An overview of results from the long-term no-tillage trials at Winchmore

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Abstract

Tillage trials that compared changes in soil properties, earthworm populations and crop yields under conventional tillage (CT) and no-tillage (NT) were conducted for nine consecutive years at two sites in Canterbury, New Zealand. The Lismore silt loam soil had been under long-term pasture before the experiment, whilst the Wakanui silt loam soil had been under long-term arable cropping. At the Lismore site, organic C and total N contents in the top 150 mm of soil declined under both treatments during the trial, although the decrease was relatively greater under CT. Tillage treatment had little effect on soil organic matter content at the Wakanui site. Bulk density was largely unaffected by tillage treatment on the Lismore soil, but on the Wakanui soil it was greater under NT at 0-150 mm depth throughout most of the trial. At both sites, earthworm populations were greater under NT than CT. Yields of wheat tended to be greater under NT at both sites, but yields of spring barley were greater under CT. Under CT there is a flush of mineralisation following cultivation, whilst under NT mineralisation is more evenly distributed over the growing season. Wheat crops grown following cultivation in autumn/winter have a more adequate N supply during the growing season under NT than CT, as much of the N that is mineralized after cultivation of CT soil is leached before the spring. Barley crops grown following cultivation in the spring have a more adequate N-supply than those under NT, as the flush of N mineralisation under CT occurs immediately before the onset of rapid crop growth.

Additional key words: *organic C, total N, earthworms, bulk density, macroporosity, aggregate stability, yields.*

Introduction

The Canterbury Plains region covers approximately 750,000 ha and is the major area for grain production in New Zealand. Crops are commonly grown for 2-5 years in rotation with 2-5 years of grazed grass/clover pasture. Economic pressures have encouraged farmers to lengthen the arable phase of their rotations in which the mouldboard plough is the primary tillage implement. However, with increasing time under the arable phase, N becomes limiting to crop production and soil physical conditions deteriorate (Haynes and Francis, 1990). As a result, increasing interest is being shown in NT farming in which there is often a slower decline in both N content and soil physical properties than under CT (e.g., Dick, 1983; Francis *et al.,* 1987). Consequently, two trials were established about a decade ago on sites with contrasting cropping histories and soil types to compare the long-term effects of NT and CT systems on selected soil physical and chemical properties and on crop growth and N economy. The results of these experiments are reported here.

Materials and Methods

Tillage experiments were established in 1978 on a high-fertility Lismore stony silt loam and in 1980 on a low-fertility Wakanui silt loam (Kear *et al.,* 1967). The Lismore soil had been under ryegrass/white clover pasture for approximately five years before the trial began, whereas the Wakanui site had been under a cropping rotation of wheat, barley, peas for the previous 10 years. The mean annual rainfall at both sites is approximately 750 mm which is relatively evenly distributed throughout the year.

The two tillage treatments at each site were: (a) conventional tillage (CT), comprising mouldboard ploughing to approximately 150 mm depth followed by at least two secondary tillage operations, and (b) no-tillage (NT), which involved spraying existing vegetation with herbicide (glyphosate) before drilling seed into the undisturbed soil. At both sites treatments were replicated three times, with plots 30 m wide and 90 m long. A continuous arable rotation was adopted in both experiments.

Both trials were sampled after harvest each year. Bulk density was measured using a percussion corer (vol 617 cm^3). Wilting point was determined on disturbed samples using a pressure plate apparatus with a positive pressure of 1500 kPa (Cassel and Nielsen, 1986). Field capacity was determined using an *in situ* field method (Cassel and Nielsen, 1986), with the available water holding capacity (AWHC) calculated as the amount of water retained in the soil between field capacity and wilting point. Aggregate stability was measured by wet-sieving air-dried 2-4 mm diameter aggregates (Haynes and Knight, 1989). Earthworms were counted by hand-sorting from soil (0.04 m^2 area to 0.3 m depth). Organic C was determined colorimetrically by the Walkley and Black method (Blakemore *et al.*, 1972) and total N was determined by semi-micro Kjeldahl digestion (Bremner, 1965). Crop yields were obtained from machine harvests of all plots.

