SOIL QUALITY UNDER LONG-TERM CROPPING BY NO-TILLAGE COMPARED WITH CONVENTIONAL CULTIVATION AND PERMANENT PASTURE IN THE MANAWATU

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Abstract

Soil quality after 20 years of continuous no-tillage barley/peas and winter forage crops was compared with 16 years of continuous cultivated maize crops and permanent pasture in the Manawatu. All soil quality properties, except for Olsen-P, exchangeable cations and bulk density immediately after cultivation, were higher under pasture than both cropping regimes. Soil organic matter in the 0–20 cm zone decreased 11% under no-tillage cropping and 17% under cultivated cropping, compared with pasture.

Soil microbial properties under no-tillage cropping were about 80–85% of pasture but declined to 50–70% with cultivated cropping. Anaerobically mineralizable-nitrogen was a particularly sensitive indicator: no-tillage being 85% of pasture compared with 24% under cultivation. Earthworm populations under no-tillage were 77% of pasture, whereas there were very few small earthworms under cultivated cropping. Aggregate stabilities showed a small decline under no-tillage but significant decline with cultivation.

Visual assessments of soil structure showed surprisingly little difference between the pasture and no-tillage cropping. A dense, coarse cloddy structure, however, was evident under cultivated continuous maize. These results suggest that continuous no-tillage cropping systems conserve soil quality. In comparison, significant soil degradation occurs with conventionally cultivated continuous arable cropping.

Introduction

Soil quality (defined as "fitness for use"; in an arable or forage cropping context, providing for sustainable crop production with minimal adverse impacts on the environment) has been shown to degrade under continuous cultivated intensive cropping in New Zealand (McQueen & Shepherd 2002; Shepherd et al. 2001; Saggar et al. 2001; Francis et al. 2001; Sparling et al. 2000; Haynes & Tregurtha 1999; Haynes 1995; Cotching et al. 1979; Gradwell & Arlidge 1971; Packard & Raeside 1952).

Traditionally, farmers have used restorative pasture phases in crop rotations to sustain soil conditions long-term; typically 2 to 4 years pasture following 2 to 4 years of cropping (Haynes & Francis 1990). Alternatively, farmers have coped with deteriorating soil quality by putting on extra fertilizer, using more powerful machinery and more cultivation to develop seedbeds, and/or tolerated declining crop performance until production becomes uneconomic.

More intensive forage cropping is occurring in New Zealand farming systems, particularly as a consequence of the expansion of dairy farming in the South Island. This is placing increasing

pressure on arable soils, and has led to renewed interest in no-tillage as an alternative to degradative cultivated cropping.

No-tillage offers an alternative farming system that claims to conserve soil quality under intensive cropping without the need for restorative pasture phases. No-tillage systems applicable to New Zealand farming practices are described in Ritchie et al. (2000). Previous studies in New Zealand (e.g., Francis & Knight 1993; Horne et al. 1992; Haynes & Knight 1989; Ross & Hughes 1985; Ross & Cox 1981) compared the effects on soil properties of different cultivation regimes, including no-tillage. These examined only a limited set of soil quality indices, for cropping periods of up to 10 years, and generally did not make comparisons with permanent pasture, as a benchmark.

This study, carried out in the Manawatu, compares soil quality indices under no-tillage and under conventional cultivation systems of intensive continuous cropping, using permanent pasture as a benchmark. The forage and maize crops grown on the monitor paddocks in this study have relevance to forage production aspects of dairy farm soil management.

Experimental

Soil quality indices tested were a suite of physical, chemical and biological indices used in New Zealand as environmental indicators (Schipper & Sparling 2000). The soil sampling system was the same as that described by Sparling and Schipper (1999), except that two depths (0–10 cm and 10–20 cm) were used. Results are presented for the combined 0–20 cm depth. Statistical analyses using SYSTAT were used for analysis of variance tests.

Soil quality indices were measured on two paddocks (mean values are presented) after 20 years of no-tillage, 18 years of which were double-cropped – either summer barley or pea crops on a 2-year cycle (one of the paddocks had 3 years of maize) and winter forage crops of brassicas, oats, annual ryegrass, or tic beans with wheat or oats. The cultivated-cropping comparison had 16 years of continuous maize and winter fallow, under a regime of ploughing and secondary cultivations. The permanent pasture site was the paddock adjacent to the no-tillage paddocks and had relatively low-management sheep and young cattle grazing. The soils were poorly drained alluvial silty clay loams (Orthic Gley soils).

