Rowarth, J.S.; Roberts, A.H.C.; Manning. M.J. 2020. Learning from the past: a comparison of food production systems for managing nutrients. In: *Nutrient Management in Farmed Landscapes*. (Eds. C.L. Christensen, D.J. Horne and R. Singh). http://flrc.massey.ac.nz/publications.html. Occasional Report No. 33. Farmed Landscapes Research Centre, Massey University, Palmerston North, New Zealand. 7 pages.

LEARNING FROM THE PAST: A COMPARISON OF FOOD PRODUCTION SYSTEMS FOR MANAGING NUTRIENTS

Jacqueline S. Rowarth[1], Ants H.C. Roberts[2] and Mike J. Manning[2]
[1]*Agri-environment analyst, Tirau*
[2]*Ravensdown, Christchurch*

Abstract
Many solutions are being offered for ensuring that food production does not impact upon the environment. The spectrum being practiced in New Zealand ranges from Biodynamic to Organic, Ecological, Regenerative, Conventional and Industrial, with proponents of some systems suggesting that New Zealand farmers can change to another system, generally one nearer the beginning of the list, for the better – that is, do 'better' by the environment and make more money, even without attracting a premium for the product.
Some of them can, but one size never fits all.
Part of the difficulty in the debate is differences in starting points, goals and resources available to achieve those goals. For New Zealand, the extra challenge is whether the goal should be to minimise environmental impact per unit of production (intensity), or to minimise impact per hectare (absolute). The latter is the focus in Europe and agricultural subsidies offsetting opportunity cost have been increasing in recent years. There has, however, been little positive effect in decreasing environmental impact. The OECD nutrient balance figures suggest nitrogen losses are increasing again.
Within this setting of intensity or absolute, the production and environmental aspects of organic and conventional systems are considered. Information on yield and nutrient losses, including greenhouse gases, both per kg of production and per hectare are presented. The paper also considers the economic aspects, bringing in recent research for credence factors. New Zealand farmers, unsupported and unconstrained by government subsidies, are in the fortunate position of having options. They generally choose the farming approach that suits their farm (soil, topography, climate, location), values and inclination. Imposing 'systems' based on belief rather than analysis, however well-meaning, could result in unintended environmental consequences. It could also have a negative impact on the profitability of individual farm businesses and the national economy.

Background
Food production has always involved resources and always generated waste. The original apple tree used energy from the sun and nutrients from the soil to create the perfect apple. Eve expended energy in reaching for the apple, consuming it and throwing away the core, which returned organic matter to the soil. At the other end of the scale, organophosphates involved extraction and processing of materials by humans, as well as fuel in application; the residues are still hanging around several decades later. Research, increasingly performed with scientific rigour and investigation of unintended consequences, has enabled increased quantity and quality of food to be produced. An ever-increasing population has created pressures on the food system. In the developed world these pressures have moved from being on the production system to the impacts of production systems on the environment.
The current combination of goals for agricultural scientists has been highlighted by the 2030 Agenda for Sustainable Development 'End hunger, achieve food security and improved nutrition and promote sustainable agriculture'. The meaning of 'sustainable' is still subject to perspective. Although the Paris Agreement suggested cutting greenhouse gases (GHG) without compromising food production, New Zealand has a Carbon Zero imperative which

includes agriculture. Economic viability, one of the five factors in the FAO definition of sustainability (Smyth & Dumanski, 1993), is very much under investigation. [The five are *maintain or enhance production/services, reduce the level of production risk, protect the potential of natural resources & prevent degradation of soil & water quality, be economically viable, and be socially acceptable.*]

Against this background the agricultural community is trying to identify a future. Efficient systems capture nutrients, whether synthetic or 'natural', into material that is harvestable for human use. Many solutions are being offered to improve management, most of which centre on changing inputs and some of which are supported by science. In the range of production systems (Fig. 1) there tends to be an increase in inputs from left to right.

Fig. 1. Representation of input intensity for different agricultural production systems, and reliance on petrochemical industry…. Note that Biodynamic and Organic are associated with strict criteria around not using synthetic compounds. The terms ecological and regenerative are sometimes used interchangeably and can be organic in approach.

This paper examines the literature behind some of the suggestions. By bringing past research to the fore, and examining the factors involved as well as results in a New Zealand context, the aim is to identify actions that might assist with achieving sustainable food production.