Results and Discussion

Organic C, total N and aggregate stability

At the high-fertility Lismore site, the continuous arable rotation led to an overall decline for both tillage treatments (0-150 mm depth) in soil organic carbon (Table 1) and total soil nitrogen (data not shown) compared with the initial high level under the grazed pasture. The decline was greater under CT in the surface 0-75 mm depth as cultivation exposed previously-inaccessible soil organic matter to microbial decomposition. Organic C and total N contents were more evenly distributed in the top 0-150 mm of CT soil due to the mixing effect of cultivation. NT soil had its highest organic matter contents in the top 0-20 mm, where most of the crop residues were returned to the system.

At the low-fertility Wakanui site, neither organic C nor total N contents (0-150 mm depth) changed significantly during the trial, with organic matter inputs more-or-less balanced by organic matter decomposition in both tillage treatments. However, as at the Lismore site, a different distribution of organic C and total N developed during the trial, with higher contents in the NT soil in the surface layers (0-75 mm) and higher contents in the CT soil deeper (75-150 mm) in the profile. The greater organic C content in the Lismore soil was reflected in a greater aggregate stability compared with the Wakanui soil (Table 1). At both sites, aggregates from NT soil were more stable throughout the depth of tillage (0-150 mm) than the corresponding CT aggregates. The greater stability of NT aggregates in the top 0-75 mm appeared to be related to their greater organic C content. However, at 75-150 mm depth the stability of NT aggregates was not related to total organic C content, but was probably a reflection of a small active fraction of the total soil organic matter pool (Haynes and Swift, 1990).

Earthworms

At the Lismore site earthworm numbers were greatest under the initial grazed pasture (Fig. 1). Adoption of

Table 1. The effect of nine years of no-tillage (NT) and conventional-tillage (CT) on the amount and distribution of organic C in the soil profile and on soil aggregate stability.

Depth (mm)	Organic C content (kg ha^{-1})				MWD (mm)[a]		
	Initial	9th year NT	9th year CT	LSD[b]	9th year NT	9th year CT	LSD
Lismore							
0-20	8.8	7.5	4.3	1.0	2.45	1.63	0.21
20-75	20.3	17.8	13.7	2.1	2.43	1.70	0.19
75-150	25.2	20.1	20.9	3.0	2.15	1.50	0.24
Total	54.3	45.4	38.9	4.2			
Wakanui							
0-20	5.0	5.3	4.6	0.5	1.52	1.15	0.12
20-75	15.8	14.3	12.7	1.2	1.44	1.13	0.11
75-150	20.6	17.2	18.2	1.5	1.40	1.16	0.08
Total	41.4	36.8	35.5	2.1			

[a] Mean weight diameter (max value=3.0, min value=0.25)

[b] Between tillage treatments (P<0.05)

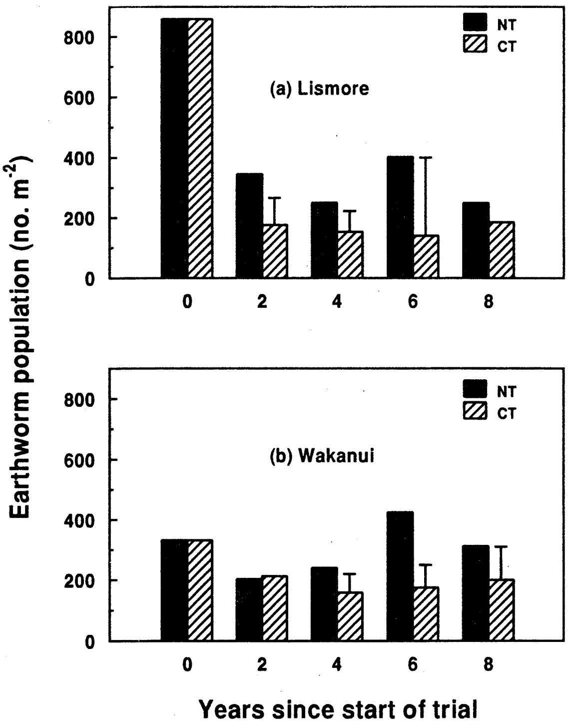

Figure 1. Total earthworm populations in no-tilled (NT) and conventionally-tilled (CT) soil at the (a) Lismore site and (b) Wakanui site during the trial. Error bars indicate LSD (P<0.05).