Results and Discussion

Results showed that, with the exception of some nutrients, all soil quality parameters were better under pasture than either of the cropping regimes. With the exception of nutrient levels, soil quality parameters, under no-tillage were generally about 80% of those under pasture and significantly better ($p<0.001$ to 0.01) than cultivated cropping (Figs 1–4).

Organic matter content (Fig. 1) in the tillage zone (0–20 cm) decreased 11% under no-tillage cropping and 17% under cultivated maize, despite 16% more clay at the cultivated site, which would be expected to retain higher organic matter levels. As evaluated by the drop-shatter test of the Visual Soil Assessment method of Shepherd (2000), soil structure under no-tillage was very similar to pasture, whereas it was coarse cloddy under continuous cultivated cropping (Fig. 2). Aggregate stability (Fig. 3) was adversely affected by cultivation but only slightly reduced by no-tillage.

Similar results showing better soil structural conditions under no-tillage compared with cultivation have been reported from surveys of different tillage regimes from about 70 mixed-

cropping paddocks in Canterbury (Beare et al. 2001). Beare et al. (2001) have also demonstrated that crop yields are related to soil structural condition, so these factors are important for crop productivity and farm profitability. A tillage pan was evident under cultivated cropping but not under no-tillage or pasture. Field variability was greater than differences between the different tillage regimes for bulk density, hence there were no statistically significant differences. This suggests that bulk density is not a particularly sensitive indictor of soil quality.

A number of measures of soil microbial activity showed similar trends to aggregate stability, as illustrated by anaerobically mineralisable-N (Fig. 4) and biomass C (Table 1). Earthworms were particularly depleted by cultivated cropping (Fig. 5): no-tillage maintained 77% of pasture populations, whereas only a very few small worms remained after 16 years of cultivated cropping.

Soil nutrient levels (available-P, -K, -Mg) were highest under cultivated maize cropping, intermediate for no-tillage cropping, and least under pasture (Table 1). For example, cultivated maize had Olsen P values of 52.9 mgP/kg, no-tillage averaged 24.3 mgP/kg, and pasture 7.4 mgP/kg. These differences in soil nutrient levels reflected differences in fertilizer application rates. There were no significant differences in pH (5.6–5.9) across the three systems.

Table 1. Soil fertility and bulk density indices under permanent pasture, no-tillage and cultivated cropping.

	Pasture	No-till	Cultivation	Significance
pH	5.9a	5.8b	5.6c	***
Olsen-P (mg/kg)	7c	22b	53a	***
% BS	64a	56b	70a	**
Biomass C (kg/ha)	1889a	1536b	976c	***
Bulk density (t/m^3)	1.33	1.30	1.31	NS

Different letters indicate significant differences. ** P<0.01, *** P<0.001, NS=not significant

