Agricultural Systems 144 (2016) 101–112

Contents lists available at ScienceDirect

Agricultural Systems

journal homepage: www.elsevier.com/locate/agsy

Intensification, nitrogen use and recovery in grazing-based dairy systems

Kerry J. Stott [a,*], Cameron J.P. Gourley [b]

[a] Agriculture Research, Department of Economic Development, Jobs, Transport and Resources, 32 Lincoln Square North, Carlton, Victoria 3053, Australia
[b] Agriculture Research, Department of Economic Development, Jobs, Transport and Resources, Ellinbank, Victoria 3821, Australia

ARTICLE INFO

Article history:
Received 15 July 2015
Received in revised form 7 January 2016
Accepted 17 January 2016
Available online 19 February 2016

Keywords:
Whole-farm nitrogen balances
Nitrogen use efficiency
Milk production
Grazing-based dairy systems
Australia

ABSTRACT

There is increased international interest in the intensification of grazing-based dairy systems such as those that occur in Australia. However, associated with increased milk production on a per ha basis is the potential for decreasing nitrogen (N) recovery and increased N losses to the environment. In this study we produced a 22-year (1990–2012) time series of N recovery measures, for the entire Australian dairy industry and largest dairy producing State, Victoria, using a farm-gate N balance method and long-term farm survey data. Nitrogen recovery measures included whole-farm N surplus (kg N ha^{-1}), N use efficiency (%), milk production N surplus (g N l^{-1} milk) and total industry-wide N surplus (t N). On-going intensification in dairy production at both the national and state level led to fewer and larger dairy farms, with increased stocking rates, reliance on imported feed, nitrogen fertiliser use and milk production per cow and per hectare. All N recovery measures deteriorated markedly over the 22 year period, although the adverse trend moderated somewhat since 2006. The Victorian industry was higher-performing in terms of N recovery compared to the national dairy industry as a whole, though there was some convergence during the last decade. The whole-farm N surplus for the 'industry' average Australian dairy farm increased from 54 to 158 kg N ha^{-1} and 38 to 136 kg N ha^{-1} $yr.^{-1}$ for the average Victorian dairy farm. Nitrogen use efficiency declined from 40 to 26% and from 51 to 29% for the average Australian and Victorian farm, respectively. Milk production N surplus increased from 10.2 to 17.3 (Australian farm) and 6.9 to 15.2 g N l^{-1} milk (Victorian farm). Total N surplus increased from 63,076 to 164,621 t N for the Australian dairy industry as a whole, despite a decline of 470,000 ha in land used in dairying, suggesting a growing problem in terms of higher losses of reactive N. Looking to the future, we examined a scenario whereby N use efficiency for Victorian dairy farms increases to 35% by 2030 due to higher milk yields per cow and per hectare, increased forage yields, improved bovine genetics and feed conversion efficiencies. Given the trends over 22 years and current N use efficiency, this goal will be difficult to achieve within current grazing-based dairy farming operations. Improvements in N recovery will likely depend on significant on-farm mitigation incentivised by cost-effective policy measures, as well as future technological advances stemming from strong public and industry investment in research and development.

1. Introduction

The substantial growth in global agricultural production over the past 50 years has in large part been attributed to intensification of farming systems (Tilman et al., 2002; Fuglie, 2012). For dairy production, intensification generally means increasing milk production per animal and land area and leads to more complex management systems (Oenema et al., 2014). For dairy animals, intensification typically results from increase in feed intake and optimisation of feed conversion efficiency (Jacobs, 2014), while for pasture and forage production, the focus is generally to increase total feed grown, through improved utilisation of land and greater inputs of water and nutrients, in particular nitrogen (N) fertiliser (Leaver, 1985; Chapman et al., 2008).