The Global Scene

In a world with increasing population, increasing food requirements can be met by expanding the area of land in food production, or increasing the quantity of food from the land already in production. The former, i.e., agricultural land expansion, is a major contributor to loss of biodiversity. The latter, increasing the yield per hectare, has been implicated in environmental impact (greenhouse gases and contaminants in water). The challenge is therefore to increase production without this impact by managing nutrients sustainably.

Three papers presenting (1) a meta-analysis, (2) a new framework and (3) LCA for New Zealand dairy in comparison with data from Sweden and Germany are used to consider nutrient management.

Counterintuitively perhaps, intensification has reduced environmental impact per kg of food produced– yields have increased more than impacts have increased. This has been shown in a meta-analysis of 164 published life-cycle analyses (LCA) across 742 agricultural systems (Clark & Tilman, 2017) comparing conventional (more intensive) production systems with organic (less intensive) production systems. The research reported high variability in results but found that organic production systems for cereals and fruit tended to produce fewer GHG per kg of product and for every product except vegetables used less energy than conventional production systems. However, for acidification potential, eutrophication potential and land use, conventional systems in meat, dairy, cereals, pulses and oil crops, fruits and vegetables outperformed organic systems

The authors concluded that increasing agricultural input efficiency (the amount of food produced per input of fertilizer or feed) would have environmental benefits for both crop and livestock systems.

This sentiment was echoed by Balmford *et al*. (2018). The authors acknowledged concerns about high-yielding farming because of the potential to generate high GHG and nutrient losses (externalities) per unit area but suggested that these metrics underestimate the overall impacts of lower-yielding systems. Their analysis indicated that improved pasture, whether for dairy or beef systems, had lower environmental impacts (GHG, N, P and soil) than low input or organic systems. Benefits increased for the 'improved' systems when the opportunity cost of soil carbon was included and authors indicated that high-yield farming has the potential, provided land not needed for production is largely used for carbon sequestration, to make a substantial contribution to mitigating climate change.

New Zealand and the input debate

Focussing on New Zealand, Basset-Mens *et al*. (2005) assessed environmental impact of milk production per hectare of land and per kg of milk solid (MS) in New Zealand and compared the results with data from Sweden and Germany. The New Zealand system had three-fold lower eutrophication potential and acidification potential per kg of milk, two-fold lower energy use and land use, and 50% to 80% lower global warming potential. Even compared to Swedish and German organic farm systems, New Zealand milk production potential impacts per kg of milk were similar or most often lower, than those from Sweden and Germany. Basset-Mens *et al*. suggested that the difference was due to the New Zealand farming system being based almost entirely on high-producing perennial pastures and all-year grazing compared with European farming systems with high supplementary feed use. However, using the new framework considering externalities, Balmford *et al*. (2018) showed that conventional systems—especially those using less grazing and more concentrates—had substantially lower land and also GHG costs. This is, in part because concentrates reduce methane emissions from fibre digestion. Systems with greater use of concentrates (which have less rumen-degradable protein than grass) also showed lower losses of N, P and soil per unit production.

New Zealand research (Ledgard *et al*., 2017) confirmed that GHG increased per hectare with use of supplement but decreased per kg MS. N leached per kg of MS was also marginally decreased because of the 'greater use of feed-pad facilities' which enabled improved capture of excreta-N and ability to spread the effluent across the farm in low-risk conditions. However, nitrogen use efficiency (NUE) was reported as only 28.8 to 31.2% (Ledgard *et al*. 2017). Although this is around average according to Fonterra data, there are examples of higher NUE with good management of animal shelters. Bassset-Mens *et al*. (2009) affirmed that improvements could be achieved with new technologies. Good practice objectives for Waikato dairy farmers were identified (Beukes *et al*., 2012) as 1200 kg MS/ha with a farm-gate N surplus of 100 kg/ha. Long-term average nitrate leaching losses of approximately 25-30 kg/ha/yr were calculated and key factors in efficiency were use of low protein supplement to capture more N as milk protein (which also assists with the goal of reducing replacement rate and longer lactation period each year) and using a loafing pad (now more commonly a feed shelter).

The requirement for income to pay for new technologies has resulted in the suggestion that farmers should go back to basics and simple systems. The theory is that they would be better off if they decreased stocking rate and inputs because decreased costs of production would more than offset the decreased income from sales. Environmental benefits would also accrue because of lower leaching from clover fixation than urea, and reduced intensity of GHG emissions.

