Cover crops and tillage intensity affect nitrate leaching

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Abstract

The potential for nitrate (NO_3^-) to leach is enhanced following cultivation of pastoral land for arable cropping, due to the rapid mineralisation of soil organic matter and possible changes in soil water storage and drainage. The impacts of tillage intensity [i.e., intensive (ploughing to 20 cm), minimum, and no-tillage] and winter cover crops on nitrate leaching were assessed over a seven year period following cultivation of a long term (> 14 years) pasture. Permanent pasture and permanent fallow treatments were included as controls. The total amount of NO_3^- leached ranged from about 20 to 428 kg N ha^{-1}. Overall, the presence of winter cover crops reduced winter NO_3^- leaching by almost 50%. Generally, NO_3^- leaching increased with increasing amounts of winter rainfall, but leaching was also strongly influenced by the tillage method used in the preceding autumn. Overall, the intensive tillage treatment had the highest NO_3^- leaching losses and minimum tillage had the lowest NO_3^- leaching losses of the cultivated treatments, both in the presence or absence of cover crops. Nitrate leaching losses from soils under continuous no-tillage were similar to those from minimum tillage where winter rainfall was between 175 and 275 mm, but when winter rainfall exceeded about 275 mm the losses increased substantially under no-tillage. Under arable production, the use of minimum tillage may reduce the potential loss of nitrogen over the ensuing winter period particularly in years or localities of high rainfall. Given that cover crops can substantially reduce NO_3^- leaching, soil should not be left bare over the winter.

Additional keywords: Cultivation, minimum tillage, no-tillage, crop rotation, arable, solution samplers

Introduction

Leaching of nitrate-N from agricultural land can adversely affect groundwater quality. The leached nitrate may be derived either from applied fertiliser N or from the mineralisation of organic N. The total nitrogen (N) concentration in topsoils generally increases during the grass/pastoral phase of arable cropping rotations, due to both symbiotic N_2 fixation by clover and the accumulation of soil organic matter (Haynes and Francis, 1990). Cultivation of grass/pasture to sow arable crops can result in rapid mineralisation of organic N and a consequent increased risk of nitrate (NO_3^-) leaching. Autumn sown cover crops (e.g.

forage rape [*Brassica napus* L.] commonly grown as winter grazing fodder) can alter the supply of N and the timing of its availability to spring sown crops within a arable crop rotation (Thorup-Kristensen, 1994). Uptake of N by winter cover crops can potentially reduce the amount of leachable N. Where these crops are grazed by livestock, the N returned in urine and dung may increase the risk of NO_3^- leaching following grazing (Haynes and Williams, 1992) and/or increase the availability of N to the succeeding crop (Stute and Posner, 1995). A recent review has highlighted the need for research to optimise N management in crop production (Galloway *et al.*, 2008). In particular, information on the impact of cover crops on N leaching in cereal crop rotations is scarce (Herrera and Liedgens, 2009).

Reduced tillage systems to establish arable crops have been proposed as management strategies to reduce NO_3^- leaching associated with soil organic matter mineralisation. However, conflicting results have been reported with respect to the ability of reduced tillage to curtail NO_3^- leaching (Hooker *et al.*, 2008). Reduced tillage can sometimes (Power and Peterson, 1998) reduce the loss of N via leaching, but it seems that this effect may be dependent on site-specific factors related to soil physical and biological characteristics (Tan *et al.*, 2002).

A long term field trial was established in 2000 to evaluate the effect of winter cover crops and reduced tillage systems on nitrate leaching. This paper summarises the findings of how tillage and cover crop management practices influenced nitrate leaching losses over the first seven years (2000-07) of the trial.

Materials and Methods

In the spring of 2000, a field trial was imposed on long term pasture (> 14 years) that had grown on Wakanui silt loam soil at Lincoln, Canterbury (43° 40’ S; 172° 28’ E), New Zealand. The trial had six cultivation treatments (combinations of spring/autumn tillage events, varying in intensity; Table 1) plus a ‘control’ treatment. The control consisted of an uncultivated permanent pasture (PP), which was split to also include an uncultivated, permanent (chemical) fallow (PF) treatment. Each treatment was replicated three times. Combinations of three main tillage methods were used, (i) ‘No-tillage’ - where the crops were established without cultivation; (ii) ‘Minimum tillage’ - where the soil was disked (0-10 cm) and (iii) ‘Intensive tillage’ - mouldboard ploughed (0-20 cm), where the latter two were each followed by secondary cultivation (Table 1).

