Agriculture, Ecosystems and Environment 201 (2015) 70–82

Contents lists available at ScienceDirect

Agriculture, Ecosystems and Environment

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

Soil phosphorus, potassium and sulphur excesses, regularities and heterogeneity in grazing-based dairy farms

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ARTICLE INFO

Article history:
Received 27 May 2014
Received in revised form 20 December 2014
Accepted 23 December 2014
Available online 7 January 2015

Keywords:
Nutrient distribution
Accumulation
Soil test levels
Manure loading rates
Dairy pastures
Grazing

ABSTRACT

Efficient nutrient management is a critical component of profitable and sustainable milk production on modern dairy farms. While the impact of intensification on nutrient surpluses at the farm scale is well recognised, there are few studies that have quantified the corresponding soil nutrient concentrations within dairy farms at a national scale. In this study, we examine soil phosphorus (P), potassium (K), and sulphur (S) concentrations on 2092 grazed dairy paddocks and animal containment areas within 43 contrasting dairy farms from all dairy producing regions of Australia. More than three quarters of the routinely grazed paddocks sampled had available P, K and S concentrations above agronomic requirements, while 20% of paddocks were at least 3 times above agronomic requirements. An exception to these generally high levels were paddocks sampled on organic or biodynamic dairy farms, which had lower soil P and S concentrations. Within farm nutrient heterogeneity was substantial, irrespective of the characteristics of the dairy farm or the regional location. Animal holding areas often had excessively high soil nutrient concentrations. Overall, there were significant relationships ($P < 0.01$) between soil P, K and S concentrations and farm management and paddock characteristics including distance from milking parlour, application frequency of mechanically applied effluent, frequency of grazing herd visits, frequency of feeding of conserved forage and frequency of mechanical pasture harvesting. These results highlight generic management practises that exacerbate elevated soil nutrient concentration within grazed dairy farms and have direct implications to farmers and advisors. There are clear opportunities to strategically apply, and more often reduce, P, K and S fertiliser inputs on dairy farms without a loss of production. A greater understanding of farm nutrient fluxes and expected patterns of within-farm nutrient distribution, complemented by comprehensive soil testing, will help guide profitable and environmentally beneficial nutrient management decisions.

1. Introduction

The challenge of managing nutrients in animal agriculture to meet both production and environmental goals is faced by most industrialized countries (Steinfeld et al., 2006), including Australia (Gourley and Weaver, 2012). This is particularly the case in dairy production where nutrient fluxes on individual farms are often large (Rotz et al., 2005; Mihailescu et al., 2014; Fangueiro et al., 2008; Raison et al., 2006; Plaizier et al., 2014; Gourley et al., 2012a). Moreover, dairy production systems are inefficient at capturing nutrients in exported product and consequently nutrient imports onto dairy farms, mainly in the forms of fertiliser and feed, are usually much greater than that exported in milk and animals (Brouwer et al., 1995; VandeHaar and St-Pierre, 2006). These nutrient surpluses (positive nutrient balances) at the farm scale, tend to increase as farms intensify and stocking rates increase (Gourley et al., 2012a; Weaver et al., 2008).

Over the longer term, nutrient surpluses can result in soil nutrient accumulation beyond agronomic requirements, as has been reported within dairy systems worldwide, including Europe (Tunney et al., 2007; Behrendt and Boekhold, 1994; Lalor et al., 2010), the USA (Ketterings et al., 2005) and New Zealand (Monaghan et al., 2008). Nutrient surpluses also increase the risk of environmental losses, notably P in surface runoff (Sharpley et al., 2003; Dougherty et al., 2011) and leachate

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http://dx.doi.org/10.1016/j.agee.2014.12.010
0167-8809/

(Fortune et al., 2005; Heckrath et al., 1995), with dairy systems recognised globally as a critical threat to water quality (Steinfeld et al., 2006). In addition to off-farm environmental impacts, excessive K accumulation and excess plant uptake can cause severe metabolic disorders in ruminants (Reid and Horvath, 1980).

In a recent analysis of P use in dairy systems across Australia, Weaver and Wong (2011) determined a median P surplus of 18 kg P ha^{-1} $year^{-1}$ and a median P use efficiency of 19%. However, these authors also noted a high degree of variation, with some farms having P use efficiencies of more than 100% over a defined time-period when inputs were low or nil, corresponding to greater P removal than importation. Broad ranges of P balances have also been reported for commercial dairy farms in Northern Portugal (5–72 kg P ha^{-1} $year^{-1}$; Fangueiro et al., 2008), Western Europe (4–36 kg P ha^{-1} $year^{-1}$; Raison et al., 2006), Ireland (−7 to 20 kg P ha^{-1} $year^{-1}$; Mihailescu et al., 2014), Canada (−5 to 40 kg P ha^{-1} $year^{-1}$; Plaizier et al., 2014), as well as Australia (8–105 kg P ha^{-1} $year^{-1}$; Ovens et al., 2008).

Accumulation of K is often of a greater magnitude, as in addition to K fertiliser imports, the relatively high K concentration in imported forages can result in substantial K surplus. Although the studies are fewer in number, broad ranges of K balances on dairy farms have also been reported (Northern Portugal, 52– 07 kg K ha^{-1} $year^{-1}$, Fangueiro et al., 2008; Canada, −16 to 135 kg K ha^{-1} $year^{-1}$, Plaizier et al., 2014; Australia, 22–156 kg K ha^{-1} $year^{-1}$, Chataway et al., 2012). Even fewer studies have considered S balances on dairy farms, although the similarity between S and P concentrations in feed and animal products, suggests that these balances may be of a similar magnitude. While these studies largely focus on nutrient balances at the whole-farm level, there are few studies which quantify within-farm nutrient fluxes and the implications for resultant soil nutrient concentrations at the field or paddock scale.

