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THE EFFECT OF WINTER FORAGE CROP AND ESTABLISHMENT METHOD ON N LOSSES DURING DAIRY PASTURE RENEWAL

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Abstract

There is concern about the fate of mineral nitrogen (N) in dairy systems, particularly from grazing of winter forages during pasture renewal. A field experiment was conducted on a poorly drained soil in Canterbury to investigate the effects of renewal via a crop of winter rape, or direct to pasture, on N losses. Two different tillage techniques to establish the crops were compared: intensive cultivation and direct drilling. Grazing effects on losses were compared by further splitting the plots. Additional treatments were: with and without treading, and with and without urine-amendment. Measurements made during the experiment included plant N, soil mineral N to 1 m, soil water content, and mineral N in porous cups at 1 m depth. Drainage was modelled using APSIM.

Nitrate leaching losses ranged from 15–28 kg N/ha over the period of the experiment (March 2012–January 2013). In this experiment, where urinary N inputs were equal, winter nitrate leaching losses were higher from plots sown directly to ryegrass than from plots re-grassed via forage rape. A mass balance of N inputs less N measured in the plant, soil or lost through leaching accounted for 77–100% of the applied N. We speculate that a large proportion of the N we could not account for was lost through gaseous transformations of added N and that compaction in the treaded plots may have enhanced denitrification losses. The addition of urine caused a large increase in unaccounted for N losses, but had comparatively little effect on nitrate leaching. Tillage technique had no significant effect on yields or N leaching.

1 Introduction

Pasture renewal is commonly practised by New Zealand dairy farmers to improve productivity (Bryant et al. 2010). Renewal is commonly achieved by spraying out the old pasture in late summer followed by cultivation. This cultivated land is then sown directly back into pasture, or into a short-term crop and then sown into pasture the following spring. The purpose of the short-term crop is to supply a large amount of feed for dairy cows over winter; it also creates a second opportunity to spray and eradicate problem weeds, and provides a pest and disease break (Bryant et al. 2010).

The decomposition of the old pasture during the process of renewal results in a large release of nitrogen (N) into the soil (Francis et al. 1995; Smit and Velthof, 2010; Velthof et al., 2010) in autumn. High concentrations of soil mineral N can lead to unwanted winter and spring leaching or nitrous oxide losses. Similarly, winter grazing a high N-containing crop results in the excretion of a large amount of N onto the soil, which may also be lost by leaching or gaseous emissions.

There have been no studies comparing N losses under the two systems of pasture renewal, although there have been three recent studies (Smith et al. 2012; Monaghan et al. 2013; Malcom et al. 2015) investigating the losses of N under brassica crops, which often form a component of pasture renewal, and studies investigating N losses under pasture.

Another choice farmers need to make during pasture renewal is the method of establishment. Some international studies have found less nitrate leaching under direct drilling than under intensive cultivation (Colbourn 1985; Dowdell et al. 1987; Meek et al. 1995). In contrast, Turpin et al. (1998) found greater leaching of nitrate under zero-tillage than cultivated soil and Hansen et al. (2015) found no overall effect of cultivation on nitrate leaching. It is therefore of interest to investigate the effect of tillage on N leaching under New Zealand field conditions.

The aim of this study was to investigate whether the type of pasture renewal, including establishment method and grazing factors (urine and treading) affect N leaching losses in a poorly drained Canterbury soil.

2 Material and Methods

2.1 Field trial design.

A field trial was conducted on a poorly drained Flaxton Deep Silty Loam over Clay soil in Lincoln, New Zealand. This site received 653 mm of rain over the experimental period (14 March 2012 to 23 January 2013), with 30% of precipitation falling during the winter grazing phase.

A grass/clover pasture (>15 years old) was sprayed twice with glyphosate (Table 1). Three establishment methods were used; rape by intensive tillage (IT Rape) or direct drilling (DD Rape), and ryegrass by direct drilling (DD Pasture). The IT Rape plots were mouldboard ploughed on 5 March to *c*. 20 cm, power harrowed and Cambridge-rolled twice. All treatments were sown on the 14 March with rape (*Brassica napus* L. *spp. biennis* ‘Titan’) or ryegrass (*Lolium perenne* L. ‘Nui’).