However, N leaching, depends upon quantity of input, not source (Sprosen *et al*., 1997), and Beukes *et al*. (2012) indicated that reducing replacement rate and increasing lactation days are important for decreasing GHG intensity – both are dependent on a good feeding regime. A further concern is that the economic research indicating economic viability (Dewes *et al*., 2014) reported 'return on capital' without indicating how the return had changed before and after the change to 'basics'. In particular, the research stated that the strongest performing farms also had an ability to store and spread effluent at optimum times over much of the farm (>40%) and minimise imported soluble fertiliser. This implies investment in infrastructure which has been shown (Macdonald *et al*., 2015) to be more affordable with more intense systems than all grass because of profit per hectare based on production per hectare. DairyNZ Economic Data support the contention: over the last decade, higher input systems have given, 12% better return on assets, 31% better return on equity, 37% growth in equity and 3% lower debt per kg of MS.

Regenerative agriculture

On the spectrum between organic and conventional agriculture, the system termed regenerative agriculture is gaining traction. Advocates are promoting regenerative agriculture as the way to cut inputs and sequester carbon by managing the soil. Regenerative agriculture uses cover crops, no-till, crop diversity, little or no chemical fertilisers and pesticides, and livestock integration to promote healthier ecosystems by rebuilding soil organic matter. Soil carbon, which is over half of soil organic matter, has positive effects on soil chemistry, physics and biology.

Research in America is being used by regenerative agriculture proponents as an example of success at building organic matter. An increase in soil carbon has been measured at eight tonnes per hectare per year (Machmuller *et al*., 2015). The paddocks in the research started as degraded cropping soils (10 tonnes carbon/ha in the top 30cm) and were 'managed for maximum forage production, employing N fertilization, irrigation and selective rotational grazing with a 15 to 45-day rotation'. Nitrogen inputs were 605 kg/ha N fertilizer as urea, 134 kg/ha as N as poultry litter (which contains carbon) and another 97kg/ha of nitrogen in grain (also containing carbon). The increase brought the soils to 30-40 tonnes of carbon/ha in the top 30cm, at which point a plateau was reached, reflecting a dynamic equilibrium between inputs and outputs. The authors of the research did not mention the term 'regenerative' and did use considerable inputs. The example does not meet the 'little or no chemical fertiliser' aim – but it is still being used as an example of what is possible.

To alter the equilibrium to achieve more carbon after the plateau has been reached would require another change – either overcoming whatever is limiting production with more inputs or keeping the inputs steady while reducing 'offtake' (cutting stock numbers, for instance, to allow more 'litter'). The ultimate quantity of carbon able to be stored in a soil is a reflection of the dynamic equilibrium operating within the soil texture, structure and climate – waterlogged soils have historically built up carbon (peat bogs); dry soils lose it (desert). Of importance for productive soils is the fact that a decrease in inputs would result in a decrease in soil carbon and more nitrogen being released to the environment (Parsons *et al*., 2016). For New Zealand, with 95% of tested sites reported to be in the target range for soil carbon (Ministry for the Environment & StatsNZ, 2018), and a dynamic warming and drying environment, the risk of losing carbon, and the combined nitrogen, is high.

A further problem for New Zealand, particularly where pastures are managed closely, is that reduced grazing pressure could have quality effects on intake (stalky growth and weed ingress), which in turn reduces meat and milk per unit of intake.

Credence Attributes

Much has been made of premium prices over the years, but farmers are yet to gain overt benefits. (Note that this is not the case for kiwifruit, where Monopsony Zespri manages supply and hence is able to maintain price paid to New Zealand kiwifruit growers at a premium.)

Research, much instigated by The Lincoln University Agricultural Economics Research Unit, has evaluated Willingness To Pay (WTP) in various countries for a range of products. Yang

& Renwick (2019) reported that consumers were more willing to pay a price premium for Credence Attributes in Australia and New Zealand, followed by Asia, Europe, and other regions (including Chile, Russia and Turkey), while the lowest WTP is associated with the North American market. They also reported that consumers stated WTP for organic, followed by animal welfare, then hormone/antibiotic-free. Grass-based and environment-friendly were down the list.