either tillage system resulted in a marked decline in earthworm numbers by the second year of the trial. This decline was associated with the removal of the grazed pasture and the continual returns of fresh organic matter and sheep dung. The initial decline in earthworm numbers was significantly greater following CT than NT due to the additional death of earthworms during conventional tillage operations (Francis and Knight, 1993). These differences persisted throughout most of the trial. Initial numbers were much less at the Wakanui site, as expected for a long-term arable soil. With time, a significantly greater population developed in the NT soil, again probably due to reduced death during tillage (Edwards and Lofty, 1982).

Bulk density and pore size distribution

Tillage effects on bulk density were a reflection of soil aggregate stability. At the relatively stable Lismore soil (Table 1), adoption of NT did not lead to a significant increase in bulk density values (Table 2). In contrast, the Wakanui soil was less resistant to compaction by agricultural machinery during the growing season, resulting in significantly greater bulk density values in the tillage depth under NT compared with CT. This compaction was relieved by annual cultivation under CT, whereas under NT compaction could only be relieved through biological processes (e.g. earthworm burrowing, root extension) or through wetting/drying or freezing/thawing cycles.

At both sites tillage treatment affected the soil pore size distribution. The NT soil had a significantly reduced macroporosity in the top 75 mm (Table 2), which was reflected in an increase in the volume of smaller pores that stored water for plant use (AWHC). At both sites soil macroporosity never approached the

Table 2. Soil bulk density and porosity relationships after nine years of no-tillage (NT) or conventional-tillage (CT)[a].

	Bulk density (Mg/m^3)			Total porosity (%, v/v)			Macroporosity (%, v/v)			AWHC (%, v/v)[b]		
Depth (mm)	NT	CT	LSD[c]	NT	CT	LSD	NT	CT	LSD	NT	CT	LSD
Lismore												
0-75	1.07	1.07	0.12	59.8	59.8	4.4	23.4	28.8	4.5	25.3	20.3	3.3
75-150	1.13	1.20	0.08	57.2	54.7	3.2	25.9	21.1	5.4	20.7	22.0	2.7
Wakanui												
0-75	1.23	1.18	0.02	53.7	55.5	1.1	19.0	21.4	1.8	20.1	17.2	1.7
75-150	1.33	1.28	0.04	49.9	51.7	1.5	19.3	19.2	1.0	15.9	17.8	1.3

[a] Similar results were obtained throughout the trial   [b] Available water holding capacity   [c] P<0.05

minimum value of 10% below which plant growth is often considered to be adversely affected (Marshall and Holmes, 1988).

Crop yields

The integrated effects of tillage treatment on soil chemical, physical and biological properties were expressed through crop yield. At the high-fertility Lismore site, crop yields were relatively unaffected by tillage treatment in the first seven years of the trial, but in years eight and nine, yields were significantly greater following NT (Fig. 2). This was presumably a reflection of the greater decline in total N content in the CT soil during the trial, which resulted in an inadequate production of mineral N for plant growth in years eight and nine of the trial.

At the low-fertility Wakanui site, the effect of tillage treatment on crop yield was different for winter- and spring-sown crops. For winter wheat (Fig. 3a), there was a trend towards greater yields under NT throughout the trial. As total N levels were unaffected by tillage treatment at this site, it is suggested that the difference in crop yield was due to the contrasting patterns of net N mineralisation during the growing season under NT and CT. For winter wheat, cultivation in autumn stimulated a flush of N mineralisation and the accumulation of mineral N in the profile (Francis and Knight, 1993). Uptake of mineral N by the wheat crop during the autumn/winter would have been low, resulting in the leaching loss of most of the accumulated nitrate in the profile following winter rainfall (Francis *et al.*, 1992). As a result, it is probable that there would have been an inadequate supply of mineral N in CT soil during rapid crop growth in the spring. In contrast, net N mineralisation would have been more evenly distributed throughout the growing season under NT, with less nitrate leached during the winter and a better matching of N mineralisation and demand by the crop (Francis and Knight, 1993).