A randomised split plot design was used. The main plots (replicated four times) were IT Rape, DD Rape and DD Grass. Four split plots (6×2m) were imposed within each of the establishment methods at simulated grazing; consisting of with (+) and without (0) urine, and with (+) and without (0) treading.

Table 1. Phases and management of the field trial

Phase	Date	Activity
Pasture destruction phase	24 Jan 2012	Old pasture sprayed off
24 Jan–13 Mar 2012	21 Feb	Second spray off
	5 Mar	Ploughing and power harrow
Cropping phase	14 Mar	Cambridge roll (IT only), drilling and harrows
14 Mar–1 Jul 2012	20 Mar	Fertiliser application (Cropzeal 20 at 50 kg N/ha)
	30 Apr	Urea application (50 kg N/ha)
	11 May	Grass cut
Winter grazing phase	2–4 Jul	Grass and rape cut
2 Jul–24 Sep 2012	11–18 Jul	Treading
	18–19 Jul	Synthetic urine application
	28 Aug	Herbicide
	5 Sep	Grass cut
Grass phase	25 Sep	Re-grassing
25 Sep–23 Jan 2013	16 Oct	Grass cut
	23 Nov	Grass cut
	11 Dec	Grass cut
	23 Jan 2013	Grass cut

2.2 Simulated Grazing

A single grazing event was simulated in July 2012 (Table 1). Rape was cut *c*. 20 cm above ground level and grass plots were mown to a residual of *c*. 1500 kg DM/ha. Herbage was carefully removed from the plots. Approximately 9 mm of irrigation was applied to the site 24 hours prior to treading to simulate treading in wet conditions. Treading was then applied to split plots using a cow hoof simulator comprising 16 circular plates (100 mm diameter) providing downward pressure of 225 kPa evenly to the entire surface of treaded split plots. Synthetic urine was applied to split plots by watering can at 10 L/m^2. The urine was formulated as described by Kool et al. (2006), with urea and hippuric acid rates adjusted to achieve a rate a 600 kg N/ha.

2.3 Regrassing

Plots were left in post-grazing conditions for 10 weeks after simulated grazing. IT and DD Rape plots were then sprayed off with glyphosate, and sown with ryegrass on 25 September using the same establishment method used for the March 2012 sowing (i.e. DD or IT). Grass plots were not re-sown.

2.4 Measurements

Volumetric soil moisture content (0–15 cm depth) was measured using Water Content Reflectometers. Soil moisture from 15 to 150 cm depth was measured fortnightly using a neutron probe. Soil cores (5 cm diameter) were collected for determining the bulk density of the 0–7.5, 7.5–15 and 15–25 cm soil depths. A soil solution sampler (2.2 cm diameter tube with porous ceramic cup) was installed on an angle to 1 m depth in the centre of each plot. Soil solution was collected when drainage (>15 mm) was estimated from the water balance. Soil mineral N was measured at increments to 1 m depth on four occasions during the trial.

Grass plots were mown on seven occasions to a height of 5.4 cm, which is equivalent to a residual biomass of approximately 1500 kg/ha (Table 1). Prior to mowing, a 0.5 m^2 quadrat was removed from each plot for yield determination, and the dried biomass analysed for total N.

2.5 APSIM modelling

The Agricultural Production Systems Simulator APSIM 7.5 (Holzworth et al. 2014) was used to estimate drainage. Meteorological data for the experimental period were collected from the Broadlands weather station in the NIWA cli-flo database. Irrigation was added to the rainfall data.

Values for the air dry soil and for saturated hydraulic conductivity were taken from the default Canterbury soil in APSIM except for below 34 cm where saturated soil water conductivity set to 0.1, since drainage at this depth was described as slow (Trevor Webb, pers. comm.). Water content values for saturation, drained upper limit and drained lower limit were estimated from measurements made in the field.

A very shallow rooting depth of 25 cm was used for rape. The rooting depth for ryegrass was set to 1 m.

