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A system N balance for a pasture-based system of dairy production under moist maritime climatic conditions

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ABSTRACT

A small proportion (15–35%) of nitrogen (N) entering pasture-based livestock production systems is converted to tradable agricultural products. The majority of remaining N (surplus N) is largely unaccounted for. While some surplus N is retained in the system, which can be beneficial, most is lost through a range of pathways with potential environmental consequences. The objectives of this study were to (i) account for the N entering a pasture-based dairy production system by determining the amount of N exiting in products and lost to the wider environment and (ii) determine the relative importance of the components of this balance sheet. Detailed measurements and estimates of N entering and exiting a pasture-based dairy production system in Ireland (52°51′N, 08°21′W) was completed in 2011 and 2012. Total N entering and exiting the system was 245 kg ha^{-1} and 269 kg ha^{-1}, respectively, averaged over both years. The latter being comprised of N exiting in products: 79 kg ha^{-1} and losses to the wider environment: 190 kg ha^{-1}. The N use efficiency of the system was 29% and 37% in 2011 and 2012, respectively. The system N balance (mean $\pm$ 95% confidences intervals) was –50 $\pm$ 82 kg ha^{-1} in 2011 and +1 $\pm$ 22 kg ha^{-1} in 2012 and, hence, came close to equality between N entering and existing the system. Of N lost by various pathways, 6.1% was lost to groundwater, 41.6% as ammonia, 8.0% as nitrous oxide and 43.7% as dinitrogen gas. Although N surpluses on pasture based livestock production systems can be substantial, the results of this study suggest that a high proportion of surplus N was lost as environmentally benign dinitrogen gas. This study also highlights that emphasis should be on ammonia and nitrous oxide to minimise environmentally damaging N losses and improve the N-efficiency of such systems of dairy production.

1. Introduction

Intensive pasture-based livestock production systems are reliant on imports of nitrogen (N) in fertiliser and purchased feeds to sustain high production. A relatively low proportion (15–35%) of this N is converted to tradable agricultural products (milk and meat) leaving large surpluses of N that are largely unaccounted for and reveals the relatively low overall N use efficiency of pasture-based livestock production systems (Treacy et al., 2008; Mihailescu et al., 2013). This has raised concerns over environmental impact with many studies highlighting the extent of nitrate losses to water and emissions of nitrous oxide (N_2O) and ammonia (NH_3) from such systems (Jarvis and Ledgard, 2002; Bouman et al., 2010; Jarvis et al., 2011; Li et al., 2011; Oenema et al., 2011; Velthof et al., 2014). Nitrous oxide is a potent greenhouse gas in the troposphere and the dominant ozone depleting substance in the stratosphere (Ravishankara et al., 2009). Ammonia volatilisation contributes to indirect N_2O emissions (Martikainen, 1985) and is also related to deterioration of regional air quality, and eutrophication and acidification of natural ecosystems (Asman et al., 1998).

Accountancy styled N balance sheets can be used to determine the amount of surplus of N or likewise deficit of N generated by a production system. The most popular form of these N accounting systems is a farm-gate N balance sheet, due to its relative ease of completion, where the N entering (fertilisers, feeds and manures)

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and exiting (N in agricultural products, such as milk and meat) through the farm-gate is taken into account (Oenema et al., 2003; Schröder et al., 2003). Other forms of farm N balance sheets can also include N entering via deposition in rainfall and biological N_2 fixation associated with legumes (Ledgard et al., 1999; Schröder et al., 2003). Numerous farm-gate N balances have been completed internationally (Nevens et al., 2006; Bassanino et al., 2007; Treacy et al., 2008; Buckley et al., 2013; Mihailescu et al., 2013). These balance sheets are useful for estimating potential for losses and for comparing the potential environmental impact of production systems (Oenema et al., 2003). However, they do not differentiate between various components such as N loss to groundwater, N_2O, NH_3, dinitrogen gas or accumulation of N in soil organic matter (SOM). These various components can have substantially differing environmental impacts. Many other studies have investigated losses of individual components from pastures and farm buildings (Misselbrook et al., 1998; Sommer and Hutchings, 2001; Bouman et al., 2010; Necpálová et al., 2012; Burchill et al., 2014b) but despite much research, there is a lack of holistic studies accounting for both the N entering and existing the production system.

This study involved detailed measurements and estimates of N entering and exiting a pasture-based system of dairy production over two consecutive years, with the aim of increasing our understanding of N cycling within pasture-based systems. An eleven year dataset from the system was also collated with the results of the current study to take greater account of annual variation in N dynamics. The objectives of this study were to (i) account for the N entering a pasture-based dairy production system by determining the amount of N exiting in products and lost to the wider environment and (ii) determine the relative importance of the components of this balance sheet.