Grazing of high quality permanent pastures by lactating dairy cows is the dominant dairy production system in countries such as Australia, New Zealand, Argentina and Ireland, while mechanically harvested forage and grain, fed in confinement dairy systems, is more prevalent in the USA (Haumann and Wattiaux, 1999). In many European dairy systems, the rotational grazing of pasture is routinely undertaken in spring and summer (Hopkins and Wilkins, 2006).

Typically, a grazing-based dairy farm is divided into fenced paddocks with at least one gateway to allow entry and egress, and which often contain a fixed watering point (Aarons and Gourley, 2012). Pastures are generally dominated by grasses with varying proportions of legume and associated weed species. Pasture production is largely limited by temperature and insufficient water, both of which contribute to a temporal growth pattern specific to a particular region (Hopkins and Wilkins, 2006; Rawnsley et al., 2007).

Lactating and pre-calving dairy cows generally graze pastures on a rotational basis throughout the entire year (Aarons and Gourley, 2012). Most grazing based dairy farms also include paddocks and animal holding areas with a high frequency of use and high animal densities for at least some of the year. These are often located close to the dairy parlour, where cows are held between the evening and morning milking and used for routine feeding, particularly when pasture availability is limited or when soils are excessively wet. Farms may also have other high animal density areas where cows are held pre- and post-calving, for selected breeding stock, or for welfare.

At the paddock scale, key fluxes of P, K and S inputs in grazing based dairy systems are generally from grazing animal excreta, fertiliser applications, the redistribution of collected manure, and through removal of forage either by the grazing animal or mechanical harvesting (Gourley et al., 2007a). Grazing dairy cow excreta, directly deposited onto pasture soils, plays an integral role in recycling nutrients and soil nutrient accumulation (Haynes and Williams, 1993). As dairy farms become more intensive and stocking rates increase, nutrient loads from dairy cow excreta on a per ha basis also increase (Lanyon, 1994; Powell et al., 2005; Monaghan et al., 2007). Collected manure generally represented <10% of total manure produced by cows on grazing based dairy farms (Gourley et al., 2012b) but on intensively managed farms with greater feed imports and specific feeding areas, this percentage is much higher. In specific feeding and holding areas, particularly where manure is not routinely collected, there can also be an excessive accumulation of nutrients (Powell et al., 2005; Fu et al., 2010; Gourley et al., 2012b).

Despite the importance of these nutrient fluxes, there has been limited assessment of soil P, K and S concentrations and distribution patterns within pasture-based dairy farms, and how these nutrient concentrations relate to routine farm management practises. In this paper we report findings from a national dairy nutrient study involving 43 grazing-based dairy farms representing the diversity of current dairy production systems across Australia. Our objectives were to (i) determine the soil test P, K and S concentrations of all routinely grazed pasture paddocks and other animal visitation areas, (ii) compare these levels against national agronomic soil test targets, and (iii) investigate heterogeneity at the paddock, farm and regional scales. In addition, we sought to define regularities in soil P, K and S concentrations associated with whole-farm nutrient inputs and balances, routine farm management decisions, paddock characteristics and milk production. Finally, we discuss the opportunities for farmers and advisors, locally and internationally, to reduce nutrient excesses and heterogeneity within grazing based dairy farms.

2. Materials and methods

2.1. Farm selection and description

The selection of the 43 dairy farms involved in the study is described in detail in Gourley et al. (2012a). Briefly, an initial pool of 124 ‘diverse but representative’ dairy farms were identified by regional research and extension workers. The farmers indicated their willingness to participate in the study and provided basic descriptive and demographic information. To ensure that the participating dairy farms were representative of the diversity of Australian dairy farming systems, six key criteria were identified: (i) farms would be present in all dairy regions, with the number of selected farms in each region broadly representing the region's relative contribution to total farm numbers in Australia; (ii) milk production (litres per grazed hectare), (iii) farm size (grazed hectares), (iv) reliance on irrigation (as a percentage of grazed area irrigated); (v) soil phosphorus sorption, as determined by the major soil type present and the corresponding phosphorus buffering index (PBI) measure (Burkitt et al., 2002), and (vi) the inclusion of a limited number of organic/biodynamic farms. Each of the quantitative criteria (ii)–(v), was classified into the lower 25%, the middle 50% and the upper 25% of available data.

Thirty-eight of the initial 124 farms were excluded from selection due to incomplete descriptive data. From the remaining 84 farms, the final selection of farms was achieved using an iterative optimisation routine, using GenStat 16 (GenStat Release, 2013), aimed at providing an equal representation of farms across these classes and all multi-way cross-tabulations, subject to regional and organic/biodynamic representation constraints. This resulted in the selection of 43 dairy farms with a wide range of combinations of desired key characteristics, located in the major dairy producing regions of Australia which included temperate (Tasmania and Victoria), Mediterranean (Western Australia and South Australia), sub-tropical (New South Wales) and tropical (Queensland) climatic zones (Fig. 1).