The default rape cultivars in APSIM were oilseed varieties that produced much less above-ground biomass than 'Titan' forage rape, therefore a number of changes needed to be made to the canola.xml file to simulate the yields grown. Important changes included increasing the radiation use efficiency to 1.76 (Chakwizira and Fletcher 2012) and increasing leaf size by 1.5 because forage rape has much larger leaves than oil rape varieties.

'Claire' winter wheat was used as a proxy for ryegrass, because there was no model in APSIM that would grow perennial ryegrass from seed, and a number of changes were made to the wheat file so that it more accurately followed the growth of ryegrass. Important changes included increasing 'thermal time end of juvenile' to maintain crop development in the juvenile phase so that it kept producing leaves, leaf size was decreased to make it more like ryegrass, and "initial total plant leaf area" was changed from 200 mm^2/plant to 8 mm^2/plant, which gave a much more realistic plant establishment rate.

2.6 Data processing and statistics

Nitrate leaching was calculated by multiplying the nitrate concentrations measured in suction cups located in each plot by the drainage values modelled using APSIM for each treatment. Significant differences among treatments in the amount of nitrate leached were determined by ANOVA. Log transformations were used if the raw data residuals were not normally distributed. Differences were deemed to be statistically significant if $P<0.05$.

3 Results

3.1 Yields

By the 2 July 2012, rape had produced approximately four times more dry matter (DM) than the grass treatment during the cropping phase (*P*<0.001, Figure 1A). The method of establishment did not affect DM production of rape (P=0.462, Figure 1A).

Establishment method also had no effect on summer production of ryegrass following the rape crop (*P=0.583*, Figure 1B). The increase in DM production resulting from winter urine addition on persisted into summer (*P<0.001*, Figure 1B). Treading decreased yields of ryegrass by 9% in the following summer (*P= 0.017*, Figure 1B). Ryegrass leaf N concentrations in the treaded treatments were lower (*P=0.025*) than those of the untreaded treatment in December (3.2% c.f. 3.3%), and were also lower (*P=0.012*) in January (1.9% c.f. 2.0%).

Cumulative yield data for the whole experimental period (13 March 2012 – 23 January 2013) show there was no difference in DM production between the rape and grass treatments (*P=0.429*), method of establishment (*P=0.618*), and treaded and untreaded treatments (*P=0.603*, Figure 1C). The addition of winter urine increased total DM by (*P<0.001*, Figure 1C).

3.2 Bulk density

Treading compacted the topsoil (0–15 cm), as shown by both the increase in bulk density post-treading, and in the greater bulk density of treaded than untreaded plots in September (Table 2). The increase in bulk density was still evident in September, two months after treading. The IT treatment was much more susceptible to compaction than the DD treatments, as shown by the highly significant treading × tillage interaction (Table 2).

3.3 Soil water-holding capacity

The estimates of soil water content by APSIM generally agreed well with measured values (Figure 2), particularly during winter when drainage occurred.

