IMPROVING NITROGEN USE EFFICIENCY: FROM PLANET TO DAIRY PADDOCK

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Introduction

At a global scale, human activity has increased the flux of N two-fold (Vitousek *et al*. 1997), particularly driven by large scale fertiliser manufacturing (Fowler et al. 2013). Additionally, the ability to transport inputs and outputs cheaply and extensively has led to substantial growth in agricultural production over the past 50 years with an accompanying 40% increase in world population and extensive urbanisation. However, this has also lead to a spatial disconnection between nitrogen flows required for agricultural production systems and reduced incentives to capture and recycle nitrogen at the farm scale. Moreover, agricultural production systems are inherently in efficiency at capturing nitrogen, with excess nitrogen dissipated into the broader environment. Of the total N applied to agricultural land worldwide only 5–15% is eventually transformed into human food (Erisman *et al*., 2012). In cropping systems nitrogen use efficiency (NUE) will often range between 35 – 65%, while in more intensive animal systems such as dairy production, NUE will typically range from 15 – 35% (Powell *et al.* 2010). Major pathways of agricultural N loss to the environment are gaseous emission of ammonia and nitrous oxide, and the leaching of nitrate through soil, with various transformations causing a cascade of potential environmental problems (Galloway *et al.* 2008). In the past decade, measuring losses for nitrous oxide and the effectiveness of mitigation strategies have received considerable attention due to a policy focus on greenhouse gas emissions. In contrast, grazing based dairy farms in Australia and New Zealand have been encouraged to increase production through greater reliance on imported feed and fertiliser (Thorold and Doyle 2007), with likely greater nitrogen losses per ha. Growing societal expectations for air and water quality, stricter standards from international markets, and increasing costs for purchased nitrogen will mean that improving NUE and reducing nutrient losses will be a necessary part of agricultural production systems. This is likely to require difficult choices to better balance production and environmental goals, particularly for intensive livestock industries such as dairy production.

Nitrogen at a global scale.

The story of N spans more than 600 years (Galloway *et al.* 2013), since its discovery as an atmospheric element in 1770 by Rutherford. The role of reactive N, though the process of biological N fixation and in manures and inorganic forms such as salt petre, in promoting plant growth and increasing crop yields followed in the 1840s, through the work of Boussingault in France, Liebig in Germany and Lawes in England. It was not until 1913, when the significant development of Haber-Bosch technology that converts atmospheric nitrogen (N2) to reactive nitrogen as ammonia, enabled N fertilisers to be manufactured at an industrial scale. This breakthrough dramatically increased food production over the past 50 years which has supported around 40% of the world's population.

"In 1908, 1 ha of land fed 1.8 people, now 1 ha will feed 4.3 people". Professor Klaus Butterbach-Bahl, Department Atmospheric and Environmental Research.

The uptake of this technology for large scale fertiliser manufacture following the end of the second world war, was closely followed by a rapid adoption of fertiliser use on crop lands, particularly across the USA and Europe, and more widely in most agricultural production systems worldwide (Figure 1), with the exception of Africa. The lag in Australia was reflected in wheat production systems being slow to switch from the traditional lay-legume rotation, with a similar shift from pasture legumes to bag fertiliser N in dairy production.

