J. Dairy Sci. 98:1–14
http://dx.doi.org/10.3168/jds.2014-8693

The effect of stocking rate on soil solution nitrate concentrations beneath a free-draining dairy production system in Ireland

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ABSTRACT

Economically viable and productive farming systems are required to meet the growing worldwide need for agricultural produce while at the same time reducing environmental impact. Within grazing systems of animal production, increasing concern exists as to the effect of intensive farming on potential N losses to ground and surface waters, which demands an appraisal of N flows within complete grass-based dairy farming systems. A 3-yr (2011 to 2013) whole-farm system study was conducted on a free-draining soil type that is highly susceptible to N loss under temperate maritime conditions. Soil solution concentrations of N from 3 spring-calving, grass-based systems designed to represent 3 alternative whole-farm stocking rate (SR) treatments in a post-milk quota situation in the European Union were compared: low (2.51 cows/ha), medium (2.92 cows/ha), and high SR (3.28 cows/ha). Each SR had its own farmlet containing 18 paddocks and 23 cows. Nitrogen loss from each treatment was measured using ceramic cups installed to a depth of 1 m to sample the soil water. The annual and monthly average nitrate, nitrite, ammonia, and total N concentrations in soil solution collected were analyzed for each year using a repeated measures analysis. Subsequently, and based on the biological data collated from each farm system treatment within each year, the efficiency of N use was evaluated using an N balance model. Based on similar N inputs, increasing SR resulted in increased grazing efficiency and milk production per hectare. Stocking rate had no significant effect on soil solution concentrations of nitrate, nitrite, ammonia, or total N (26.0, 0.2, 2.4, and 32.3 mg/L, respectively). An N balance model evaluation of each treatment incorporating input and output data indicated that the increased grass utilization and milk production per hectare at higher SR resulted in a reduction in N surplus and increased N use efficiency. The results highlight the possibility for the sustainable intensification of grass-based dairy systems and suggest that, at the same level of N inputs, increasing SR has little effect on N loss in pastoral systems with limited imported feed. These results suggest that greater emphasis should be attributed to increased grass production and utilization under grazing to further improve the environmental impact of grazing systems.
Key words: stocking rate, grass utilization, nitrate leaching, milk production

INTRODUCTION

During the next half century, global agricultural production faces 2 fundamental challenges: to produce enough food for the growing numbers of, on average, increasingly affluent and longer living people, and simultaneously preserve natural resources and the environment. Current figures estimate that 26% of global land area is covered by grasslands, which provide an important feed source for livestock and contributes positively to environmental protection (FAO, 2014). Consequently, it is essential that improvements in productivity are achieved within grassland agriculture but, without adverse effects on the natural environment. The process of producing more food, while reducing the environmental impact of dairy production systems, has become a global challenge and requires what has been referred to as sustainable intensification (Pretty, 1997; Royal Society, 2009) of global agricultural production. Despite the positive effect of N fertilizer use on agricultural production (Whitehead, 1995), the efficiency with which N is used is variable (Watson and Atkinson, 1999). As N moves within grassland systems, unavoidable losses occur through 3 major loss pathways: NO_3^- leaching, N_2O emissions, and NH_3 volatilization (Whitehead, 1995). In recent years, agricultural production systems within the European Union (**EU**) have increasingly been subjected to stringent environmental restrictions to reduce losses of bioavailable forms of N to water and air (Stark

Received August 1, 2014.
Accepted February 19, 2015.
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and Richards, 2008; Richards et al., 2009). Grazing is accompanied by localized deposition of N in urine and dung patches, which can contribute to environmental N pollution either as NH_3 and N oxides in air or as NO_3^- in soil and ground water (Tamminga, 1992). Nitrate leaching losses are problematic within grazing systems (Haynes and Williams, 1993; Ledgard et al., 1999), as elevated N applications via urine deposition by grazing animals is poorly attenuated within the soil (Haynes and Williams, 1993; Decau et al., 1997).