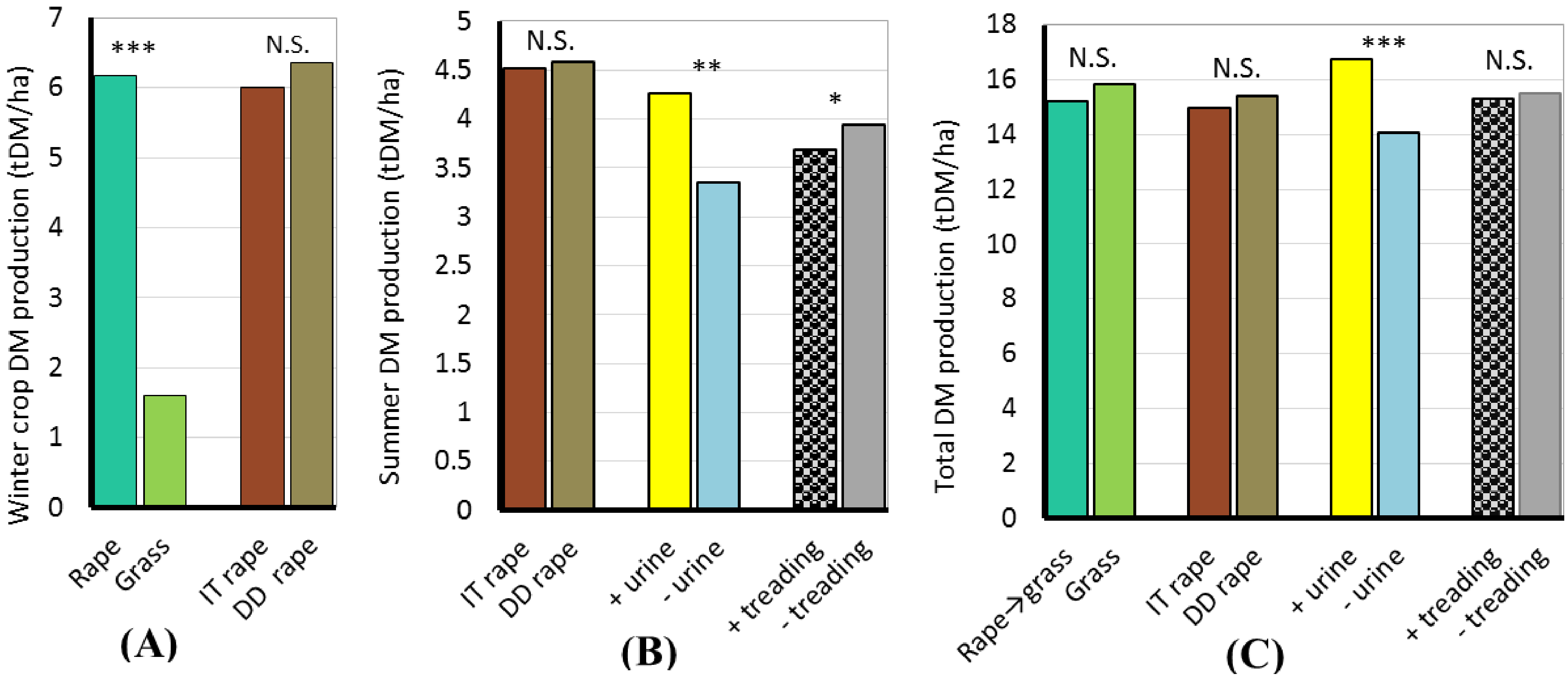

Figure 1. Dry matter production (kg DM/ha) of the experimental treatments over (A) winter (May and July cuts), (B) summer (December and January cuts), and (C) the entire experiment (total). * = significantly different at P<0.001, * = significantly different at P<0.05, N.S. = not significant.**

Table 2. Effect of treading and tillage on soil bulk density (ρ, kg/dm^3). Dates for pre- and post-treading were 10 July 2012 and 6 August 2012, respectively.

	Plots compared pre- and post-treading						Untreaded compared with treaded (19 Sep 2012)					
Depth (cm)	0-7.5		7.5-15		15-25		0-7.5		7.5-15		15-25	
	Pre	Post	Pre	Post	Pre	Post	Untreaded	Treaded	Untreaded	Treaded	Untreaded	Treaded
ρ	1.02	1.16	1.20	1.25	1.36	1.34	1.10	1.18	1.20	1.23	1.33	1.35
P (treading)	<0.001		<0.001		0.08		<0.001		0.033		0.331	
$LSD_{(0.05)}$	0.02		0.02		0.02		0.03		0.03		0.04	
Tillage												
ρ IT	0.98	1.27	1.10	1.20	1.27	1.21	1.17	1.32	1.14	1.20	1.19	1.26
ρ DD	1.04	1.10	1.25	1.28	1.41	1.41	1.07	1.11	1.23	1.25	1.40	1.40
P (treading × tillage)	<0.001		0.007		0.01		<.001		0.295		0.096	
$LSD_{(0.05)}$	0.04		0.03		0.04		0.04		0.04		0.05	