For dairy (Yang *et al*., 2020) a premium of 15% at a carbon cost of $25/tonne of CO_2-e could encourage farmers to drop stocking rate and sequester carbon (notwithstanding the problems with C stabilisation discussed earlier). However, the base farm from which the modelling occurred was leaching over 40kg/ha N (considered to be average for the Waikato) and examples discussed earlier indicate that the reduction to 25 kg/ha N modelled has already been achieved in some operations – the average for New Zealand is around 30 kg/ha N. Also not considered is the cost of increasing soil carbon and the accompanying nutrients – a tonne of C in organic matter will be associated with around 100kg N, for instance, as well as phosphorus, sulphur and other nutrients, and that presents a cost.

Last year Our Land and Water (OLW) received media coverage on some of the work discussed above. "This work showed that, on average, consumers would pay 36% more for organic, 25% more for grass-based and 24% more for "environmentally friendly" products. In addition, it was found that beef and dairy products were associated with a higher price premium compared to lamb" (Lucci *et al*., 2019)

Scenarios modelled using base data for Waikato were 'carbon-neutral, organic and grass-based. (Carbon neutral was considered at the farm scale and excluded soil carbon and what occurs outside the farm gate. The modelling approach for C-neutral was to reduce biological GHG emissions as far as practical without affecting milk production, then payment to offset the remaining carbon equivalent ($25 NZD per ton CO_2-e).

Grass-based production required more N fertiliser, whereas what was termed the C-neutral system greatly decreased N losses but relied on imported feed to maintain production. Although this gives options to meet food shortages, the externalities are not always either understood or incorporated in analyses.

The authors of the OLW research concluded that 'the potential for increased payment is there for products that go beyond standard farming practices'. They also acknowledged that this statement had been made frequently over the years (Lucci *et al*., 2019).

Discussion

Sustainable intensification (SI), is being promoted by the Food Climate Research Network at The University of Oxford. Working with researchers from various institutions and perspectives, the Network has set the context and conditions within which it should be implemented (Garnett *et al*., 2013). In particular, SI identifies a goal but not how it should be attained or which agricultural techniques to deploy. Examination of diverse approaches in different locations and context taking biophysical and social contexts into account was recommended.

New Zealand agricultural systems are already very efficient by global standards and compare well with agricultural production systems in the developed world. This is because farmers have been supported by research and extension – from the Department of Agriculture through MAF to MPI; from DSIR to CRIs. Scientifically analysed and robustly proven ideas which have been examined in the New Zealand context will always have a place in advances, which is why New Zealand has achieved efficient systems. The debate on whether we should be calculating the effects of food production per hectare or per unit of food produced, will continue if we focus on New Zealand not the overall effect on the globe.

The OECD (2019) report on Agri-environmental Performance highlighted New Zealand as a model of decline in emissions intensity. Factors identified in the success were:

1. Adoption of policies focused on R&D, farm profitability, productivity and emissions intensity reductions
2. Changes in the production mix of animal species
3. Low levels of distortionary support to agriculture

Further research, including in precision agriculture and mitigations being led globally by the NZ Agricultural Greenhouse Gas Research Centre, will create further advances. Calculating impact on protein, rather than product, might help with the intensity *versus* absolute debate, but whatever the calculation, one approach will not be a solution for all farms. Doing so could result in leakier systems – poorer management of nutrients in an era when modern technologies, based on rigorous scientific research and taken up by motivated farmers, have already achieved a considerable amount.

References

Balmford, A.; Amano, T.; Bartlett, H.; Chadwick, D.; Collins, A.; Edwards, D.; Field, R.; Garnsworthy, P.; Green, R.; Smith, P.; Waters, H.; Whitmore, A.; Broom, D.M.; Chara, J.; Finch, T.; Garnett, E.; Gathorne-Hardy, A.; Hernandez-Medrano, J.; Herrero, M.; Hua, F.; Latawiec, A.; Misselbrook, T.; Phalan, B.; Simmons, B.I.; Takahashi, T.; Vause, J.; zu Ermgassen, E.; Eisner, R. 2018. The environmental costs and benefits of high-yield farming. *Nature Sustainability* 1: 477-485.

Basset-Mens, C.; Ledgard, S.; Carran, A. 2005. First life cycle assessment of milk production from New Zealand dairy farm systems. In: *Ecological Economics in Action*. Conference Proceedings of the Australia and New Zealand Society for Ecological Economics, December 2005. 8pp.

Basset-Mens, C.; Ledgard, S.F.; Boyes, M. 2009: Ecoeffciency of intensification scenarios for milk production in New Zealand. *Ecological Economics* 68**:** 1615-1625.

