Science of the Total Environment 651 (2019) 1819–1829

Contents lists available at ScienceDirect

Science of the Total Environment

journal homepage: www.elsevier.com/locate/scitotenv

Nitrate leaching losses during pasture renewal – Effects of treading, urine, forages and tillage.

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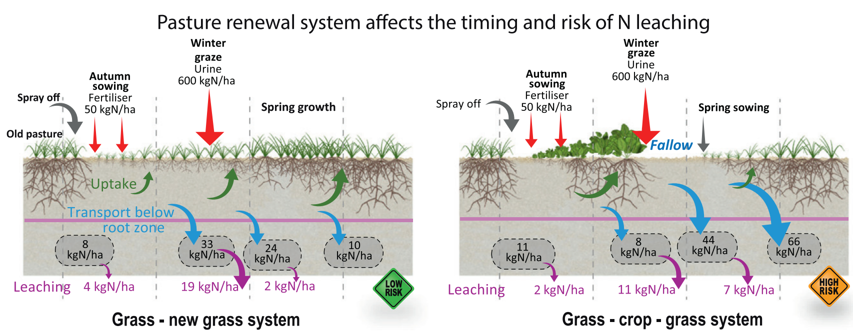
HIGHLIGHTS

- Autumn-winter nitrate leaching losses were low, but greater with grass → grass renewal.
- Winter-spring nitrate leaching losses were greater with grass → crop → grass renewal.
- Risk of nitrate leaching was greater from grass → crop → grass renewal than grass → grass.
- Treading increased compaction and reduced nitrate leaching.
- Soil was compacted more by treading in ploughed plots than direct drilled plots.

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 17 June 2018
Received in revised form 15 September 2018
Accepted 26 September 2018
Available online 27 September 2018

Editor: Charlotte Poschenrieder

Keywords:
Nitrate leaching
Pasture renewal
Grazing
Winter cropping
Cultivation

ABSTRACT

Pasture renewal is a key component of intensive temperate grassland farming. This practice is performed to improve pasture yields, but it may increase nitrate (NO_3^-) leaching losses, which can impact on water quality. Farmers face many choices when renewing pasture, however, there is limited information to guide decisions to reduce leaching losses.

An experiment was established to study how different management practices and grazing affect biomass production and NO_3^- leaching during pasture renewal on a heavy soil. Long-term pasture was either re-sown into ryegrass (*Lolium perenne*) in autumn (GG) or into forage rape (*Brassica napus*) followed by ryegrass in spring (GCG). Rape was established following ploughing or direct-drilling. Grazing was simulated in winter, whereby split plots ± urine (600 kg N ha^{-1}) and ±treading were established. Nitrate concentrations at 1 m depth were measured with suction cups and drainage predicted using a crop model.

Estimated NO_3^- leaching losses at 1 m depth ranged from 16 to 38 kg N ha^{-1}, with little difference between GCG and GG. However, the risk of future leaching was much greater below GCG plots. At the end of the study, soil NO_3^- between 0.6 and 1 m ranged from 28 to 130 kg N ha^{-1} in GCG plots and 1–28 kg N ha^{-1} in the GG plots. Timing of leaching differed between renewal systems, reflecting the differences in plant N uptake and fallow period. Overall, there was no difference in dry matter production between the two systems. Treading resulted in greater compaction, especially in tilled plots and reduced NO_3^- leaching by *c.* 40% – this can be attributed to increased denitrification. Our study demonstrates the complex nature of management and environmental factors and their interaction during pasture renewal. We show that management practices affect the risk and timing of N leaching. Practical implications for farmers are discussed.

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https://doi.org/10.1016/j.scitotenv.2018.09.333
0048-9697/

1. Introduction

Pasture renewal or renovation is an important practice for grassland farmers (e.g. Bryant et al., 2010; Creighton et al., 2011). The aim is to improve pasture production (Creighton et al., 2011; McLean, 2011) as swards become less productive due to factors such as incursion of weeds and low-yielding cultivars, soil treading damage, drought, or pest and disease. Typically dairy pastures in New Zealand are renewed every 10 years.

Common pasture renewal practice in New Zealand is to spray out the old pasture with herbicide in either spring or late summer–autumn followed by tillage (often ploughing followed by secondary cultivation). The tilled land is then sown directly into pasture (grass-grass, GG), or into one or two short-term crops and then sown into pasture in spring (e.g., grass-crop-grass, GCG). The crop sown is typically a high-yield forage with the purpose of suppling a large amount of feed for grazing animals over winter. It also creates a second opportunity to spray and eradicate problematic weeds and provides a pest and disease break (Bryant et al., 2010). There has been widespread adoption of summer and winter crops in dairy farming in New Zealand to boost feed supplies when grass production is low.

The decomposition of dead plant material and soil organic matter from the old pasture during the process of renewal can result in a large release of mineral nitrogen (N) (Smit and Velthof, 2010; Velthof et al., 2010), which is at risk of being leached during winter drainage events (Di and Cameron, 2002; Eriksen et al., 2010). Similarly, winter grazing at high stocking rates results in the deposition of a large amount of urinary N onto the soil. As rainfall often exceeds plant water use during this period it often results in drainage or runoff, which, combined with low plant N uptake, creates a large potential for nitrate (NO_3^-) leaching or runoff into waterbodies, which is a major environmental concern (Di and Cameron, 2002).