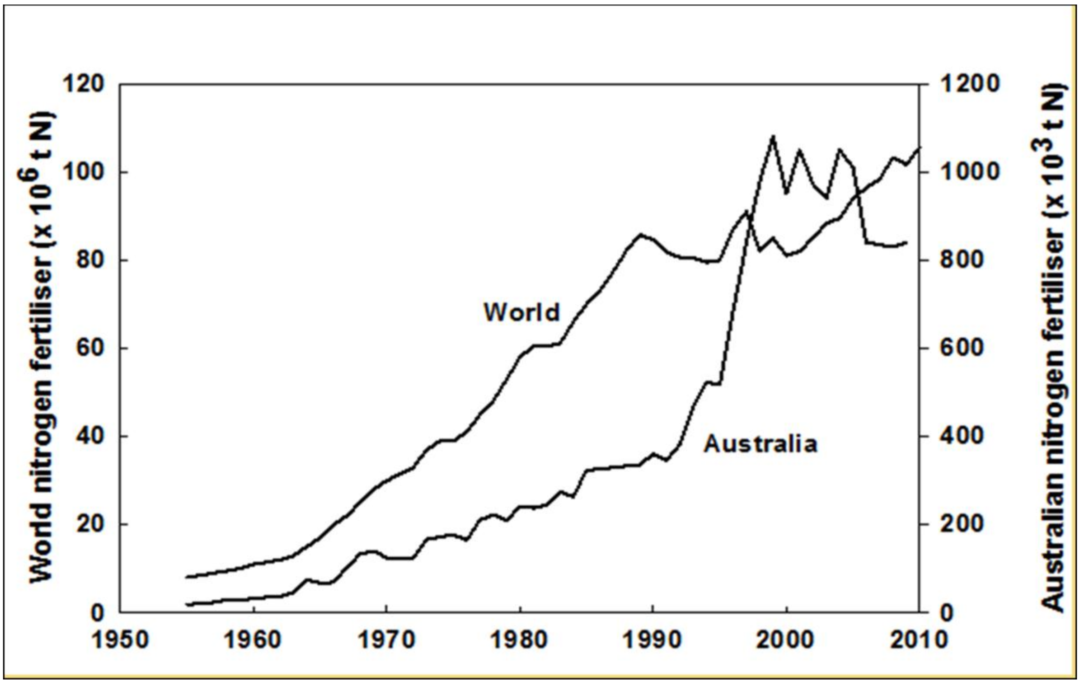

Figure 1. Changes in nitrogen fertiliser use globally and in Australia between 1950 and 2010 (from Angus and People 2012).

In contrast, to the massive increases in crop and animal production which has resulted from global N fertiliser use, the inefficiency of capturing nitrogen in agricultural products, as well as industrial emissions, has led to significant environment consequences, including increasing GHG, degraded water and air quality, reduced biodiversity, and soil acidification (Folwer *et al.* 2013). These issues are exacerbated by continued intensification of agricultural production in many developed nations. A key international issue for the next 30 years will be securing food production for an increasing world population, with 90% of this increasing demand likely to come from Asia and Africa. In part, this can only be achieved through a more efficient use of nitrogen inputs and a more equitable distribution of nitrogen and other nutrients globally.

This issue is well demonstrated by the significant increase in grain production in China, driven in large part by Chinese government policy around N fertiliser manufacture and subsidizing use to ensure food security (Figure 2, Zhang *et al.* 2013).

"The environmental losses of nitrogen through ammonia volatilisation in China are greater than the total nitrogen fertiliser use of all of Africa" Professor Mark Sutton, Chair of the International Nitrogen Initiative.

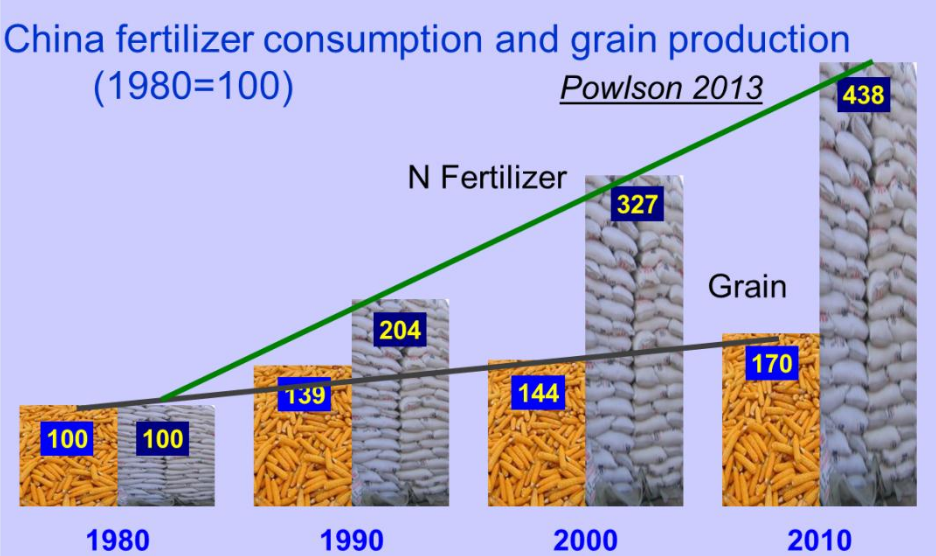

Figure 2. Changes in rice production and nitrogen fertiliser use in China between 1980 and 2010 relative to 1980 as the base year (courtesy of Professor David Powlson).

International policy environment

While much of Europe, the USA, China and Australia, have access to, and in general use, adequate and often excessive nitrogen fertiliser inputs to meet agricultural production targets, agricultural soils in much of the developing world, most notably Africa, are severely deficient in nitrogen (and other nutrients). Soil N depletion is of continued concern in Africa, while China uses 33% of the world's nitrogen fertiliser on 9% of the world's arable land.

There is considerable high level policy development internationally to improve the paradox of 'too little and too much nitrogen'. A key process is the International Nitrogen Initiative (INI) which has focused on regional nitrogen assessments, including the launch of the European and US Nitrogen Assessments, together with progress in Latin America, Sub-Saharan Africa, East Asia and South Asia. It has also been a long-term goal of INI to develop a Global Nitrogen Assessment process.

