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A regional assessment of the cost and effectiveness of mitigation measures for reducing nutrient losses to water and greenhouse gas emissions to air from pastoral farms

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ABSTRACT

Using a novel approach that links geospatial land resource information with individual farm-scale simulation, we conducted a regional assessment of nitrogen (N) and phosphorous (P) losses to water and greenhouse gas (GHG) emissions to air from the predominant mix of pastoral industries in Southland, New Zealand. An evaluation of the cost-effectiveness of several nutrient loss mitigation strategies applied at the farm-scale, set primarily for reducing N and P losses and grouped by capital cost and potential ease of adoption, followed an initial baseline assessment. Grouped nutrient loss mitigation strategies were applied on an additive basis on the assumption of full adoption, and were broadly identified as ‘improved nutrient management’ (M1), ‘improved animal productivity’ (M2), and ‘restricted grazing’ (M3). Estimated annual nitrate–N leaching losses occurring under representative baseline sheep and beef (cattle) farms, and representative baseline dairy farms for the region were 10 ± 2 and 32 ± 6 kg N/ha (mean ± standard deviation), respectively. Both sheep and beef and dairy farms were responsive to N leaching loss mitigation strategies in M1, at a low cost per kg N-loss mitigated. Only dairy farms were responsive to N leaching loss abatement from adopting M2, at no additional cost per kg N-loss mitigated. Dairy farms were also responsive to N leaching loss abatement from adopting M3, but this reduction came at a greater cost per kg N-loss mitigated. Only dairy farms were responsive to P-loss mitigation strategies, in particular by adopting M1. Only dairy farms were responsive to GHG abatement; greater abatement was achieved by the most intensified dairy farm system simulated. Overall, M1 provided for high levels of regional scale N- and P-loss abatement at a low cost per farm without affecting overall farm production, M2 provided additional N-loss abatement but only marginal P-loss abatement, whereas M3 provided the greatest N-loss abatement, but delivered no additional P abatement, and came at a large financial cost to farmers, sheep and beef farmers in particular. The modelling approach provides a farm-scale framework that can be extended to other regions to accommodate different farm production systems and performances, capturing the interactions between farm types, land use capabilities and production levels, as these influence nutrient losses and GHG emissions, and the effectiveness of mitigation strategies.

1. Introduction

Concerns about the environmental effects of nutrient enrichment of water bodies by diffuse pollution of surface water and groundwater by nitrogen (N) and phosphorous (P), along with increased greenhouse gas (GHG) emissions from livestock

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operations, continue to rise in New Zealand (Parliamentary Commissioner for the Environment, 2013). Southland, New Zealand's southern-most region with a long tradition of pastoral sheep farming, has undergone a noticeable change in its agricultural landscape in recent years (Beukes et al., 2011; Copland and Stevens, 2012). Although sheep enterprises remain the predominant land-use in the region, dairy cow numbers have increased from 200,000 in the 2000/01 milking-season to over 500,000 in 2011/12 (New Zealand Dairy Statistics, 2012).

To a large extent, the regional land use change in Southland has occurred at the expense of sheep and beef farming, on gentle slopes with relatively reliable summer rainfall (Monaghan et al., 2007). The greater profitability of dairy relative to sheep and beef farming has prompted the large number of dairy conversions over the last two decades (Beukes et al., 2011), with the potential for current farm conversion rates to continue in the next two decades (Monaghan et al., 2007; Vogeler et al., 2014). The conversion usually involves changing from a low-input sheep and beef farming system to a more intensive and high-input dairy farming system. Associated emissions of N and P to water usually also increase, raising community concerns about the impacts on regional water bodies (Environment Southland and Te Ao Marama Inc, 2010). Some of the social and economic benefits of this land use change have been reported (Forney and Stock, 2013; Kaye-Blake et al., 2014; Vogeler et al., 2014), but less is understood about the wider, regional sustainability implications associated with this land use change (Monaghan et al., 2007).

The Central New Zealand Government's 'National Policy Statement for Freshwater Management' (NPS-FM) directs Regional Councils (Authorities) to set water quality standards and limits for freshwater objectives (NPS, 2011). Setting enforceable water quality and water quantity limits are a key principle of the policy, in an attempt to balance the economic value of water with environmental requirements. Regional Councils in New Zealand have taken different approaches to address the issue of setting nutrient loss limits, N in particular, from agricultural land, including allocating nutrient loss limits based on the natural capital of the soil (Horizons Regional Council, 2014). Enhancing the availability and uptake of science and information, including good management practices and the ongoing improvement of models that can integrate site specific information, will be critical in this process, particularly in the adoption of new mitigation technologies and practices (Ministry for the Environment, 2013).