The proportion of N lost to leaching depends on a number of factors, including plant uptake (Malcolm et al., 2014) and the soil type and drainage properties (Ledgard and Luo, 2008); this can be further affected by management practices such as grazing (Hill et al., 2015) and tillage (Meek et al., 1995). It is therefore likely that the choice of pasture renewal sequence affects NO_3^- leaching. The GG and GCG systems have different temporal patterns of dry matter (DM) production and consequently of water and N uptake, with the GCG system having an additional fallow period following grazing of the crop; this is expected to affect the fate of N in the soil (e.g. Smith et al., 2012; Monaghan et al., 2013; Malcolm et al., 2015). Nonetheless, no field studies have directly compared NO_3^- leaching losses under the two systems of pasture renewal (GG or GCG). Others have investigated the losses of N under forage crops in New Zealand (Malcolm et al., 2015, 2016; Monaghan et al., 2013; Smith et al., 2012), but this covers only a component of pasture renewal. Of these studies, only Monaghan et al. (2013) used a poorly drained soil, and they measured annual losses of 34–79 kg N ha^{-1} y^{-1} from plots containing grazed kale. Three of these studies (not Malcolm et al., 2016) included atypically long fallow periods before re-establishing crop or pasture in late spring (November or December), later than common farming practice and is likely to have produced more N leaching. None of these studies compared tillage or treading effects. A few studies have investigated N losses from GG renewal systems e.g. Necpálová et al. (2013), Shepherd et al. (2001).

Treading when soils are wet can dramatically change soil physical conditions, e.g. macroporosity, air permeability and pore continuity (Ball et al., 2012; Drewry et al., 2008), leading to a reduction in soil aeration and water infiltration capacity. Reduced aeration can inhibit nitrification and stimulate denitrification (Balaine et al., 2016; Harrison-Kirk et al., 2015; Menneer et al., 2005), a sink for NO_3^- that may otherwise leach. In a field lysimeter experiment, simulated treading reduced NO_3^- leaching by 34% under urine patches on a free-draining soil (Hill et al., 2015). Treading has also been shown to markedly increase nitrous oxide (N_2O) emissions, an intermediary product of denitrification (Ball et al., 2012; Thomas et al., 2008). With the exception of Hill et al. (2015), none of the studies mentioned above have directly addressed the impact of treading on NO_3^- leaching losses.

Soil tillage also changes the structure of the surface soil, but there is disagreement on the direct effect on NO_3^- leaching. Direct drilling has been proposed as one of the strategies to reduce N leaching (Colbourn, 1985; Meek et al., 1995). However, other studies have found little or no effect of tillage on NO_3^- leaching (e.g. Hansen et al., 2015; Krol et al., 2016; Velthof et al., 2010). Increases or decreases in NO_3^- leaching losses observed from direct drilled plots compared to conventionally tilled plots are likely to depend on the effect tillage has on pore size distribution, pore continuity and solute mixing between pores of different size (Meek et al., 1995; Turpin et al., 1998).

Compaction and pugging (poaching) effects of treading may also be enhanced by the effects of tillage and high moisture content at the time of grazing. Intensively cultivated soils are less resistant to compaction than untilled soils (Tebrugge and During, 1999). Thomas et al. (2008) found that the greatest soil damage occurred in tilled plots that were treaded when soil water content was at or above field capacity. Although they did not measure the effects on NO_3^- leaching, Thomas et al. (2008) observed large increases in N_2O emissions due to treading and these effects were larger than from the application of urine alone. Plots that had been direct-drilled had much less compaction and lower emissions.

The aims of this study were to investigate the effects of pasture renewal practices on NO_3^- leaching and overall DM production. We compared: A) the effect of two different pasture renewal sequences – long-term pasture sown into (i) new ryegrass sown in autumn, or (ii) forage rape crop sown in autumn followed by a short winter fallow then sown into ryegrass in spring; B) the tillage used to establish the crops: (i) no-till and (ii) conventional cultivation; C) the effect of grazing: i) with and without applied synthetic urine and (ii) with and without treading; and D) the interactions of all these factors.

2. Materials and methods

2.1. Field trial design

A field trial was conducted on a poorly drained Flaxton Deep Silt Loam over Clay soil (New Zealand Soil Classification (Hewitt, 2010) or a Typic Endoaquept - USDA) in Lincoln, New Zealand (43° 40′ 4.3″ S, 172° 28′ 3.3″ E) from January 2012 to January 2013. The textural class and structural characteristics of the soil horizons are given in Table 1. Long-term average annual rainfall at the site is 601 mm, with approximately 50% falling over the autumn–winter period (mid-March to mid-September). The average annual temperature for the site is 12.2 °C. The pH_{H2O} of the surface soil (0–7.5 cm depth) was 6.4 and Olsen Phosphorus (P) 21 mg L^{-1} (Olsen et al., 1954). Total carbon (C) concentration was 3.6, 2.7 and 1.7% in the 0–7.5, 7.5–15 and 15–25 cm depths, respectively, and the C:N ratio was 11:1 (all depths). Depth to groundwater is approximately 5 m at the site. Shallow groundwater NO_3 concentrations in the region are typically about 5–6 mg N L^{-1} and are increasing (www.ecan.govt.nz). This increase is associated with recent land use intensification occurring across New Zealand (Parliamentary Commissioner for the Environment, 2012).

Two contrasting methods of pasture renewal were investigated: pasture renewal via a winter-grazed crop (grass-crop-grass, GCG), and reseeding of old pasture directly with new grass in autumn (grass-grass, GG). A summary of the management over the course of the experiment is given in Table 2. In brief, a grass/clover pasture (>15 years old) was sprayed twice with glyphosate over summer and the field was sown in early autumn. Three establishment methods were used following destruction of the old pasture; forage rape (*Brassica napus* L. *spp. biennis* 'Titan') established following intensive tillage (IT GCG) or direct drilling (DD GCG), and perennial ryegrass (*Lolium perenne* L. 'Nui') established by direct drilling (DD GG). The IT GCG plots were