10 times per year; 20 sheep per sub-plot). The fallow and pasture sub-plots were irrigated in summer (water application rate was the same for all treatments). Management (irrigation, fertilizer application, grazing) of the pasture plots remained essentially the same as before the trial. No fertiliser was applied to the fallow plots.

In total, samples were taken from 15 sub-plots, representing five treatments (i.e., IT, MT, or NT, pasture and fallow). The soils used in this study were taken from sub-plots that had winter cover crops. The samples used to measure total C and N, and chemical fertility were collected in autumn (February) 2013 and those used to measure C and N mineralisation were taken in spring (September) 2013. All samples were passed through a 4 mm sieve. The samples used for mineralisation measurements were maintained field moist whereas the other samples were air-dried prior to analysis. Soil C and N were determined using a Leco TruMac analyser (LECO Corporation, St. Joseph, Michigan, USA). A standard suite of chemical tests was carried out to determine soil pH, Olsen P, exchangeable cations (Ca, Mg, K) and cation exchange capacity (CEC, measured at pH 7 using ammonium acetate (Thomas, 1982)).

Mineralisation was determined in a 98 -day incubation at 25^{o}C (soils maintained at -60 kPa). The soils were incubated in 1 L incubation jars. Samples of headspace air were periodically removed from the jars with a syringe and analysed for CO_2 using an infra-red gas analyser (LI-COR, Lincoln, Nebraska). Mineral N concentrations were determined by 1-hour extraction with 2 *M* KCl and subsequent analysis for NH_4-N and NO_3-N on a Lachat QuikChem 8500 Series 2 Flow Injection Analysis System (Lachat Instruments, Loveland, Colorado, USA) (Keeney and Nelson, 1982). Net N mineralised over the 98 -day period was estimated by subtracting initial mineral N from that measured at the end of the incubation.

Statistical analyses

Data were statistically evaluated by analysis of variance (ANOVA) as a split-plot factorial design with three replicates (Genstat 14.0 for Windows). Least Significant Differences (LSD) at the 5% level were used to detect differences among means. Figures were created with SigmaPlot v.10.

Results and discussion

The effects of land use and tillage practices on soil carbon and total nitrogen

The pasture soil contained a total of 86.6 t/ha of organic C in the top 25 cm layer (Table 1). After 13 years of arable cropping, soil C stocks had decreased by an average of 13.7 t/ha relative to pasture. There was no significant difference in C stocks (0-25 cm) between tillage treatments. However, tillage type did influence the distribution of C in the profile. Under NT and MT, soil C was stratified by depth, with a higher concentration near the soil surface and a systematic decrease with depth. Cultivation and mixing to ~20 cm in the IT treatment resulted in a uniform depth distribution of soil C. The decrease in C under arable cropping (and fallow) can be attributed primarily to lower inputs of C in plant residues as compared to continuous pasture. Total soil N showed similar treatment responses to soil C.

Table 1: Effect of treatments of total soil C and N in the 0-25 cm layer

Treatment	Total C (t/ha)	Total N (t/ha)
Pasture	86.6	7.8
Fallow	65.6	6.1
IT	71.7	6.4
MT	75.5	6.6
NT	71.4	6.4
LSD (5%)	5.4	0.4

IT = intensive tillage; MT = minimum tillage; NT = no-tillage

Soil C and N mineralisation potential

Between 2.2% and 4.6% of soil organic C mineralised in the 98-day laboratory incubation (data not shown). Cumulative C mineralised in 98 d (0-25 cm layer) was greatest (P<0.05) under pasture, followed by arable cropping, with fallow soil having lowest values (Fig. 2). Relative to pasture, the decrease in C mineralisation was 28% under arable cropping and 65% under fallow.

