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Trade-offs between profit, production, and environmental footprint on pasture-based dairy farms in the Waikato region of New Zealand

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ABSTRACT

Trade-off curves are valuable formalisms for summarising the relationship between profit and environmental outcomes for individual farming systems. This concept is extended here to incorporate production, to recognise the importance of output for promoting economic growth and retaining market access. A whole-farm model is used to evaluate relationships between profit, production, and nitrogen (N) leaching for three pasture-based dairy farms of different intensity in the Waikato region of New Zealand. Using a loafing pad reduces N leaching through preventing the deposition of urinary N on pasture. In the absence of a loafing pad, the lack of cost-effective mitigation strategies means that production and profit decrease markedly when leaching is constrained. However, the use of a loafing pad on medium- and high-intensity farms allows plans with broad diversity in production and leaching to be attained at manageable cost, given the availability of supplement. Collateral impacts of nitrogen-leaching restrictions for greenhouse gas emissions are also explored. It is highlighted that even though imported supplement and a loafing pad are important for reducing nitrogen loss from Waikato dairy pastures, reliance on storage ponds to collect effluent deposited on pads allows atmospheric escape of methane, reducing the value of restricted grazing for the simultaneous reduction of greenhouse gas emissions.

1. Introduction

Profitable agricultural systems are crucial to sustain farming families and regional economies. Yet, agricultural production can have detrimental impacts on the environment (Bouwman et al., 2011; Berre et al., 2014). The empirical relationship between profit and environmental impact is easily visualised using a two-dimensional graph, generally known as a trade-off curve, generated from a farm-systems model (Zander and Kachele, 1999; Weersink et al., 2002). These are especially useful for informing policy makers of the trade-offs associated with management change (Robertson et al., 2009; Sanderson et al., 2013; Thamo et al., 2013). In addition to profit and environmental impact, the physical output of agricultural production is also an important facet to consider. Production is important to offset input costs that rise over time, sustain processing capacity, promote regional and national economic growth, and maintain a strategic ability to open or retain access to key markets (Jay, 2007; Schilling et al., 2010). Consequently, three-dimensional trade-off surfaces that describe the relationship between production, profit, and environmental impact are a logical extension to the existing formalism, which focuses just on profit and environmental outcomes.

Previous analyses have shown that divergent management plans can earn a consistent level of farm profit; these are duly presented as flat trade-off curves (Pannell, 2006; Kingwell, 2011; Thamo et al., 2013; Zehetmeier et al., 2014). Often, this arises inherently from the biophysical complexity of an agricultural system, in which the interactions of many interdependent processes yield stable farm profit as various processes offset one another (Doole et al., 2013). Nevertheless, the implications of flat trade-off surfaces relating production, profit, and environmental footprint have not been fully identified. This is problematic since they are perceivably significant in the context of farm-systems research. First, they can indicate if environmental improvement can potentially be achieved at low cost, improving the possibility that regulation or voluntary measures will be acceptable to farmers and society (Robertson et al., 2009; Pannell et al., 2014). Second, they can indicate whether it is possible to promote production without imposing significant costs or greatly increasing negative environmental impacts. This is especially important in contexts when high yield is deemed important, such as in the New Zealand (NZ) dairy industry (Jay, 2007). Last, they can reduce the chance that suboptimal management imposes a significant cost on-farm (Pannell, 2006; Kingwell, 2011).

The primary objective of this analysis is to identify the trade-offs between profit, production, and environmental footprint for a range

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of pasture-based dairy farms in the Waikato region of NZ and discuss their implications for farm management. Through focusing on these three key dimensions of farm management at the system level, more information is available to guide how producers can help satisfy strong personal and social motivations for improved performance across these criteria. A detailed non-linear optimisation model of a NZ dairy farm – the Integrated Dairy Enterprise Analysis (IDEA) framework (Doole et al., 2013) – is employed to evaluate these trade-offs. The IDEA model is used to extend the trade-off curve concept of Weersink et al. (2002) to consider production, while also considering the *feasibility* of alternative solutions with current technology.

The dairy sector is the major export industry in NZ, producing around a quarter of merchandise exports (SNZ, 2014). This sector has been market-led, receiving very little in way of subsidies for the last thirty years. Moreover, environmental pressures are relatively recent, with societal pressure for improved water quality gaining momentum over the last decade, in response to an unparalleled increase in dairy farming in NZ over the last 25 years (Monaghan et al., 2007a; Doole and Romera, 2014). This contrasts the European dairy-farming context quite markedly. Here, the Common Agricultural Policy (CAP) has protected the dairy sector through a combination of import tariffs, subsidies, and safety-net support (European Commission, 2013). Relative to NZ, there has been much longer-standing concern with regards to the environmental impact of dairy production, especially related to N loss. Indeed, the 1991 Nitrates Directive signalled the start of a pragmatic focus on reducing the environmental footprint of European dairy production, with later CAP reform in 2004 partly linking farmer subsidies to environmental standards (IEEP, 2011).