2. Materials and methods

2.1. Site description

This study was carried out at the Teagasc Solohead Research Farm in Ireland (52°51′N, 08°21′W). The topography of the site was relatively flat with elevation ranging from 148.5 to 155.5 m above ordnance datum (AOD). Detailed AOD maps of the farm are presented elsewhere (Necpálová et al., 2012). The predominant soils are poorly drained gleys (90%) and grey brown podzolics (10%) with a clay loam texture (29% clay, 36% silt and 34% sand) and low permeability. The soils are classified as eutric gleysol (humic) under the 2014 World Reference Base (WRB, 2014). The soils are seasonally wet, waterlogged or flooded due to impeded drainage and a shallow water table depth (0 to 2.2 m below ground level) at the site. Mean soil organic carbon, total N content, bulk density and pH at 0–10 cm depth are 512 g kg^{-1}, 54 g kg^{-1}, 0.87 g cm^{-3} and 6.2, respectively. The permanent grassland at the site is used predominately for grazing and occasionally harvested for silage. The swards range from 20 to 30 years in age. Mean annual rainfall at the site (1997–2010) was 1036 mm. Mean minimum monthly soil temperature (1998–2010) at 0–10 cm depth ranges from 1.7 to 8.5 °C during winter (November–January) and maximum monthly temperatures range from 10.2 to 18.2 °C in summer (May–July).

2.2. Experimental layout and design

All experimental measurements were carried out on a perennial ryegrass (*Lolium perenne* L.)/white clover (*Trifolium repens* L.: 22% of herbage dry matter) based system of dairy production. The system consisted of six paddocks ranging in size from 1.48 to 2.07 ha with a total area of 10.67 ha and an annual stocking density (spring calving Holstein–Friesian cows) of 2.25 cows ha^{-1} in 2011 and 2.35 cows ha^{-1}in 2012. The entire herd was calved in a three-month period from mid-January to mid-April. Cows were turned out to pasture after calving. Half of the farm was rotationally grazed during the main grazing season (March–November) with surplus herbage occasionally removed as baled silage. The other half were managed for first cut silage harvested in late May or early June and rotationally grazed thereafter. The grazing rotation length varied from 21 days in spring/summer to 42 days in autumn. Post grazing sward height, maintained at 4 cm, was measured using a rising plate meter (Grasstec, Charleville, Ireland) and used to determine when cows were moved to the next paddock.

Cows were housed during the winter (November–February) in one group containing cows from other experimental systems on the farm. All slurry produced was contained in one tank. Standard values for slurry production per cow, based on the European Communities (Good Agricultural Practice for Protection of Waters) Regulations 2010 (SI, 610, 2010, available online at http://www.irishstatutebook.ie/pdf/2010/en.si.2010.0610.pdf), were used to ensure that the volume of slurry produced by all cows on the system during the housing period was applied back to the system. The calculated quantity of slurry was applied back to the system in early spring and prior to closing for silage (early April). Fertiliser N was applied as urea (46% N) in a number of applications between February and May each year.

In this study, the system boundary was confined to the six paddocks within the dairy production system and the herd of dairy cows (24 in 2011 and 25 in 2012) contained within the system. Calves were exported from the system soon after birth and old cows were exported once they stopped producing milk. Young cows were imported onto the system at calving (N entering the system) and these calves were included as N exiting the system on the N balance sheet. Therefore, the rearing of replacement heifers was not part of the system. This dairy production system was established on the Solohead Research Farm in 2000 and has been under consistent management since its establishment. Measurements in this study commenced in October 2010 and continued for two years of production: 2011 and 2012. The results from individual years were confined to the annual cycle of milk production (1 January to 31 December).

2.3. Soil and weather measurements

Daily weather data including rainfall (mm), air temperature (°C) and soil temperature at 10 cm depth (°C) was recorded at the experimental site as described by Fitzgerald and Fitzgerald (2004).

2.4. N entering the system

Annual rainfall N deposition was calculated by multiplying annual rainfall by its total N concentration, determined bi-weekly, as described by Necpálová et al. (2013b). Nitrogen imported in feed was calculated by multiplying the measured quantity of imported feed per cow, mainly concentrates, by its crude protein content and dividing by 6.25 (Mcdonald et al., 1995). Above ground biological N_2 fixation was determined in each paddock using the ^{15}N isotope dilution and the ^{15}N natural abundance technique and clover yield using methodology described in full by Burchill et al. (2014a). A correction factor of 1.28 was used to account for BNF in belowground clover biomass (Vinther, 2006).

2.5. N exiting in product

Nitrogen existing the system in milk was calculated by multiplying individual cow milk yield (measured at each milking) by milk protein content (measured in milk from each of two consecutive milkings on one day each week) assuming the milk