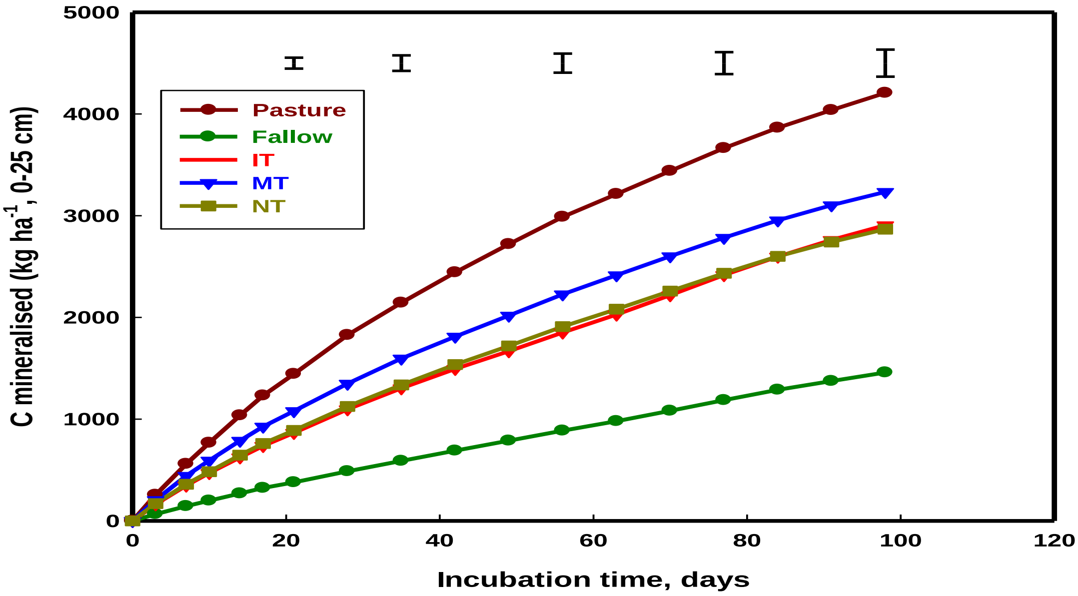

Figure 2. Carbon mineralised (0-25 cm) under different land management treatments. Error bars = LSD (5%).

As with total soil C (and N), tillage type influenced the vertical distribution of mineralisable C. In the surface 7.5 cm layer, IT soil had lower values ($P < 0.05$) than either MT or NT (Fig. 3). However, this treatment exhibited higher C mineralisation than the other tillage treatments in the 7.5-15 cm and, particularly, in the 15-25 cm layers. For the 0-25 cm layer as a whole, there was no significant difference ($P > 0.05$) between tillage treatments in total amounts of C mineralised in 98d (Fig. 2).

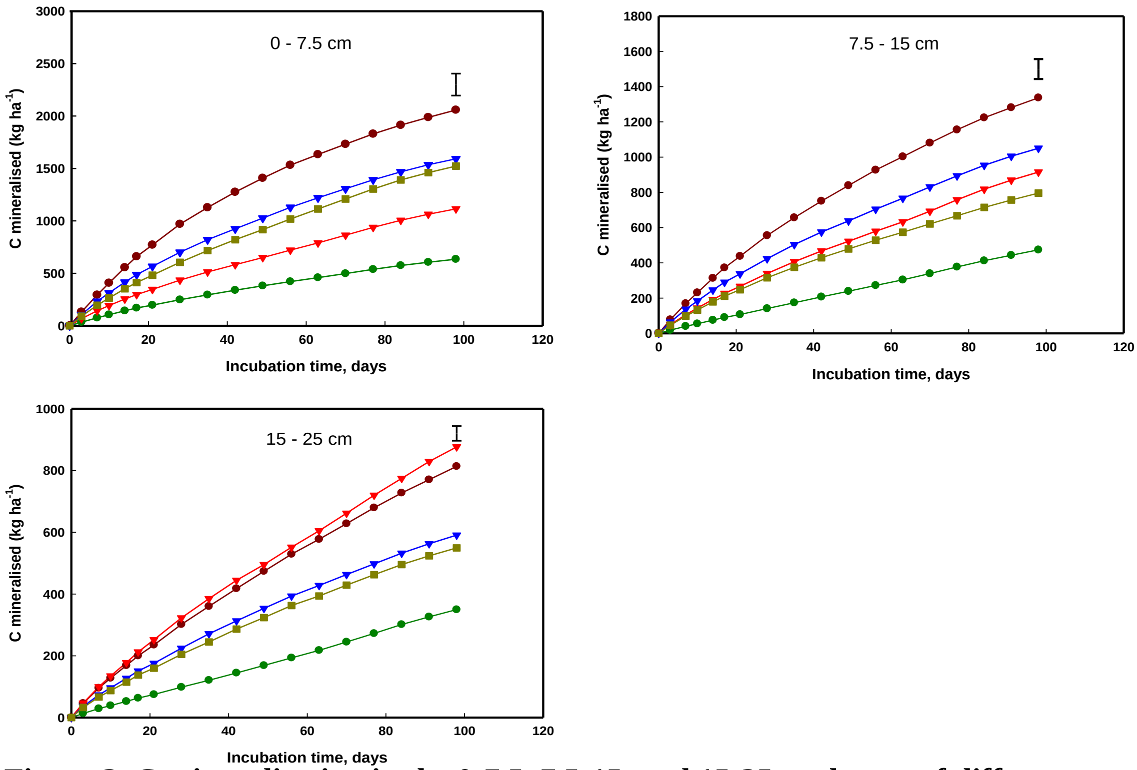

Figure 3. C mineralisation in the 0-7.5, 7.5-15, and 15-25 cm layers of different management treatments. Error bar = LSD (5%).