Confinement and housing systems dominate dairy production in the major dairy producing regions of the world (OECD, 2004; Powell et al., 2013). Future productivity gains may be limited in these intensively managed systems, where feed inputs and milk production are already optimised, and regulations may limit stock density due to caps on nutrient application rates and increasingly stringent requirements for managing manure (Bos et al., 2013; Oenema et al., 2014). Consequently, there is an expectation of greater future production from grazing-based dairy systems such as occur in Australia, as current milk production is generally lower per animal and per hectare than confinement systems (Jacobs, 2014; Dharma et al., 2012; Powell et al., 2013), and there are perceived lower environmental impacts and environmental regulations (Gourley and Weaver, 2012; Oenema et al., 2014).

Dairy farming is a well-established and highly valued agricultural industry across the temperate and subtropical zones of Australia with a farm gate value of $4.7 billion in 2013–14 (Dairy Australia, 2014a). The Australian dairy industry is characterised by grazing enterprises

* Corresponding author.
E-mail address: kerry.stott@ecodev.vic.gov.au (K.J. Stott).

http://dx.doi.org/10.1016/j.agsy.2016.01.003
0308-521X/

operating at a wide range of scales (Dharma et al., 2012), with some farms having fewer than 100 cows, and others milking over 1000 cows. Milk production primarily relies on high quality permanent pastures for year-round grazing, usually dominated by grasses such as perennial ryegrass (*Lolium spp.*) and varying proportions of legumes (e.g. clover, *Trifolium spp.*) (Jacobs, 2014; Chapman et al., 2008). Over the past few decades, the Australian industry has undergone significant structural adjustment which has transformed the industry, driving productivity growth. Production has shifted from the northern to the southern states, particularly Victoria and Tasmania. Currently Victoria has the largest number of dairy farms in Australia and accounts for 66% of Australia's total milk output. Milk production is now more intensely carried out on fewer farms, stocking rates have increased, and there have been substantial increases in the use of bought-in feed and N fertiliser to support increased milk production per cow and per hectare (CIE, 2011). These changes have reaped economic benefits in terms of average Total Factor Productivity (TFP) growth (i.e. increased output from all the resources committed) of 1.6% p.a. between 1979 and 2012 (ABARES, 2014a).

Ongoing intensification of agricultural land, particularly for animal-derived food production, has ecological consequences, including negative impacts on carbon sequestration, biodiversity and water and air quality (Steinfeld et al., 2006; Erisman et al., 2013; Hertel, 2015). Of particular concern on dairy farms are large phosphorus (P) and N fluxes (VandeHaar and St-Pierre, 2006; Gourley et al., 2012b), which are exacerbated by animal excreta and spatially heterogeneous loading rates (Gourley et al., 2015; Tunney et al., 2007; Powell et al., 2005; Monaghan et al., 2007). Consequently, intensification of dairy production systems is likely to increase nutrient losses to the environment (Rotz et al., 2005; de Klein and Monaghan, 2011), notably reactive N with its various transformations and loss pathways causing a cascade of potential environmental problems (Galloway et al., 2008).

Central to many environmental policies focussing on N within agriculture has been the quantification of N recovered in whole-farm N balances (Oenema et al., 2003), where total N inputs and outputs are estimated and the difference (N surplus) and ratio (N use efficiency) are quantified. A less commonly used recovery metric is N surplus divided by litres of milk produced (milk production N surplus), which is akin to partial productivity measures used in production economics. This latter metric recognises that dairy farming aims to increase the profitability of milk production while also ensuring environmental quality, and that these aims may jointly be better served by more intensive, highly productive farms on a more limited area, more distant from valued environmental assets (Schroder et al., 2003, de Wit, 1992).

The whole-farm approach has gained popularity because it is relatively simple to calculate using generally available farm-scale data. Furthermore, the principle that increasing feed and fertiliser inputs will increase overall farm-gate nutrient surplus (Jarvis et al., 2011; de Wit, 1992) has been well demonstrated in a number of nutrient efficiency studies from a diverse range of dairy production systems globally (Gourley et al., 2012b; Raison et al., 2006; Fangueiro et al., 2008; Nevens et al., 2006; Treacy et al., 2008). Finally, N surplus is recognised as a quantifiable estimate of N loss to the environment, assuming no net change in soil organic N (Oenema et al., 2009; Jarvis et al., 2011).