Beukes, P.C.; Scarsbrook, M.R.; Gregorinia, P.; Romera, A.J.; Clark, D.A.; Catto, W. 2012. The relationship between milk production and farm-gate nitrogen surplus for the Waikato region, New Zealand. Journal of Environmental Management 93:44-51.

Clark, M.; Tilman, D. 2017. Comparative analysis of environmental impacts of agricultural production systems, agricultural input efficiency, and food choice. Environmental Research Letters 12. https://doi.org/10.1088/1748-9326/aa6cd5 12p.

Dewes, A.; Bolt, J.; Mudge, R.; Bunyard, A.; Barber, B; Edlin, J. 2014. Farming for economic resilience and environmental performance: tomorrow's farms today 2010-2013. In: *Nutrient management for the farm, catchment and community*. (Eds L.D. Currie and C L. Christensen). http://flrc.massey.ac.nz/publications.html. Occasional Report No. 27. Fertilizer and Lime Research Centre, Massey University, Palmerston North, New Zealand. 12p.

Garnett, T.; Appleby, M.C.; Balmford, A.; Bateman, I.J.; Benton, T.G.; Bloomer, P.; Burlingame, B.; Dawkins, M.; Dolan, L.; Fraser, D.; Herrero, M.; Hoffmann, I.; Smith, P.; Thornton, P.K.; Toulmin, C.; Vermeulen, S.J.; Godfray, H.C.J. 2013. Sustainable Intensification in Agriculture: Premises and Policies. *Science* 341: 33-34.

Ledgard, S.F.; Bartlett, N.L.; van Boheemen, P.J.; Wilton, B.R.; Allen, S.B.; Muggeridge, D.P. 2017. Implications of increased use of brought-in feeds on potential environmental effects of dairy farms in Waikato. *New Zealand Journal of New Zealand Grasslands* 79: 130-148.

Lucci, G.; Yang, W.; Ledgard, S.; Rennie, G.; Mercer G.; Wang, M. 2019. The added value of value-add. The economic and environmental opportunities of delivering "Pasture-fed" "Carbon neutral" and "Organic" red meat and dairy products in New Zealand. https://ourlandandwater.nz/incentives-for-change/credence-attributes

Macdonald, T.O.R.; Rowarth, J.S.; Scrimgeour, F.G. Measuring the cost of environmental compliance for Waikato dairy farmers – a survey approach. *Journal of New Zealand Grasslands* 77: 159-166.

Machmuller, M.B.; Kramer, M.G.; Cyle, T.K.; Hill, N.; Hancock, D.; Thompson, A. 2015. Emerging land use practices rapidly increase soil organic matter. Nature Communications| DOI: 10.1038/ncomms7995 5p.

Ministry for the Environment & Stats NZ. 2018. *New Zealand's Environmental Reporting Series: Our land 2018.* Retrieved from www.mfe.govt.nz and www.stats.govt.nz. 134p.

OECD. 2019, Trends and Drivers of Agri-environmental Performance in OECD Countries, OECD Publishing, Paris, *https://doi.org/10.1787/b59b1142-en*.

Parsons, A.J.; Thornley, J.H.M; Rasmussen, S.; Rowarth, J.S. 2016. Some clarification of the impacts of grassland intensification on food production, nitrogen release, greenhouse gas emissions and carbon sequestration: using the example of New Zealand. CAB Reviews 2016 11, No. 054.

Smyth, A.J.; Dumanski, J. 1993. FESLM: An international framework for evaluating sustainable land management. http://www.fao.org/3/T1079E/T1079E00.htm

Sprosen, M.S.; Ledgard, S.F.; Thom, E.R. 1997. Nitrate leaching is similar in N_2-fixing grass-clover pasture and N-fertilizer grass-only pasture at similar N inputs. *Proceedings of New Zealand Grassland Association* 59: 125-128.

Yang, W.; Renwick, A. 2019. Consumer Willingness to Pay Price Premiums for Credence Attributes of Livestock Products – A Meta-Analysis. *Journal of Agricultural Economics* 70: 618–639.

Yang, W.; Rennie, G.; Ledgard, S.; Mercer, G.; Lucci, G. 2020. Impact of delivering 'green' dairy products on farm in New Zealand. *Agricultural Systems* 178. doi.org/10.1016/j.agsy.2019.102747