Land use had a significant effect on the N mineralisation potential in the top 25 cm. The total amount of N mineralised in 98 d was 350 kg/ha under pasture, 253-273 kg/ha under arable cropping (no significant difference between tillage treatments), with as little as 114 kg/ha mineralising in the permanent fallow soil (Fig. 4). The results in Fig. 5 show that mineralisable N was concentrated near the soil surface in the MT and NT treatments whereas there was relatively little difference between the three sampled layers of the IT plots. Approximately 50% of the mineralised N was present in the 0-7.5 cm soil layer under NT and MT; the corresponding value was 40% under IT. These results emphasise the need to choose an appropriate sampling depth when evaluating tillage effects on soil N supplying power. Shallow sampling (e.g., top 7.5 cm) may result in a significant bias in favour of tillage systems that maintain organic matter near the soil surface (low disturbance tillage). Furthermore, the exclusion of information on N mineralisation deeper in the soil profile may tend to overlook an increased risk of NO_3 leaching in some soils.

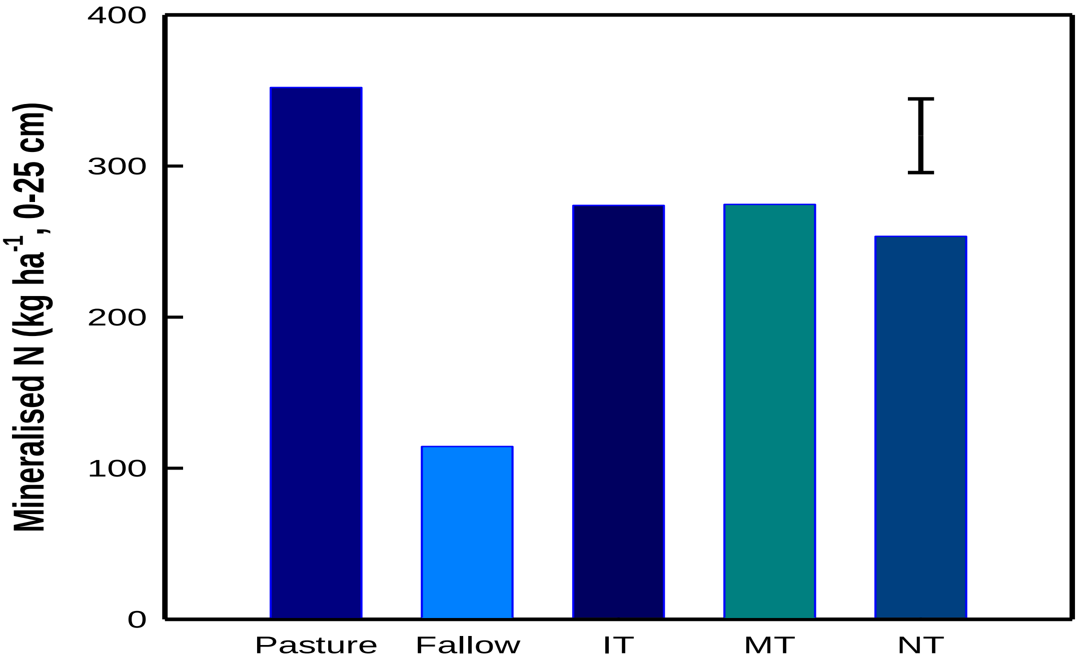

Figure 4. N mineralised (0-25 cm) under different land management treatments. Error bar = LSD (5%).