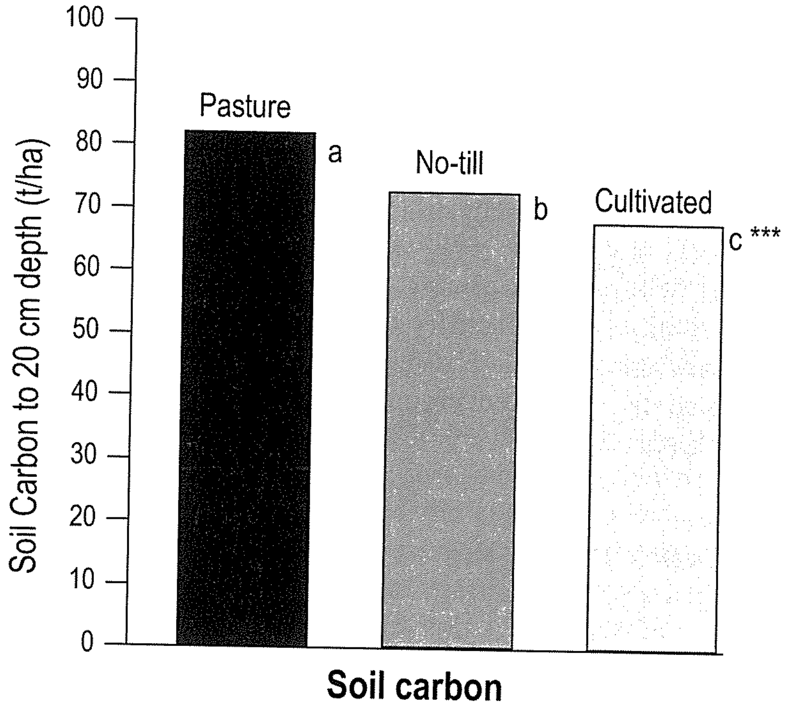

Figure 1. Soil organic matter levels in the tillage zone (0–20 cm) comparing permanent pasture with no-tillage and cultivated cropping (Different letters beside the histogrammes indicate statistically significant differences between values. $P<0.001$ ***)

Figure 2. Soil structure from the drop-shatter test, comparing permanent pasture with no-tillage double-cropping and cultivated continuous maize.

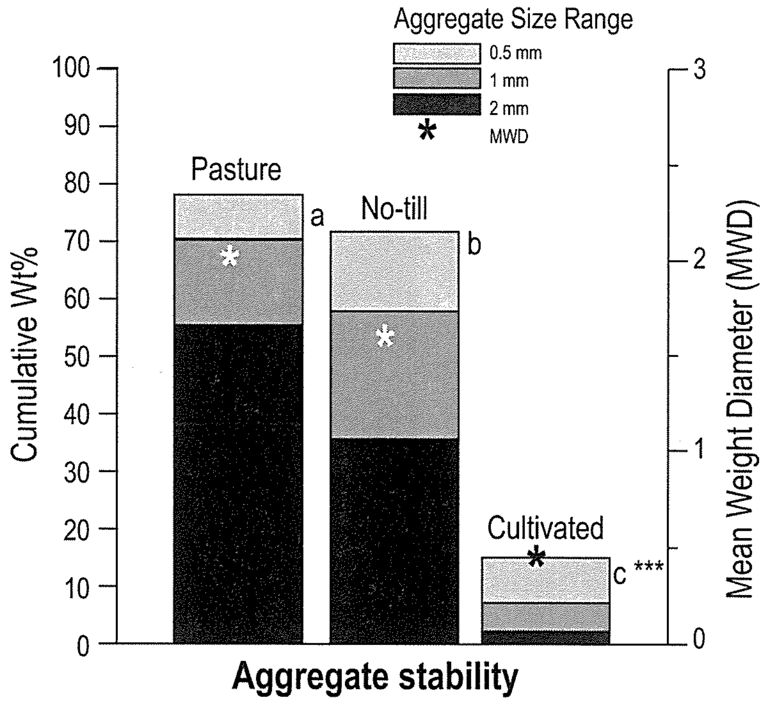

Figure 3. Aggregate stabilities from wet sieving under permanent pasture, no-tillage and cultivated cropping (Different letters beside the histogrammes indicate statistically significant differences between values. P<0.001 ***)

