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A SUMMARY OF KEY MESSAGES ARISING FROM THE PASTORAL 21 RESEARCH PROGRAMME

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Abstract
The dairy-focused component of the Pastoral 21 research programme clearly demonstrated a range of options are available for farmers to decrease N and P losses to water. A series of key messages have been identified from the research programme and are presented in this paper. Whilst the N, P and sediment management strategies will provide options for creating headroom in catchments, future research is still required to identify management systems and farming technologies that deliver greater profitability, without compromising the gains in 'footprint' made in this programme.

The Pastoral 21 Research Programme

The Pastoral 21 (P21) research programme was jointly funded by MBIE, DairyNZ, B+L New Zealand, Fonterra and the Dairy Companies Association of New Zealand during the period 2011-2016. Its overall goal was:

"to deliver industry-accessible, adoptable, systems-level solutions for profitably increasing production while reducing environmental 'footprint' (nutrient losses to water), that had been field tested for demonstrable efficacy and value".

The programme was structured into three main themes: Next Generation Dairy Systems; Mixed Livestock Systems; and Breakthrough Technologies (Feed and Environment). Due to constraints of space, the focus of this paper is on dairy production systems, although much of the information is also of direct relevance to the mixed livestock sector (as discussed later).

Next Generation Dairy Systems

There were four demonstration farmlets (Waikato, Manawatu, Canterbury, and South Otago) that compared a system currently typical of that region ('Current') with a modified system ('Future'). The Future systems were designed to achieve the dual goals of increased profitability and decreased nutrient losses to water. Their design was based on farm system modelling (Beukes et al., 2011; Vogeler et al., 2012), thus the systems were established with the aim of testing whether the modelled benefits to nutrient losses and profit could be delivered in practice.

A regional focus was important because of differences in resource availability (land, water) for dairying, and the contrasting challenges to dairy production with different soil-types and climates. Table 1 summarises the main features of the comparisons. Waikato tested an-all pasture system, focused on lower fertiliser N inputs, and standing cows off paddock in autumn/winter to decrease urinary N deposition. Manawatu focused on restricted grazing to reduce urine deposition and to protect soils and pastures during wet periods in the autumn and spring. Canterbury focused on reduced N inputs to the dairy platform and strategies for reducing N leaching from grazed winter forage crops. South Otago focused on reduced N inputs and standing cows off in winter, combined with feeding pasture silage to avoid wintering in the paddock on brassica forage crops. More detail on these systems can be found in the papers cited in Table 1.

Thus, the solutions identified by the modelling and tested within the programme had a common theme: a focus on managing urine deposition during the autumn-winter period and decreased N fertiliser inputs compared with the norm for the region, with an adjustment in stocking rate in line with reduced N input and fed supply.

Common methods of measuring animal production and pasture growth were adopted across all four studies, as was profit calculation. Estimates of N leaching were based on methods appropriate for the soil type (Table 2). Leaching estimates from winter forage crops in Canterbury were initially made by scaling up lysimeter measurements to paddock scale, based on estimates of number of urinations and urine patches; in later years, porous cups were installed under forage crops, allowing measurement *in situ*.

Table 1. A summary of the main features of the four systems comparisons

Region	S.R.[1] (cows/ha)	N fertiliser (kg N/ha/yr)	Off-paddock	More details & comments
Waikato ***(see** Glassey et al., 2014)*				
Current	3.2	c. 150	-	
Future	2.6	c. 50	6-16 hrs/day Mar-Jul	
Manawatu *(see Hedley et al., 2017)*				Future herd - duration-controlled grazing
Current	2.7		40% grazed off, winter	
Future	2.8		All grazed on	
Canterbury *(see Chapman et al., 2017)*				A separate wintering study included fodder beet & catch crops
Current[1]	3.9	c. 300	Wintered on kale	
Future	3.5	c. 150	Wintered on kale	
South Otago *(results in preparation for publication)*				
Current	2.9	140	-	
Future[2]	2.8	80	Winter and shoulders	

Notes: [1]SR=stocking rate of milking platform. [2]Canterbury - used results from Lincoln University Dairy Farm as their ‘Current’ system

Breakthrough technologies

New ideas and concepts were evaluated for their potential to contribute to the overall goal of maintaining or increasing farm profitability while reducing nutrient losses to water. Technologies either had a ‘feed’ or ‘environment’ focus. These were separate to the Next Generation Dairy systems.