Table 1: Tillage treatments

	Autumn Tillage		
Spring Tillage	*Intensive (i)*	*Minimum (m)*	*None (n)*
Intensive (I)	Ii	Im	In
Minimum (M)		Mm	Mn
No tillage (N)			Nn

Main crops of spring-sown barley (*Hordeum vulgare* L.), wheat (*Triticum aestivum* L.*)* and peas (*Pisum sativum* L.) were grown in rotation on each of the cultivated plots. All crops were sown with a Great Plains Direct Drill. Following their harvest (late summer), a winter cover crop (either oats (*Avena sativa* L.) in 2001 or forage rape (*Brassica napus* L.) in 2002-2007) was sown on half of each of the cultivated plots (split-plot treatment; cover crops were grown on same split plot side each year); the other half was similarly cultivated (as outlined in Table 1), but thereafter remained in fallow for the winter period. Minus cover crop plots received the same tillage treatments as the corresponding plots with cover crops to simplify treatment comparisons. Cover crop plots were grazed once each year by sheep in late winter/early spring. In total, the trial contained 42 split plots ((6 cultivation treatments + 1 control) x 2 crop cover treatments x 3 replicates), each 28 m x 9 m. Soil nutrient reserves were tested periodically and, after estimation of crop needs, sufficient fertiliser (N and P) was applied so that nutrients were not limiting to plant growth. Relatively conservative amounts of fertiliser N were applied (on average 134 kg ha^{-1} to spring cereal crops and 24 kg ha^{-1} for winter cover crops). The PF plots received *no fertiliser* whilst the PP received N fertiliser on only two occasions (15 kg N ha^{-1} in July 2001 and 24 kg N ha^{-1} in August 2002). The PP plots were periodically grazed (year round) as required by sheep.

Nitrate leaching was measured during the late autumn, winter and early spring periods using ceramic suction cups placed at 60 cm depth. Although we recognise the limitations of using such suction cups (Webster *et al.,* 1993) and that all current methods for measuring leachate have their limitations, this method was employed for both practical and economic reasons. Water was collected from the suction cups whenever rainfall triggered a drainage event. The amount of drainage was calculated using a simple water balance based on measured initial soil moisture, daily rainfall and evapotranspiration (Jamieson *et al.*, 1995). Soil solution samples were collected from each of three solution samplers placed in each plot and samples were analysed for NO_3^- using the standard colorimetric method (Keeney and Nelson 1982). All of the leaching data ($\log_e$ transformed) were analysed using a mixed model fitted with restricted maximum likelihood (REML, GenStat v.12, VSN International Ltd, UK). Relationships with rainfall were modelled within this analysis using smoothing splines (Verbyla, 1999).

Results and Discussion

Overall, average annual rainfall from 2000 to 2007 at the trial site was slightly lower than the long term local average (Table 2). Fertiliser N was applied to spring and winter crops ranging in rate from 15 to 206 kg N ha^{-1} y^{-1}, depending on the crops' estimated requirement (data not shown). The average soil mineral N remaining in the autumn (0-60 cm depth) ranged from 47 to 142 kg N ha^{-1} (data not shown).

Over the 7 winter periods (2001 to 2007 inclusive), total cumulative NO_3^- leached ranged from 20 kg N ha^{-1} in the PP treatment to 428 kg N ha^{-1} under PF (Table 3). Over the same period, the average cumulative total NO_3^- leached from intensively tilled soil was 208 kg N ha^{-1}, compared with 200 kg N ha^{-1} and 192 kg N ha^{-1} from the no tillage and minimum tillage treatments, respectively (Table 2). The presence of winter cover crops reduced NO_3^- leaching by 76 to 119 kg N ha^{-1} over the seven year period (Table 2). Although no N was applied to PF plots, they consistently lost the most NO_3^- via leaching (on average 60 kg N ha^{-1} y^{-1}); this N must have originated from the mineralisation of organic N. This result also suggests that the presence of plants in the system may have a greater influence on NO_3^- leaching than tillage does. The PP plots lost the least NO_3^- by leaching - presumably due to continuous uptake of N by the actively growing pasture. The large difference in NO_3^- leached by the PP and PF treatments further highlights the important role of plants as a sink for N during the winter. The presence of a winter cover crop (mainly forage rape) markedly reduced the total amount of NO_3^- leached by an average of almost 50% ($P<0.001$). Our analyses also demonstrated that the tillage applied in the preceding autumn had a significant influence ($P<0.001$) on winter leaching, whereas the tillage applied in the spring did not ($P=0.171$).

Generally, the amount of NO_3^- leached increased with increasing winter rainfall for all treatments (Figure 1). Relatively small differences existed among treatments at lower levels of winter rainfall (50-150 mm) where the leached NO_3^- was typically < 20 kg N ha^{-1} and the absence of cover crops was the main contributor to increased NO_3^- leaching. The difference among tillage treatments tended to increase above about 175 mm of winter rainfall in the absence of cover crops, and above about 250 mm of rainfall where cover crops were grown.

Table 2: Amounts of winter and annual rainfall at the trial site.

Year	Winter Rainfall[1] (mm)	Annual rainfall (mm)
2001	162.4	419
2002	173.6	675
2003	158.6	466
2004	208.2	645
2005	78.0	411
2006	352.4	853
2007	190.8	519
Average (2001-07)	189.1	570
Long term local average	-	680

[1] 'winter' is defined as period from 15 May to 15 September inclusive.

Table 3. Total cumulative NO_3^- (2001-2007) leached over successive winters (mid-May to mid-September) from the various treatments.