A key delivery of the INI leadership team has been the 'Our Nutrient World' report, where UNEP commissioned INI in cooperation with the Global Partnership on Nutrient

Management to prepare a Global Overview on Nutrient Management. This report was launched at the 27th UNEP Governing Council and Global Ministerial Environmental Forum, and has received wide press attention, particularly in relation to its proposal for a global goal to improve nitrogen use efficiency by 20%, saving 20 million tonnes of N annually by 2020.

The impact of this report has been translated into strong directives by major retailers worldwide. For example, Walmart, the world's largest food retailer has implemented a goal for food suppliers to their business to increase nitrogen use efficiency by 20% by 2015. Other international food producers and suppliers have also adopted this charter including Unilever, Kraft, both important global companies which derive supply from Australian farmers.

> 'Fertiliser optimisation is a top sustainability priority for our global food business. Our entire value chain needs to produce more with less. Fertilizer optimization is a balance to be achieved with nutrient use efficiency gains and increased productivity. Walmart is relying on its suppliers (i.e. food companies) to engage their supply chains and farmers in the process so their goals can be considered alongside those of their stakeholders. Agricultural service providers and the fertilizer industry must also have a role in this conversation as they are a key source of information and resources for the farmer.' Walmart Greenroom Sustainability Hub, http://corporate.walmart.com/microsites/global-responsibility-report-2013/supplyChain.aspx

Additionally, intergovernmental processes have provided the basis for a new platform, the International Nitrogen Management System (INMS), which is currently in development. This aims to provide an international scientific basis, options and dissemination process to support the future global nitrogen policy approach. The INMS will provide a mechanism to draw on the INI community, combined with a wide range of stakeholder engagement, to support global society in addressing the nitrogen challenge over the next decades.

Some regional nitrogen policies.

In the EU, the Nitrates Directive (ND) constrains nitrogen use and management on agricultural land across all EU member states. Currently the ND is implemented throughout the EU and constrains N applications of inorganic & organic fertilisers with a corresponding cap on livestock intensity at 170 kg organic N ha^{-1}, makes mandatory on-farm organic manure storage requirements (9 months storage), required separation of clean and dirty water from animal housing and milking shed, sets ploughing restrictions and green cover establishment, a minimum of 3 months of animal housing, and compulsory farm herd and nutrient management record-keeping on all dairy farms.

Despite similarities in grazing-based animal production systems, policy drivers for improved water quality is much stronger in NZ compared to Australia. This results from the over-arching objectives of the National Resource Management Act (1991) to maintain and improve NZ natural resources, which requires Regional Councils (similar to Australian CMOs) to develop regional policy strategies and plans for air, water, waste management, land, and biodiversity. Long-term water quality monitoring shows continued water quality deterioration from diffuse P and N sources which has been highlighted in specific iconic New Zealand lakes such as Lake Taupo and Roturua. Increased community concerns about intensification of farming, particularly dairy, and the resulting environmental pressure are encapsulated in a report from the NZ Parliamentary Commissioner for the Environment in 2004, and are also demonstrated by the 'dirty dairying' campaign promoted by the fishing and gaming lobby. Moreover, government and industry recognise that international environmental standards for dairy industries in Europe and the USA are not being met in NZ, with potential trade implications on NZ's access to export markets.

Land and water protection activities in Australia are largely delivered through catchment based programs. This usually involves co-operation or partnerships between landholders, community groups and local, State and Federal government agencies. Funding for on-ground works is provided through both Federal and State funded programs via applications to, or in concert with CMO's. In addition, State governments have also developed their own policy programs with respect to non-point source pollution. Regulatory approaches are generally controlled at the State level and States are also responsible for deciding the level of devolution of power to CMOs (Gourley and Ridley 2006), while State governments also provide the majority of research and extension staff involved in natural resource management issues.

As in other parts of the world, Australian animal agriculture, and associated industries such as fertiliser and milk companies, has been keen to promote a 'self-regulatory' approach to improving nutrient management practices and reducing nutrient losses. This is driven by concerns over potential government regulation, and a desire to manage negative environmental impacts in line with desired production goals, while at the same time being seen as pro-active in reducing externalities by domestic and international stakeholders and ensuring access to international markets. Both State and Federal governments have actively encouraged self-regulation by industry and have assisted indirectly with support and development of codes of practice from state agency staff, and also directly funded development programs. Consequently, environmental standards for Australian dairy production are currently much less demanding than nearly all other dairy industries across the developed world, but with an expectation that adherence to current international standards will be required in the near future.

Nitrogen efficiency in dairy production.

Over the past 2 decades, the use of nitrogen fertiliser has become the dominate N input in both cropping and intensive grazing systems (Fowler et al. 2013). For example, in 1990 almost no N fertiliser was applied to dairy pastures, while currently, N fertiliser is used at average rates of around 200 kilograms per hectare per year (Gourley et al. 2007).