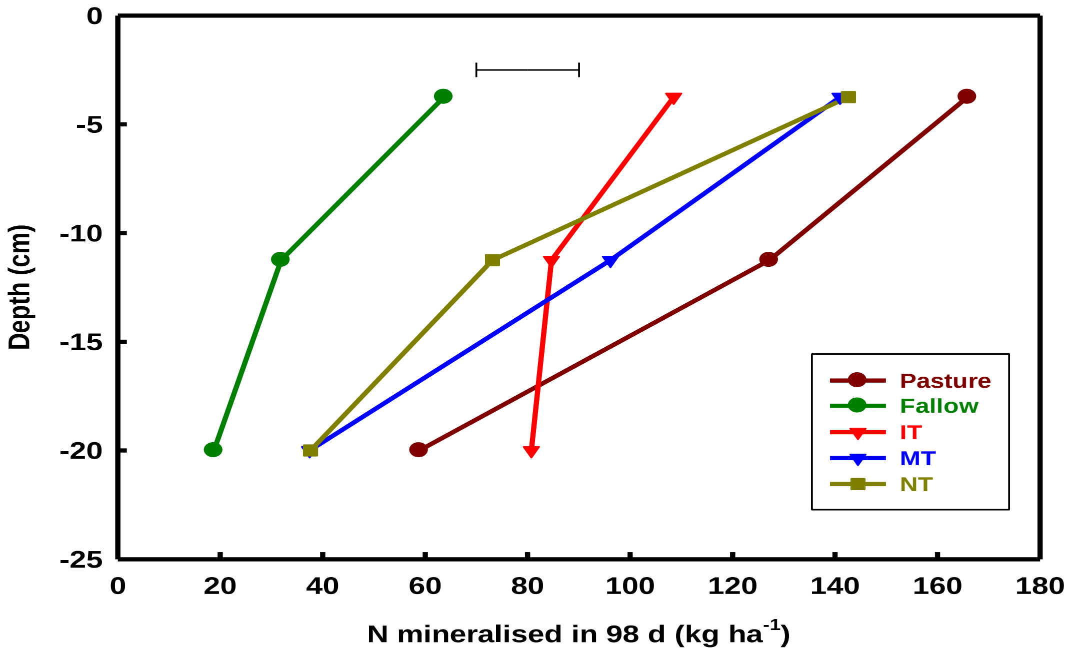

Figure 5. N mineralised as a function of depth in land management treatments. Error bar = LSD (5%).

Stocks of soil nutrients

The decline in SOM under arable cropping and fallow resulted in a decrease in CEC (pH 7) of up to 22% in the top 0-7.5 cm depth compared to pasture ($P < 0.05$) (Table 2). There was significant acidification under arable cropping and fallow (pH of fallow soil ~ 1 unit less than pasture soil). As the soil pH decreases, effective CEC associated with SOM decreases due to protonation of pH-dependent exchange sites (Morais et al., 1976). As a result of the decrease in SOM and pH, exchangeable (available) cations all declined under arable cropping, with K and Mg showing particularly large decreases (on average, K decreased by 68% and Mg by 37%). There was no significant difference in available cations (0-25 cm) between the tillage treatments (Table 2).

Table 2: Effect of treatments on available nutrients (0-25 cm), pH (0-7.5 cm) and cation exchange capacity (CEC) (0-7.5 cm).

Treatment	Olsen P (kg/ha)	Ca (kg/ha)	Mg (kg/ha)	K (kg/ha)	pH	CEC (me/100 g)
Pasture	90	3766	469	836	6.1	16.3
Fallow	111	2667	223	448	5.0	12.7
IT	73	3186	292	316	5.4	12.7
MT	78	3379	301	269	5.4	13.0
NT	66	3250	299	223	5.2	13.7
LSD (5%)	19	555	93	128	0.2	1.6

Soil under arable cropping had lower levels of available P (Olsen P) than pasture soil. This was at least partly due to greater off-take of P in harvested crops relative to P removed by sheep grazing the pasture plots. Although no fertiliser P was applied to the fallow treatment, it had the highest concentrations of Olsen P, presumably because of accumulation of mineralised P.

Summary and Conclusions
After 13 years of arable cropping, soil C stocks (0-25 cm) were ~14 t/ha less than in pasture soil. The decline in SOM following conversion of pasture to arable cropping appeared to be mainly due to decreased inputs of organic matter (roots and above-ground residues). Carbon (and N) stocks were not affected by the degree of tillage disturbance.

Nitrogen mineralisation potential (0-25 cm) decreased significantly (by an average of 25%) under arable cropping. Tillage type did not affect the overall quantity of mineralisable N in the soil but its vertical distribution differed between tillage treatments (concentrated near the soil surface in low-disturbance treatments (MT and NT) but uniformly distributed through the top 25 cm under IT. The decline in SOM under arable cropping had a substantial effect on CEC and available cations. (e.g., in the top 25 cm, exchangeable K and Mg decreased by an average of 68% and 37%, respectively). Chemical fertility levels in the top 25 cm also did not differ between tillage treatments.

In summary, land use (pasture v. arable cropping) had a dominant influence on soil biological and chemical fertility. Tillage type influenced the vertical distribution of fertility parameters, but not the total quantity in the soil. In assessing the influence of tillage, it is important that samples be collected to at least the depth of the deepest cultivation treatment.

Acknowledgements
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