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Modelling pastoral farm systems — Scaling from farm to region

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HIGHLIGHTS

- An up-scaling approach was developed that linked farm modelling with land databases.
- The up-scaling approach was compared to using representative farm systems.
- Forty-five percent of New Zealand's Southland area has the potential for dairying.
- Conversion into dairying could increase regional profit from farming by up to 75%.
- Conversion into dairying would increase regional environmental impacts.

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ABSTRACT

Farm system and nutrient budget models are increasingly being used to inform and evaluate policy options on the impacts of land use change on regional environmental and economic performance. In this study, the common approach of up-scaling representative farm systems to a regional scale, with a limited input of resource information, was compared with a new approach that links a geospatial land resource information data base (NZLRI, Agribase™) that includes independent estimates of the productive capacity of land parcels, with individual farm-scale simulation (Farmax® Pro and Farmax® Dairy Pro) and nutrient budgeting models (Overseer®). The Southland region of New Zealand, which is currently undergoing enormous land use change, was used as a case study. Model outputs from the new approach showed increased profit of about 75% for the region if the current land area under dairying increases from 16% to 45%, with the shift to dairy constrained to high pasture production classes only. Environmental impacts associated with the change were substantial, with nitrate leaching estimated to increase by 35% and greenhouse gas emissions by 25%. Up-scaling of representative farm systems to the regional scale with limited input of resource information predicted lower potential regional profit and higher N leaching from dairy conversion. The new approach provides a farm scale framework that could easily be extended to include different systems, different levels of farming performance and the use of mitigation technologies.

1. Introduction

New Zealand (NZ) contains 14.6 million ha of farm land, approximately 75% of which is hill country, characterised by predominant land slopes above 15°. The major land use on hill country in NZ is sheep and beef (S&B) farming, whereas on flat and rolling landscapes, land use is more intensive, comprising dairying and a diversity of horticultural and arable farming. In the last years NZ has seen a large shift in land use, with a large number of dairy conversions driven mainly by the greater profitability from dairying relative to S&B (Beukes et al., 2011a). The national sheep flock has decreased in the last 5 years from 38 million to 31 million sheep, whereas the national dairy herd increased from 5.3 million to 6.4 million cows (Statistics New Zealand, 2012).

Southland, NZ's southernmost region, has a long tradition of sheep and beef farming (Monaghan et al., 2005). In the last 20 years (1990–2010) dairying has expanded from 100 to 850 herds, making up 16% of the pastoral farmed area (New Zealand Dairy Statistics, 2010–11). In the Southland region there is still a potential for further dairy conversion. Conversion from S&B to dairying sees a shift from grazed legume based pastures, relying largely on N input by legume fixation, to a greater use of nitrogen (N) fertiliser, irrigation, supplements (including concentrates) and off-farm grazing, enabling large increases in per hectare production levels. As in many parts of the world concerns about environmental effects from these intensive livestock operations, especially on nutrient enrichment of water bodies are increasing

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(Hamill and McBride, 2003; Monaghan et al., 2007; Smith and Western, 2013).

The National Policy Statement for Freshwater Management (NPS, 2011) directs Regional Councils to set water quality limits for freshwater bodies. In cases where these limits are not met policies and plans are implemented to ensure that these are met in the future. Policy development to achieve these targets will require an extension of current controls around point source discharges, which represent only a very small percentage of total discharges, to diffuse losses from agricultural land (Elliott et al., 2008). Farm system and nutrient budget models are increasingly being used to inform and evaluate policy options. Such models can be used to explore the impacts of policies on the financial performance of land owners, sector and the regional economy and emissions to the environment.

Farm system and nutrient budget models widely used to evaluate the influence of farm systems and practices on on-farm production, profitability and emissions include the DairyNZ Whole Farm Model (Berntsen et al., 2003; Vogeler et al., 2012), DairyMod (Johnson et al., 2008) and Fasset (Berntsen et al., 2003; Beukes et al., 2008; Johnson et al., 2008), Farmax® Pro and Farmax® Dairy Pro (www.farmax.co.nz), and Overseer (Wheeler et al., 2006). The Farmax models are whole-farm decision support models that use monthly estimates of pasture growth, and farm and herd information to determine the production and economic outcomes of managerial decisions. Further details and evaluation of the models for selected farm scenarios in NZ can be found in Bryant et al. (2010) and White et al. (2010). Overseer®, a nutrient budget model, has been widely used in NZ as an agricultural management tool to support decision-making for on-farm nutrient management. The model can also be used to explore the relationship between production and emissions, including leaching, run-off and greenhouse gas (GHG) emissions from the farm (Wheeler et al., 2008), and has been shown similar N leaching as the process based SPASMO (Soil Plant Atmosphere System Model) model (Rutherford, 2012). The model also contains a suite of N, phosphorus (P) and GHG mitigation options.