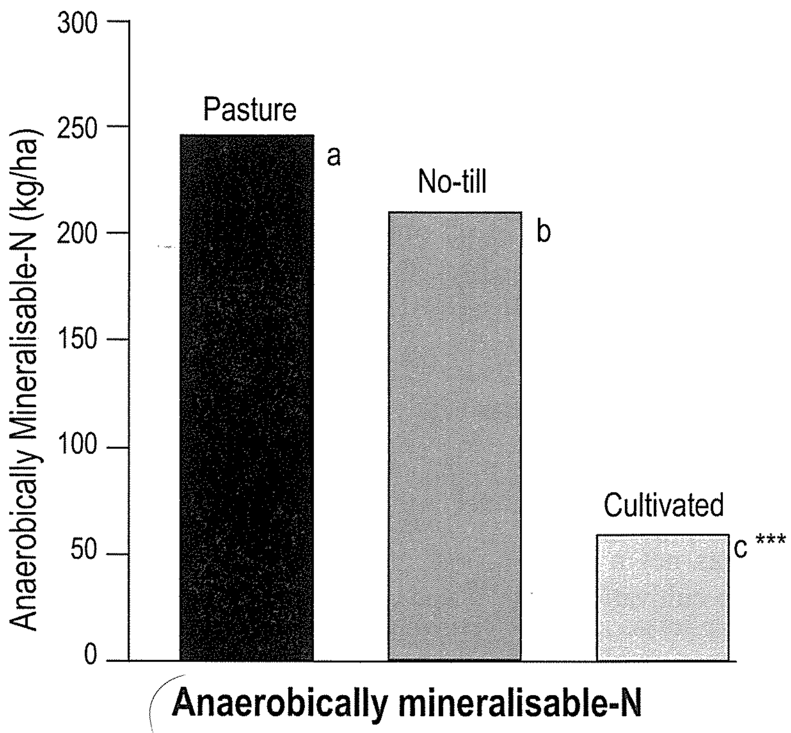

Figure 4. Anaerobically mineralisable-N under permanent pasture, no-tillage and cultivated cropping (Different letters beside the histogrammes indicate statistically significant differences between values. P<0.001 ***)

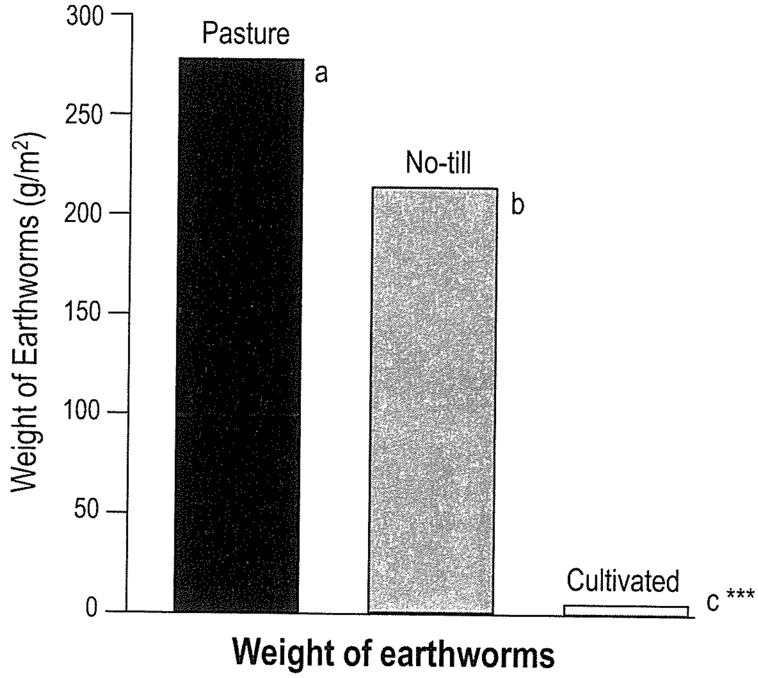

Figure 5. Earthworm populations under permanent pasture, no-tillage and cultivated cropping (Different letters beside the histogrammes indicate statistically significant differences between values. P<0.001 ***)

Conclusions

- Soil quality indices of soil structure, organic matter and microbial activity under no-tillage were generally about 80% of pasture
- Levels under cultivated cropping were 50% or less of pasture
- Chemical fertility was highest under cultivated maize, intermediate under no-tillage double-cropping, and lowest under pasture. These reflected differences in fertilizer and lime applications
- Earthworms under no-tillage were 77% of pasture, compared with negligible populations under cultivated maize
- Intensive long-term no-tillage cropping conserved physical and biological indices of soil quality compared with significant declines with cultivated cropping
- Bulk density was not a sensitive soil quality indicator for distinguishing differences between the two cultivation regimes and pasture.

Acknowledgements

This study was funded by the Foundation of Research, Science and Technology Contract C09X0016. Thanks to Dr John Baker, Brent Smith and Robert Fleming for access to sample their paddocks, and to the staff of Baker No-tillage Limited for their support and encouragement.

References

Beare, M.; Fraser, P.; Curtin, D. 2001: Tillage, soil structure and crop performance. Crop & Food Research INFO sheet No. 3-7-2001.

Cotching, W.E.; Allbrook, R.F.; Gibbs, H.S. 1979: Influence of maize cropping on the soil structure of two soils in the Waikato district, New Zealand. *New Zealand Journal of Agricultural Research 22*: 431–438.

Francis, G.S.; Knight, T.L. 1993: Long-term effects of conventional and no-tillage on selected soil properties and crop yields in Canterbury, New Zealand. *Soil and Tillage Research 26:* 193–210.