Whole-farm N balance assessment has been widely adopted in the European Union (EU) (Jarvis et al., 2011) and New Zealand (Beukes et al., 2012; Sneath and Furness, 2006), where it has become a requirement of milk supply. In the USA, whole-farm N balance on dairy farms continues to be evaluated in specific states (Koelsch, 2005; Cela et al., 2014). In contrast, the determination of N balance and N use efficiency at the farm scale is primarily viewed in the context of voluntary nutrient management planning in Australia (Dairy Australia, 2014b). There is however an increasing recognition of the need to improve N use efficiency globally (Sutton et al., 2013) with international food processors and retailers seeking evidence that food production practises are meeting environmental standards (Gourley and Weaver, 2012). Consequently, Victorian dairy industry productivity goals for 2030, which aim to increase current milk production by 70%, also aspire for an average whole-farm N use efficiency of 35% (CIE, 2014). These goals, developed by a panel of government and industry experts, assume a future expansion of dairy production in Victoria, further intensification, improved pasture production and quality, enhanced cow performance and genetics, increased supplement use and more efficient utilisation of fertiliser and feed inputs (CIE, 2014). This aspirational goal is in line with the national dairy industry sustainability framework for decoupling enhanced dairy industry livelihoods from environmental impacts (Australian Dairy Industry Council, 2012).

Despite the ongoing intensification of grazing-based dairy farms and future expectations for improvements in productivity and environmental performance, there has been no systematic determination of long-term trends and associations between milk production, N inputs and N recovery. The objective of this study was to investigate N use, balance and efficiency measures, for grazing-based dairy farms over a period of 22 years (1990–2012), which encapsulates continued industry intensification. The assessment was done for Australia and Victoria, the largest milk-producing state. We sought to investigate the key changes in farm characteristics and N fluxes over this time, examine the increases in milk production and N recovery under current trends, and changes needed to achieve a whole-farm N use efficiency of 35% by 2030. Finally, we discuss the implications of ongoing intensification of a grazing-based dairy industry on N use efficiency and N emissions.

2. Materials and methods

2.1. Data sources

The N recovery metrics determined in this analysis followed a commonly used farm-scale N balance approach (Fangueiro et al., 2008; Mulier et al., 2003; Nevens et al., 2006; Treacy et al., 2008; Soberon et al., 2013) modified to suit Australian dairy farm operations (Gourley et al., 2012b). Briefly, determining whole-farm N budgets involved quantifying total N inputs and outputs at the farm scale, over a 12 month period. Inputs and outputs included the N embodied in the various forms of purchased feed (fodder, concentrates, grains and by-products) and fertilisers, milk sales and animal purchases and sales. Inputs from N fixation and atmospheric deposition were also included as described by Gourley et al. (2012b).

The study required population estimates and average annual per farm data on farm size, herd size and dynamics, and the mass of key N inputs and N outputs, between 1990 and 2012. Time series for these variables (means and standard errors) were sourced wherever possible from the Australian Bureau of Agriculture and Resource Economics (ABARES) Australian Dairy Industry Survey (ADIS). For the most part, the survey results were freely available on-line from the AgSurf database (ABARES, 2015) from 1990 onwards, or from ABARES on request.

The ADIS has a number of advantages, namely (i) it is a unique and detailed source of data widely utilised in Australia to track economic performance, productivity and management practices of farm businesses in the dairy sector; (ii) it is routinely conducted as part of ABARES' annual farm survey programme so there is a long (30 year) data series on most of the key variables used in this study; and (iii) it is based on a sample of 300 dairy farms across Australia drawn at random from the total population (ABARES, 2011), so the survey provides industry data relevant to the ‘average’ producer.

A short-coming of the ADIS however, is the incomplete time series on N fertiliser usage. The collection of data on N fertiliser usage ceased after 2003, with only expenditure data on all fertilisers continuing beyond this time. Although Australia-wide N fertiliser consumption can be deduced from international trade and domestic production data (FAO, 2015), no data are available for individual states or industries. For the purposes of this study, a consistent annual time series was created for each state for the period 1990 to 2012 by linear interpolation