An analysis of trade-offs between profit, production, and nitrogen (N) leaching is pertinent to NZ dairy farms for a range of reasons. Moreover, these impacts concern multiple stakeholders that have diverse goals and are broadly distributed across NZ. First, it is important to maintain or improve profit in this industry, given rising cost pressures (Ho et al., 2013). This is important for farmers themselves, particularly given high debt levels in this industry (Howard et al., 2013), but also for the health of regional and national economies given that it promotes expenditure by producers and thus flows onto other sectors (Schilling et al., 2010). Indeed, the NZ government retains a strong focus on building primary-sector profitability as a driver of regional economic development. Second, maintaining or increasing production remains of central importance to sustain processing capacity (Guan and Philpott, 2011) and help to build market access or retain market share (Jay, 2007). Indeed, the Ministry for Primary Industries in New Zealand is committed to significantly increasing the value of New Zealand's primary industry exports over the next decade. This is also a core goal of processing industries and agricultural regions within NZ, given the high labour intensity, value added, and export focus of dairy processing, relative to other industries (Rae and Strutt, 2011). Last, nutrient outflows to waterways from NZ dairy farms have come under increased scrutiny in recent years. There is strong societal pressure to improve water quality across the nation, but the potential for negative impacts on farm profit and production complicate the development and application of cost-effective solutions by farmers, industry, and researchers.

There is a broad disparity in the N content of agricultural plants and the requirements of grazing animals, with the latter requiring relatively little of the protein they ingest to meet their needs for milk and meat production on typical NZ pastures (de Klein and Monaghan, 2011). Subsequently, 75–90% of N ingested by dairy cows is excreted, 40–60% into urine patches where high levels of nitrate are susceptible to being lost to waterways (Monaghan and de Klein, 2014). The risk of nitrate loss is particularly high for N deposited during late summer–winter when plant uptake is low, soil N reserves are significant following mineralisation over summer, and there is high soil drainage in the following winter months (Monaghan et al., 2007a). For these reasons, around 95% of N leached from NZ dairy systems arises from N deposited within urine spots, with the remaining 5% arising from N fertiliser and effluent application (de Klein et al., 2010). Nitrogen losses from dairy farms contribute to water-quality deterioration throughout NZ (Parfitt et al., 2012), which is now seen as the leading environmental issue in this nation and thus is a major focus of regional and national policy directives. Presently, stakeholders within much of the Waikato region (the location of this study) are involved in an intensive participatory process to identify appropriate regulatory responses to high contaminant loss from dairy farms, among other types of land use, as prescribed under the *National Policy Statement for Freshwater Management 2014* (NPS-FM, 2014). Studies of the kind presented here are valuable in this context, to provide better understanding about the trade-offs facing farmers, and ultimately society, regarding the impacts of decisions at the land-water interface.

This study also explores the collateral implications of changes in N-leaching loads for greenhouse gas emissions (GHG-e). Dairy systems are a major emitter of greenhouse gases, being responsible for around 5% of global anthropogenic GHG-e (FAO, 2010) and around a fifth of NZ GHG-e (MfE, 2014). There is presently no legislated date for when biological emissions from agriculture will be included within the NZ Emissions Trading Scheme (ETS). Indeed, they will only be incorporated in the NZ ETS if trading partners make more progress towards making reductions and economically-viable mitigations are developed (MfE, 2014). For this reason, they are allocated less attention than nitrogen leaching here.

2. Methods

2.1. Description of the IDEA model

This section provides a concise overview of the IDEA model closely following Doole and Romera (2014); more detail is provided in Doole et al. (2013).

IDEA is solved using nonlinear programming in the General Algebraic Modelling System (GAMS) using the CONOPT3 solver (Brooke et al., 2014). Nonlinear programming is a valuable technique for farm-systems modelling because it allows the development of models containing a rich description of key economic and biophysical processes (Doole and Romera, 2013); has substantial scope to incorporate strong nonlinearities; can integrate diverse data without recourse to statistical estimation involving all system equations; and allows the efficient identification of solutions that maximise a given objective. The main alternative is the use of a simulation model, which involves the use of trial-and-error to identify superior management plans that satisfy given constraints (e.g. Smeaton et al., 2011; Vogeler et al., 2013). Simulation models can incorporate much greater complexity than nonlinear-programming models, but it is more difficult within them to efficiently identify these superior solutions in a consistent and coherent way (Doole and Pannell, 2008). Stochastic-search techniques can be used to optimise simulation models, but there is typically wide qualitative variation in optima because these methods are not suited to considering system constraints, the models they seek to optimise are often complex and highly nonconvex, and the search procedures are inherently random (Deb, 2000).

IDEA identifies the feeding strategy that maximises annual earnings before interest and tax (EBIT) in this analysis. EBIT consists of total revenue minus total cost. Total revenue is earned from the sale of milk (including the consideration of processor dividend), culled cows, and excess young stock. Total cost is the sum of the costs incurred for grass-silage production, imported supplement, fertiliser, grazing off, labour, animal health, breeding, herd improvement, electricity, pest and weed control, vehicles and fuel, repairs and maintenance, freight, administration, insurance, and rates. Depreciation is included also in this assessment. This is appropriate given that the systems studied here differ broadly in terms of their depreciable capital, particularly since some simulations differ in terms of whether or not a loafing pad is utilised (see below). However, changes in the value of dairy livestock, feed