Francis, G.S.; Tabley, F.J.; White, K.M. 2001: Soil degradation under cropping and its influence on wheat yield on a weakly structured New Zealand silt loam. *Australian Journal of Soil Research 39*: 291–305.

Gradwell, M.W.; Arlidge, E.Z. 1971: Deterioration of soil structure in the market gardens of the Pukekohe district, New Zealand. *New Zealand Journal of Agricultural Research 14*: 288–306.

Haynes, R.J. 1995: Soil structure breakdown and compaction in New Zealand soils. MAF Policy Technical Paper 95/5. 29p.

Haynes, R.J.; Francis, G.S. 1990: Effects of mixed cropping farming systems on changes in soil properties on the Canterbury Plains. *New Zealand Journal of Ecology 14*: 73–82.

Haynes, R.J.; Knight, T.L. 1989: Comparison of soil chemical properties, enzyme activities, levels of biomass N and aggregate stabilities in the soil profile under conventional and no-tillage on selected soil properties and crop yields in Canterbury, New Zealand. *Soil and Tillage Research 14:* 197–208.

Haynes, R.J.; Tregurtha, R. 1999: Effects of increasing periods under intensive arable vegetable production on biological, chemical and physical indices of soil quality. *Biology and Fertility of Soils 28*: 259–266.

Horne, D.J.; Ross, C.W.; Hughes, K.A. 1992: Ten years of a maize/oats rotation under three tillage systems on a silt loam in New Zealand. 1. A comparison of some soil properties. *Soil and Tillage Research 22:* 209–219.

McQueen, D.J.; Shepherd, T.G. 2002: Physical changes and compaction sensitivity of a fine-textured, poorly drained soil (Typic Endoaquept) under varying durations of cropping, Manawatu Region, New Zealand. *Soil and Tillage Research 63*: 93–107.

Packard, R.Q.; Raeside, J.D. 1952: Deterioration of soil structure in a South Canterbury soil. *New Zealand Journal of Science and Technology 33*: 40–53.

Ritchie, W.R.; Baker, C.J.; Hamilton-Manns, M. 2000: Successful no-tillage in crop and pasture establishment. Centre for International No-Tillage Research and Engineering, Fielding. 96p.

Ross, C.W.; Cox, T.I. 1981: Soil physical conditions of a Levin silt loam following intensive cropping with and without cultivation and under repeated wheel traffic. *New Zealand Journal of Agricultural Research 24*: 177–182.

Ross, C.W.; Hughes, K.A. 1985: Maize/oats forage rotation under three cultivation systems, 1978–83. 2. Soil properties. *New Zealand Journal of Agricultural Research 28:* 209–219.

Saggar, S.; Yeates, G.W.; Shepherd, T.G. 2001: Cultivation effects on soil biological properties, microfauna and organic matter dynamics in Eutric Gleysol and Gleyic Luvisol soils in New Zealand. *Soil and Tillage Research 58*: 55–68.

Schipper, L.A.; Sparling, G.P. 2000: Performance of soil condition indicators across taxonomic groups and land uses. *Soil Science Society of America Journal 64*: 300–311.

Shepherd, T.G. 2000: Visual Soil Assessment. Vol. 1. Field guide for cropping and pastoral grazing on flat to rolling country. Horizons mw & Landcare Research, Palmerston North. 84p.

Shepherd, T.G.; Saggar, S.; Newman, R.H.; Ross, C.W.; Dando, J. 2001: Tillage-induced changes to soil structure and organic carbon fractions in New Zealand soils. *Australian Journal of Soil Research 39*: 465–489.

Sparling, G.P.; Schipper, L.A. 1999: Soil quality changes under intensive and extensive land use in New Zealand. In Currie, L.D.; Hedley, M.L.; Horne, D.J.; Loganathan, P. eds: 'Best soil management practices for production'. Occasional report No. 12. Fertilizer and Lime Research Centre, Massey University, Palmerston North. pp. 53–62.

Sparling, G.; Schipper, L.A.; Hewitt, A.; Degens, B.P. 2000: Resistance to cropping pressure of two New Zealand soils with contrasting mineralogy. *Australian Journal of Soil Research 38*: 85–100.