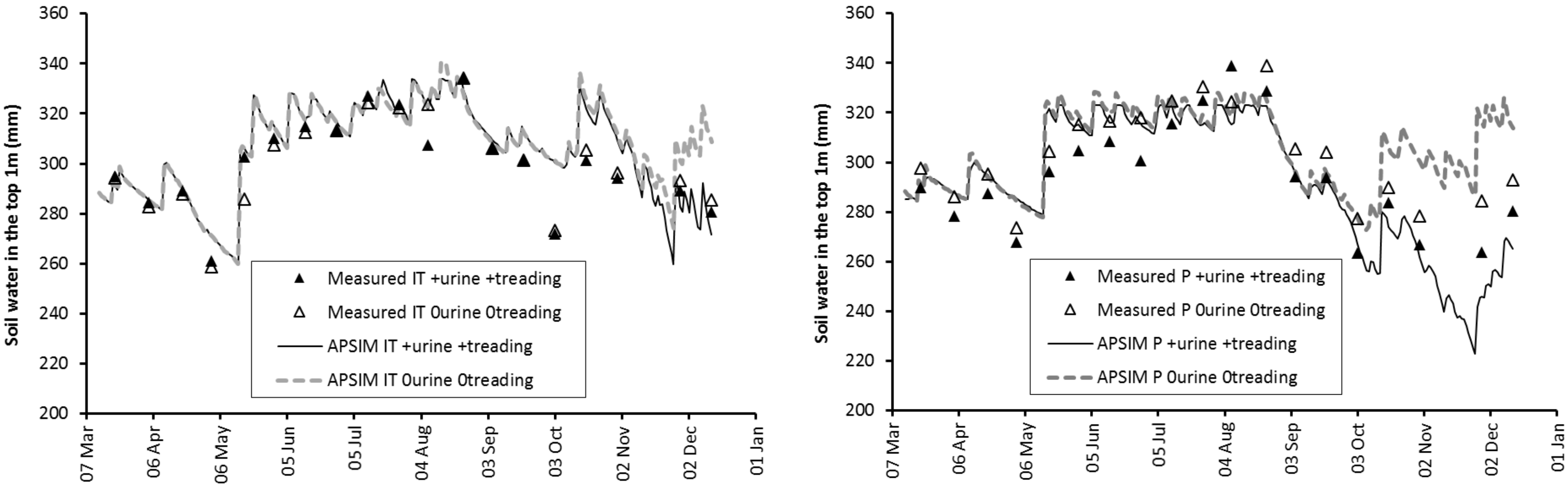

Figure 2. Measured water content (mm) and that predicted by APSIM for IT Rape and Pasture treatment The agreement of the APSIM modelling with the DD data was similar (data not shown).

3.3 Drainage

Approximately 250 mm of drainage was estimated over the experimental period, with approximately half of this occurring during the grazing phase (Table 3). Most of the drainage peaks occurred between May and August.

3.4 Nitrate leaching losses

3.4.1 Cropping phase

Average nitrate leaching losses (Table 3) were small (≤4 kg N/ha). Approximately twice as much N leached from the grass treatment as the rape treatment (Table 3). The amount of N unaccounted for (i.e. not measured in the soil, crop, or as leaching) from the grass treatment was 106 kg N/ha, whereas all of the N inputs into the rape treatment were accounted for (Table 3).

3.4.2 Grazing phase

More N leached from the grass treatment than the rape treatment (Table 3). All of the N inputs into the 0 urine treatment were accounted for by measured plant uptake, mineral N in the soil and leaching (Table 3). The addition of urine resulted in a large increase in N unaccounted for (Table 3). There was also a large increase in N unaccounted for in the treading treatments.

3.4.3 Whole experiment

Average leaching losses for treatments over the whole experiment ranged from 16 to 28 kg N/ha (Table 3), which accounts for <5% of mineral N inputs (measured soil mineral N at the start of the experiment, added fertiliser and urine, and mineralisation predicted by APSIM). An extra 12 kg N/ha of nitrate was measured under the grass plots than under the rape-to-grass plots (P=0.018, Table 3). Tillage treatment had no effect (P=0.753) on nitrate leaching, nor did urine (P=0.203). Treaded plots leached less urine than non-treaded plots (P=0.017).