Aggregating on-farm performance, outputs and emissions produced by the modelling tools across landscapes to explore the implications of land use and practice change at scales beyond individual farms requires the linking of the farm-based models to land resource information. This ensures that interactions between diverse landscape units and farm systems and practices are captured in the modelling exercise and reflected in the outputs. Common practice in the investigation of land use change is the up-scaling of outputs from modelling a "typical" farm system, which is assembled to represent the types of farms that would be expected to be found in the region. This approach is relatively easy to implement but does not account for variation in land resources and the associated impacts the required changes in farm systems design have on performance, outputs and emission levels. Alternatively, regions can be subdivided into smaller "uniform" areas with specific soil characteristics, land use and farm management. Models can then be run for these different areas and the outputs aggregated. Several catchment models, including, CLUES (Catchment Land Use Environmental Sustainability (Elliott et al., 2011)), SWAT (Soil and Water and Assessment Tool (Neitsch et al., 2011)), and the NIWA land use model (Rutherford, 2012) use this approach. CLUES has been applied in several locations in NZ to assess the impact of land use change on water quality and socioeconomic factors at a regional or national scale and has been extensively calibrated and tested by NIWA. The NIWA land use model has been used to assess the impact of land management on the quality of receiving waters and aquatic plant growth in the Hawkes Bay region of New Zealand. SWAT has been used extensively in the USA and internationally, as well as in NZ. However, the model is physically-based, and difficulties with obtaining suitable input data and parameter values have been reported. Ekanayake and Davie (2004) found that the model could predict mean annual N concentrations reasonably well, but not inter-annual variations. From this the authors concluded that simpler models might be equally suited for predicting the impact of land use change.

Another catchment model that has been used to inform policies and to assess relative costs of alternative environmental policies for 'land use optimisation' is the New Zealand Forest and Agriculture Regional Model (NZFARM). The model is designed to optimise economic outcome, based on various policy scenarios, and has been used to model economic impacts of nutrient reduction policies in the Canterbury area of NZ (Samarasinghe et al., 2011).

For catchment modelling estimation of deep drainage, stream and groundwater attenuation is needed, which adds additional complexity. Catchment models also require external input data of N loss from land. Both Overseer and the process based SPASMO (Green et al., 2003) have been used to provide such data (Rutherford, 2012). Alternatively outputs from other process based, such as the widely used open access APSIM (Agricultural Production Systems sIMulator) could be used to provide N loss data from different land management (Vogeler et al., 2013). The drawback of such process based models for estimating losses of nutrients from land for different farm systems and different management is that it would be very time consuming and costly, and they also require accurate model parameterisation and calibration.

As the focus of this study was to estimate the impact of land use and management on economic impacts, N losses and GHG emissions from land, rather than looking at the effect on receiving waters, a new approach was developed rather than using catchment models. The approach uses a geospatial land resource information database (NZLRI, Agribase™) that includes independent estimates of the productive capacity of each land parcel, to inform individual farm-scale simulations (Farmax® Pro and Farmax® Dairy Pro) and nutrient budgeting models (Overseer®). Impacts were assessed from individual farms, using actual farm boundaries. The approach was compared to an approach based on up-scaling representative farm systems to a regional scale, with limited input of land resource and pasture production information, to quantify the impact of land use change on the economy and environment of the Southland region in NZ.

2. Methods

To estimate the regional economic and environmental impacts of agricultural farming (dairying and S&B farming) in the Southland Region of NZ two different scenarios were investigated, with:

- Scenario 1: the current mix of dairying and S&B
- Scenario 2: conversion of S&B farm land into dairying using a geospatial land resource information database (NZLRI, Agribase™) that includes independent estimates of the productive capacity of land to inform the farm-scale simulations.

Two different approaches for estimating the regional impacts of land use change were then compared. The first approach (Approach 1) was based on linking farm system models with land resource and pasture production information, whereas the second (Approach 2) was based on up-scaling representative farm systems to a regional scale.

The scenarios and approaches were explored in the following steps, with steps 4 to 6 being only used for Approach 1:

1. Defining the current mix of land use based on land resource information, which provides the information for Scenario 1;
2. Estimating the productive potential of the land across the region based on land resource information, and classification into Pasture Production Classes (PPCs);
3. Estimation of the potential conversion of land into dairying, which provides information for Scenario 2;
4. Farm system modelling for dairying and S&B for various PPCs;
5. Aggregation of the model results for individual farms;
6. Aggregation of model outputs for the regional scale for Scenarios 1 and 2;