Farm system and nutrient budget models are increasingly being used to assess current and potential management options to reduce nutrient losses and to evaluate policy options. Field trials (Ledgard et al., 2006; Monaghan et al., 2007, 2009) and farm management surveys (Monaghan and de Klein, 2014) have identified land management strategies that can reduce nutrient losses and GHG emissions. An adequate representation of farming systems within a region and the ability to link farm models to land resource information were identified as critical elements in any assessment of the influence of farm practices at a regional scale (Vogeler et al., 2014). Estimates of the cost-effectiveness of adopting on-farm mitigation strategies have also been obtained via integrated modelling and simulation (i.e. integrated at a farm, catchment or regional scale) (Happe et al., 2011; Doole, 2012; Dymond et al., 2013; Kaye-Blake et al., 2014). Regional environmental and economic assessments from varying management practices have been reported using an aggregation approach from individual farms or farm systems to the regional scale (Vatn et al., 2006; Neufeldt and Schafer, 2008) or by using a regional or sectorial modelling approach (Lehtonen et al., 2007; Leip et al., 2008). Using a novel approach that links geospatial land resource information with individual farm-scale simulation and nutrient budgets, the objectives of this study were to assess N and P emissions to water and GHG emissions to air from the current predominant mix of pastoral industries in Southland (i.e. sheep and beef, and dairy farming) and to examine the impact of integrated nutrient loss mitigation strategies. The modelling approach used provides a region-wide estimate of the potential for different farming practices to mitigate some of the environmental impacts of pastoral agriculture.

2. Methods

A brief description of the Southland region including geospatial data and land use capability data (2.1) is followed by some of the modelling assumptions related to pasture production (2.2), a brief description of the farm-scale models used (2.3), modelled farm systems (sheep and beef, and dairy) (2.4), the mitigation strategies chosen within groups (2.5), the regional up-scaling method (2.6), and finally, the modelling scenarios tested (2.7).

2.1. Location and land resource data

Southland covers an area of almost 1.7 million hectares (ha), of which 1.1 million ha (65%) was pastorally farmed in 2007 (Statistics New Zealand). According to AgriBase™ (AsureQuality, 2012), a spatial and demographic census of all known New Zealand farms, approximately 0.18 million ha (16%) of the pastoral farming land is currently used for dairy farming, with the balance mainly a combination of sheep and beef (cattle) farming. The 4150 farms that were either under sheep and beef (3396 farms) or dairy (754 farms) were included in the regional scale modelling, accounting for just over 1 million ha. Other land use activities (e.g. arable, horticulture, forestry) were beyond the scope of this study and therefore not considered. By overlaying the geospatially identified individual farms from AgriBase™ with additional geospatial information from the Land Resource Information (LRI) system (Landcare Research), land area, land use capability (LUC), topography, predominant soil order and drainage class were obtained for each pastoral farm in the Southland region. The LUC system (Lynn et al., 2009) was conceived to provide a reliable basis on which to promote sustainable land management throughout New Zealand; land is grouped into classes reflecting potential sustainable use. Capability herein refers to the suitability for productive use. Briefly, the LUC system has two fundamental components, the LRI (based on physical factors critical for longstanding land use and management), and the LUC Classification, with Class 1 to 7 being potentially suitable for pastoral use (Class 1 with the highest productive potential and Class 7 with the most limitations to pastoral use).

To allow for a further characterisation of the land on each farm, the predominant soil order, topography and drainage profiles were identified. Soil orders on each farm were identified using the New Zealand Soil Classification (NZSC) soil orders (Hewitt, 1998). Only the dominant soil orders across the different LUC classes were considered (Brown and Pallic soils; Dystrudepts and Aeric Fragiaqualf in the USDA Soil Taxonomy, respectively) (Vogeler et al., 2014). The predominant topographies on farms were obtained by overlaying AgriBase™ data layers with slope data based on a digital elevation model, as described by Vogeler et al. (2014). Two drainage classes were defined based on the New Zealand Soil Classification (NZSC) drainage classes (Landcare Research): poorly drained soils comprising NZSC drainage classes 1–3 (very poor, poor and imperfectly drained), and well drained soils comprising NZSC drainage classes 4–5 (moderately well and well drained). Southland pastoral LUC classes and their areas, predominant soils orders,