3.5 Soil mineral N

3.5.1 Cropping phase

At the end of the cropping phase, there was 35% less (p=0.060) mineral N to 1 m in the soil under rape that under grass (Table 3). Tillage had no effect on soil mineral N (p=0.692).

3.5.2 Grazing phase

By the end of the grazing phase there was 79% more (P =0.006) soil mineral N in the plots that were in rape (Table 3). Again, tillage had no effect (P =0.986) on soil mineral N to 1 m. Urine greatly increased (P <0.001) soil mineral N, and treading decreased (P <0.001) soil mineral N (Table 3). There was a strong (P <0.001) treading by urine interaction, with the amount of mineral N to 1 m in the urine plots showing a large difference between treaded (203 kg N/ha) and untreaded (353 kg N/ha) plots, whereas in the non-urine plots there was much less difference between treaded (83 kg N/ha) and untreaded (90 kg N/ha) plots.

Table 3. Fate of mineral N from 13 March–24 September 2012, averaged across treatments. Root uptake and drainage over the period was modelled by APSIM. All other values were measured. "Unaccounted for" equals total mineral N inputs less N in measured or modelled fractions. LSD= Least significant difference at P=0.05, LSR%=Least significant ratio at P=0.05. Nitrate (NO_3) in solution is the average for that phase. Means for NO_3 in solution and NO_3 leached are back-transformed log data, and are significantly different if the ratio of (mean a)/(mean b) > LSR(%).

Amount at the end of phase	Crop			LSD or	Tillage (in rape tmt)		*P*	LSD or	Urine		*P*	LSD or	Treading		*P*	LSD or
Cropping Phase (1 Jul)	Rape	Grass	*P*	LSR%	IT	DD		LSR%	+	0		LSR%	+	0		LSR%
Drainage (mm)	83	102			82	82										
NO_3 in solution (µg/mL)	2.4	4.0	0.018	151%	2.5	2.3	0.578	161%								
NO_3 leached (kgN/ha)	2	4	0.011	139%	2	2	0.800	147%								
Soil min. N to 1m (kgN/ha)	56	91	0.060	37	52	60	0.692	43								
Shoot uptake (kgN/ha)	214	68	<0.001	117%	212	215	0.834	120%								
Root uptake (kgN/ha)	33	28			33	33										
Unaccounted for (kgN/ha)	-8	106			-3	-13										
Grazing Phase (24 Sep)																
Drainage (mm)	129	134			129	129			135	126			130	131		
NO_3 in solution (µg/mL)	8.3	13.1	0.036	151%	8.2	8.5	0.867	161%	11.4	8.2	0.067	141%	7.2	13.0	0.002	141%
NO_3 leached (kgN/ha)	11	19	0.028	157%	11	10	0.833	169%	15	11	0.079	141%	10	16	0.011	141%
Soil min. N to 1 m (kgN/ha)	238	133	0.006	140%	237	238	0.986	148%	335	98	<0.001	114%	155	211	<0.001	114%
Shoot uptake (kgN/ha)	0	179			0	0			249	108	<0.001	1.9	169	188	0.053	19
Root uptake (kgN/ha)	0	16			0	0			46	15			31	31		
Unaccounted for (kgN/ha)	123	146			127	119			267	-6			184	77		
Whole experiment (23 Jan)																
NO_3 leached (kgN/ha)	16	28	0.018	153%	16	15	0.753	163%	21	17	0.203	142%	15	24	0.017	142%

4 Discussion

4.1 Effect of crop type

The amount of nitrate leached during the cropping phase was dominated by the amount of N taken up by the crop, which explains the lower N leaching under rape (Table 3). The large N uptake by the rape crop reduced soil N concentrations in the soil during the cropping phase, which resulted in soil solution nitrate concentrations at 1 m depth during the grazing phase, and lower leaching losses than from the grass treatment (Table 3), despite the absence of plants in the rape treatments post grazing.

Note that the N losses reported in Table 3 do not necessarily imply that, in practice, more N would be lost under grass than rape during grazing. This is because much more N would be excreted per hectare by cattle grazing a 6 t/ha rape crop than a 1.6 t/ha grass crop (Figure 1A) and N losses under urine patches were high (Table 3). This study provides data about N losses under urine patches and non-urine areas, which can then be used to model N losses on a per hectare basis (e.g. Cichota et al. 2016).