In much of the industrialised world the conversion of N imported onto dairy farms, generally as fertiliser N and imported in feed, but also as biologically fixed N, into exported N in products, is often low relative to other agricultural systems (Powell et al. 2010). For example, a national Australian study of nutrient use on dairy farms (Gourley et al. 2012) found that whole-farm N surplus (the difference between total nutrient imports and total nutrient exports) ranged from 47 to 601 kg ha^{-1} yr^{-1} and N use efficiency (the ratio of total nutrient exported in product divided by total nutrient imported at the farm scale) ranged from 14 to 50%. Similar ranges in N surpluses and use efficiencies have been reported (Table 1) on commercial dairy farms in New Zealand (Ledgard et al. 2004), the USA (Rotz et al. 2006), Canada (Hristov et al. 2006), and Europe (i.e. Raison et al. 2008).

Table 1. Average N input and N use efficiency (total farm N outputs as a proportion of total farm N inputs for dairy farms in major dairy producing countries.

	Farm N inputs	**Farm N Use efficiency (%)**	
USA	215 to 568 kg ha-1	14 to 55	Rotz et al., 2006
Canada	Not available	25 to 64	Hristov et al., 2006
Europe	235 to 870 “ “	19 to 40	Raison et al., 2006
New Zealand	150 to 550 “ “	18 to 37	Ledgard et al., 2004
Australia-wide	88 to 808 “ “	14 to 49	Gourley et al., 2012

There are a number of commonly identified opportunities to improve N use efficiency in contrasting dairy systems, but solutions may also need to be tailored for individual systems and sometimes seasons (Monaghan et al. 2007; Gourley et al. 2012; Powell et al. 2010). Improving ration balancing and feeding optimum N concentrations appears to be an appropriate strategy to increase Feed N use efficiency, milk production and reduce N excretion in both confinement and grazing-based production systems. Milk urea N concentrations of bulk milk provided a useful indicator of overall CP intake (Powell et al. 2010). However, managing seasonal fluctuations in N intake appears to be a particular challenge in grazing-based systems as MUN levels indicated that excessive CP levels were common on many Victorian dairy farms in spring, while insufficient CP intake was common in summer(Gourley et al. 2010).

This issue of profitable and sustainable N fertiliser decisions is critical to farm productivity gains, as N fertiliser is now a major input and operating cost for the Australian and New Zealand pasture based dairy industries. However there is significant uncertainty around productivity gains from N fertiliser decisions (McKenzie et al. 2003) because of (i) substantial variability in pasture dry matter response, and (ii) the economic costs and benefits associated with fertiliser decisions on an individual dairy farm are specific to the whole production system (not just the pasture production component).

On dairy farms, many factors impact on production and economic responses to N fertiliser applications. For example, weather conditions, soil characteristics such as moisture, temperature, and plant available P, K, S status, timing and rates of applications, management of defoliation and supplementary feeding of cows, all influence responses in pasture production and the conversion of pasture to milk.

Understanding the variation around expected pasture production responses to marginal N applications (that is the response to the next unit applied, not the average response) would illustrate the risks of assuming ‘more is better, just in case.’ Improved recommendations for N applied to pastures would therefore increase overall farm profits, and reduce the proportion of the marginal application that is wasted through loss pathways.

While the collection of manure N is largely determined by the type of dairy system, significant amounts of manure N may be uncollected and that management and redistribution of collected N may be poor, irrespective of system type. In predominantly grazing-based systems, the greatest proportion of excreted N is deposited directly on to pasture soils. This is in contrast to confinement-based dairy systems where the largest proportion of excreted N was collected from barns and stored for redistribution, almost entirely on to cropped land. Substantial amounts of N may also be excreted in non-productive areas with no routine collection, such as exercise areas on confinement-based systems, and holding and feeding paddocks, on grazing-based dairy systems (Gourley et al. 2012). The resultant high N loading rates in these areas may pose a significant environmental threat.

On-farm assessments of N use, including diet and manure management, can be used successfully across different dairy systems internationally to provide an appraisal of current N use efficiencies, and assist farmers and advisors to identify opportunities for improving farm management. Such an approach needs to recognise specific challenges in quantifying and managing N intakes within grazing-based systems, as well as heterogeneous redistribution of manure N within all systems. We also suggest that a broad application of this approach could be used to determine industry-based N use efficiency benchmark values which would help set appropriate policy goals for improved N use efficiency and manure management practices. However further research work is needed to better understand how and why on-farm management decisions impact actual N use efficiencies and to quantify the productivity and economic gains from capturing more N within these production system. This information can then be used to develop and apply recommendations that have a high probability of being implemented on commercial dairy farms.

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