Within the EU, the abolition of milk quotas in April 2015 is anticipated to result in a redistribution of regional milk production (Lips and Reider, 2005). By virtue of lower production costs, milk production from grass-based systems in Ireland and northwest Europe are anticipated to expand based on the production and utilization of increased quantities of high-quality grass (Lips and Reider, 2005; O'Donnell et al., 2008; DAFM, 2011). Stocking rate (**SR**; cows/ha), defined as the number of animals per unit area of land used during a specified period of time, is well accepted as the main driver of productivity within grazing systems (Hoden et al., 1991; Macdonald et al., 2008; McCarthy et al., 2011), and recent studies have highlighted the beneficial effects of a high SR on animal productivity, grazed grass utilization, and overall farm system efficiency (Kelly et al., 2012; McCarthy et al., 2013a). Notwithstanding these beneficial effects, previous studies have also indicated that where increased SR are associated with increased chemical fertilizer N application and off-farm supplementary feed importation, N surpluses increase and N utilization is reduced, resulting in increased N loss to ground water and the general environment (Di and Cameron, 2002a; Treacy et al., 2008; Ryan et al., 2011).

Previous studies have identified the necessity to reduce N output through animal excretions by improving N utilization by the animal (Jonker et al., 1998). However, the opportunity to mitigate N losses are considerably reduced within grazing systems where a large proportion of the total diet consists of grazed grass (Dillon et al., 2005) and N utilization of grazing animals is often lower than 25% (Tas et al., 2006; Jarvis et al., 2011). From an overall farm systems perspective, previous studies have highlighted excessive N inputs in fertilizer and feed supplements, heterogeneous N deposition on the available area, and the cultivation of high-N soils as key reasons for inefficient N use (Gourley et al., 2012). Consequently, increasing international emphasis has focused on various N fertilizer application, animal, dietary, sward, and soil manipulation strategies to reduce NO_3^-N loss (Di and Cameron, 2002b; Moir et al., 2012; O'Connor et al., 2013). In practice, however, it is not possible to implement a combination of individual management effects, as these are interrelated within an overall system and there remains a paucity of quantitative data on N losses from intensive farming systems incorporating best practice N and grazing management practices. In response to this information gap, a 3-yr field experiment was uniquely designed to investigate the effect of overall farm SR on N use efficiency within intensive grass-based production systems. Consequently, the objective of the current study was to evaluate the effect of alternate whole-farm grass-based SR on N loss beneath a free-draining soil type within farming systems based on highly productive grassland swards combined with best practice grazing and N management over 3 consecutive years. The hypothesis of our study was that increases in overall farm system SR would have no deleterious effect on N losses in soil solution to 1 m of soil depth where the increased SR was derived from increased grazed grass utilization, based on fixed N inputs, and best practice agronomic and N management practices.

MATERIALS AND METHODS

Site Characteristics

The experiment was conducted over a 3-yr period (2011 to 2013) on a permanent grassland site at Curtins Research Farm, Teagasc, Animal & Grassland Research and Innovation Centre, Moorepark, Fermoy, Co. Cork, Ireland (52°9′N, 8°16′W). The area has a mild moist oceanic climate without extremes in temperature. The soil on site (to a depth of 2.5 m) is a freely drained acid brown earth, derived from mixed sandstone-limestone glacial till overlying a karstified limestone bedrock aquifer with bedrock commonly occurring at an average of 2.5 m below the ground surface (Bartley and Johnston, 2006; Gibbons et al., 2006). This site is representative of soils vulnerable to NO_3^- leaching, and represents between 4 and 10% of the riskier soils in Ireland (Ryan et al., 2006). The on-site swards were predominantly perennial ryegrass (*Lolium perenne* L.) and had been reseeded over the previous 1 to 9 yr.

Experimental Design, Treatments, and Herd Management

The current experiment formed part of a larger study designed to examine the biological and economic effect of SR in the context of the removal of EU milk quotas; a more detailed description of the animals, treatment, and experimental design has previously been reported (McCarthy et al., 2013b). In spring 2011, 138 high Eco-