4.2 Effect of urine

The fate of added N could be accounted for in the absence of urine, but there was a large amount of N (267 kg N/ha) that could not be accounted for in the urine treatment (Table 3). We speculate that there were large N losses via denitrification in this poorly drained soil, as also found by Hatch et al. (1998). This is supported by the highly significant decrease in mineral N in the soil on the urine treatments that were compacted by treading during winter. APSIM modelling indicated an average denitrification loss of 156 kg N/ha from the urine treated plots over the cropping and grazing phases. This unaccounted for N will also be partly explained by volatilisation, errors in the leaching measurements because of preferential flow and changes in the soil solution nitrate concentration that will not have been captured by fortnightly sampling, as well as measurement errors in soil mineral N concentration and plant uptake.

In comparison to the large effect on unaccounted for N, urine had little effect on the amount of N leached.

4.3 Treading

The 9% decrease in summer DM production in the treaded treatment is likely to be the result of enhanced N losses from the treaded treatments. Evidence for enhanced N losses in the treaded treatments is shown by less N in the soil profile and a lower average leaf N concentration in December and January. There was also a large increase in N unaccounted for in the treading treatments. We speculate that the increased compaction caused by treading (Table 2) led to an increase in denitrification, as found in other studies (Menneer et al. 2005, Hill et al. 2015). The lower nitrate leaching losses measured in the treaded treatments (Table 3) support our speculation that more nitrogen was lost by gaseous losses from the treaded treatments.

4.4 The effect of direct drilling on N losses

These data show that N losses were similar under intensive cultivation and direct drilling. Colbourn (1985) found that direct drilled pastures leached 8 kg N/ha less N than those established by conventional tillage on a clay soil, however denitrification losses were >5 kg N/ha higher, suggesting that the overall N losses were similar.

4.5 Leaching

The amount of nitrate leached from March to January in this study (15–28 kg N/ha) is at the lower end of the 9–475 kg N/ha measured in other studies (Smith et al. 2012; Monaghan et al. 2013; Malcom et al. 2015) of leaching under cropping (the mean of all the studies, including each year and excluding DCD treatments, is 131 kg N/ha). One reason for the higher values in the earlier studies is that the subsequent crops were not sown until November–December, creating a much longer risk period for nitrate leaching than in the present study, where the following crop was sown in September. A second reason for less leaching measured in this study is that the leaching cups were placed at 1 m depth rather than the shallower depth used in other studies – 0.7 m (Malcom et al. 2015), 0.8 m (Monaghan et al. 2013) and 0.55 m (Smith et al. 2012). A third reason for the differences is explained by the soil types: the soils used by both Smith et al. (2012) and Malcom et al. (2015), where amounts of nitrate leached of more than 100 kg N/ha were recorded, were free-draining. In this study, the subsoil was poorly drained, causing waterlogging in the topsoil, and even surface ponding. This is likely to have generated large denitrification losses (Hatch et al. 1998).

5 Conclusions

- Leaching losses from this poorly drained soil were low, accounting for <5% of mineral N inputs.
- Estimates of N losses indicate that denitrification was the dominant loss pathway in this poorly drained soil.
- Where urinary N inputs are equal, winter nitrate leaching losses are higher when sowing directly back into pasture than via a forage rape crop.
- The type of tillage used to establish forage rape does affect nitrate leaching or the amount of mineral N remaining in the soil profile in spring.
- Direct drilling crops during pasture renewal can reduce the risk of compaction from stock treading during winter grazing.
- In poorly drained soils, livestock treading can reduce nitrate leaching and the amount of mineral N in the soil profile compared to non-treaded soil. The difference in soil mineral N might be attributed to an increase in gaseous emissions.
- Urine application had little effect on winter losses by leaching in this heavy soil, although we speculate that urine greatly increased gaseous losses. However, mineral N concentrations in the soil profile were much higher in the +urine than the -urine plots, indicating an increased risk of future nitrate leaching.

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