A different pattern was apparent for spring barley at the Wakanui site (Fig. 3b), with yields either unaffected by tillage treatment or greater under CT. It is suggested that the flush of mineral N production following

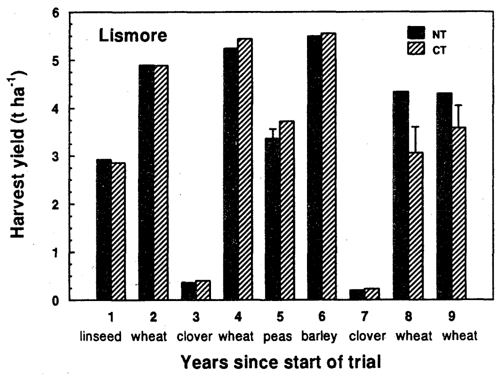

Figure 2. Harvest yields at the Lismore site from no-tilled (NT) and conventionally-tilled (CT) plots during the trial. Error bars indicate LSD (P<0.05).

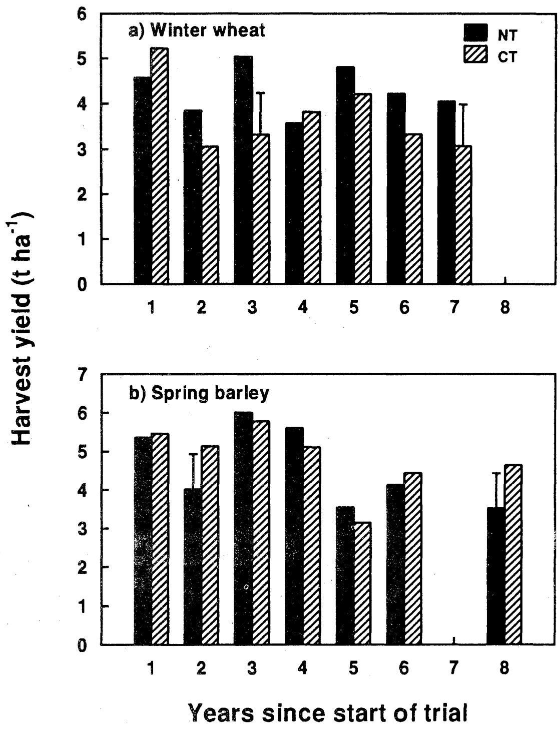

Figure 3. Harvest yields of (a) winter wheat and (b) spring barley at the Wakanui site from no-tilled (NT) and conventionally-tilled (CT) plots during the trial. Error bars indicate LSD (P<0.05).

cultivation in the spring (after winter leaching had ceased) was beneficial for spring-sown crops as the nitrate produced was not susceptible to leaching and was readily-available to the crop in the spring. In contrast, in some years the rate of mineral N production in NT soil was probably not sufficient to meet crop requirements.

Summary

Irrespective of cropping history, contrasting distributions of organic C, total N and related parameters developed with time in NT and CT soil. For soil with an initially high organic C content, the rate of its decline was slower in a continuous arable rotation under NT than CT. In contrast, tillage treatment had no effect on overall organic C content of long-term arable soil. Tillage effects on soil physical properties were more pronounced for the less stable Wakanui soil, but at both sites these differences were unlikely to significantly affect crop growth. Differences in yield at the Lismore site were thought to be associated with the slower rate of total N decline and N-supplying capacity of the soil during the trial under NT compared with CT. At the Wakanui site, effect of tillage treatment on crop yield varied between winter- and spring-sown crops and was thought to be due to contrasting patterns of mineral N production through the growing season.

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