Treatment	Cumulative NO_3^- leached, 2001-2007 (kg N ha^{-1})		Reduction in NO_3^- leaching over seven winters due to presence of cover crops (kg N ha^{-1})
	+CC[1]/pasture	-CC[1]	
Intensive	93	208	115
Minimum	73	192	119
No tillage	124	200	76
Permanent pasture	20	-	-
Permanent fallow	-	428	-
$LSD_{0.05}$ (t = 2)	44.2		-

[1] where +CC means in the presence of and -CC means in the absence of winter cover crops.

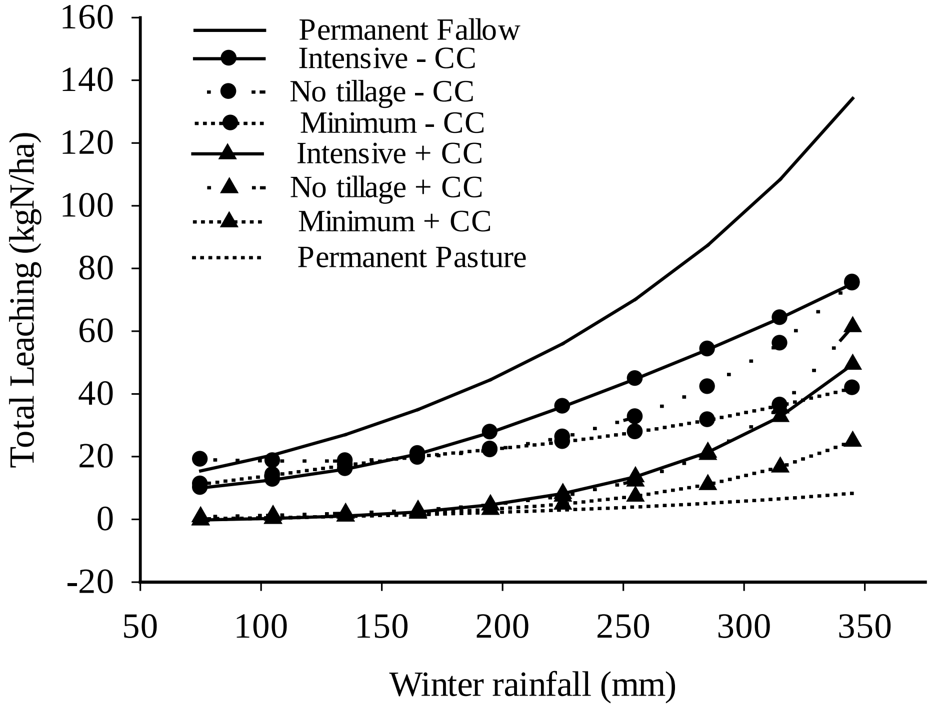

Figure 1: Modelled NO_3^- leaching (using spline model) as a function of winter rainfall (back transformed data), where -CC = without winter cover crops; +CC = with winter cover crops.

Overall, the minimum tillage treatment had the lowest NO_3^- leaching losses of the cultivated treatments both in the presence or absence of cover crops. Minimum tillage also produced the smallest increases in leaching in response to rainfall. Even at a winter rainfall of 350 mm, only about 20 kg N ha^{-1} was leached from minimum tillage in the presence of a cover crop (~35kg N ha^{-1} without cover crops). Under the cropping treatments, the highest NO_3^- leaching losses were recorded under intensive and no-tillage management practices, although the effect of rainfall differed among the three main tillage treatments where cover crops were present. In general, our statistical model predicted that NO_3^- leaching losses under no-tillage remained lower and similar to those of minimum tillage at winter rainfalls between about 175 and 275 mm, but the losses increased substantially when winter rainfall exceeds about 275 mm. There was also a convergence of NO_3^- leaching losses between plus and minus cover crop treatments at the highest rainfall (i.e. 300-350 mm), especially under intensive and no-tillage management.

Although this trial mainly focussed on the effects of tillage and cover crops on nitrate leaching, other aspects of the N cycle must also have to be taken into consideration when assessing the overall environmental impact of farming systems. The N cycle is analogous to a "leaky pipe" (Davidson and Mosier, 2004) and controlling one leak can cause or increase leaks in other parts of the cycle. Studies comparing the effects of reduced to conventional tillage systems with regard to emissions of N gases have given highly inconsistent results (Stark and Richards, 2008). Nitrate-N concentrations have been shown to be lower in drainage water from no-till compared to conventional tillage systems and this has been attributed to higher rates of denitrification in the no-till soils (Mkhabela *et al.,* 2008). So although minimum tillage reduced nitrate leaching in the current experiment, the potential associated implications for gaseous N emissions are unknown. Future work in which the losses of N via both leaching and gaseous emissions are determined from different arable management systems in New Zealand may be useful in resolving this leaky pipe conundrum.

Conclusion

Use of minimum tillage rather than intensive cultivation (ploughing) within arable cropping rotations may reduce N loss via leaching, particularly in years with higher winter rainfall. The use of winter cover crops can reduce NO_3^- leaching by 50% and so, where possible, soil should not be left bare over winter in order to reduce the potential for NO_3^- leaching loss.

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