Results and key messages

Systems-based solutions

The systems comparisons ran for 3 or 4 lactation seasons, depending on the site. Full results will be published in peer-review journals but Table 2 provides an interim summary. The results clearly show evidence of marked reductions in N leaching, both in percentage and absolute terms. Note that amounts of N leaching were smaller from the heavy textured soils in Manawatu and S. Otago than from the free-draining soils of Waikato and Canterbury.

Effects on production were generally slightly negative, associated with less feed produced from lower N inputs (Waikato, Canterbury and South Otago) (Table 2). There were positive gains from housing and feeding cows (no change in N inputs) at the Manawatu site. Implications for profit are discussed later in the paper.

Key messages

At the end of the programme, the research team identified and agreed the key learnings from the programme. These are documented below.

1. No 'silver bullet'

The systems design were based on a sound understanding of how nutrients cycle through dairy systems, with the aim of decreasing the amount of urine hitting the paddock in total, or at times of the year when N leaching risk is greatest (Figure 1).

While a number of interventions are being developed that target the urine patch to reduce the amount of N leaching from the patch (see later), the farm systems design focused on the other three approaches outlined in Figure 1. This emphasis was a consequence of the voluntary removal of DCD from the market at the start of the research programme. Thus, reductions in N leaching were achieved without any intervention that specifically treated the urine patch.

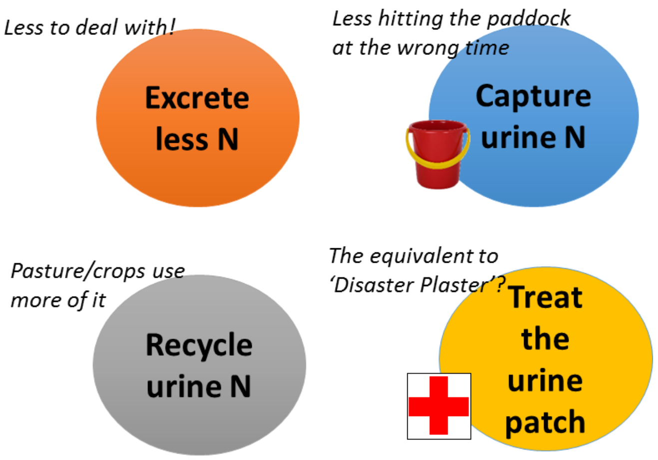

***Figure 1**. Main approaches to reduce N leaching from urine in a farm system*

***Table 2**. A summary of production and N leaching losses achieved in the four farm systems comparisons. In all cases comparing a 'Future' system targeting lower nutrient losses was compared with a 'Current' system, typical of the region. Note: Interim data[1].*

Region		**Average production**		**N leached & how estimated**		
		kg MS/ha	**% Change**	**kg N/ha**	**% Change**	**Method**
Waikato	Current	1193		54		Measured: NO_3-N, porous cups
(4 seasons)	Future	1162	-3	31	-43	
Manawatu	Current	1210		19		Measured: total N in pipe drainage
(3 seasons)	Future	1290	+7	11	-40	
Canterbury	Current[2]	1821		57		Modelled (OVERSEER)
(4 seasons)	Future	1782	-2	32	-44	Milking platform only
S Otago	Current	963		18		Measured: soil mineral N in autumn
(3 seasons)	Future[3]	930, 947	-3, -2	14, 13[4]	-24, -29	and direct measurements of loss from winter forage crop areas

Notes:
[1]While these results represent our best estimates at the end of the experiments, values might change as a more detailed assessment is undertaken as a part of the peer-review and publishing process
[2]Canterbury - using results from LUDF 2011/12 -2013/14 for comparison
[3]South Otago - included two 'Future systems': values documented for a low N input and barn system, respectively
[4]South Otago - also 30-40% reduction in P loss; 50-65% reduction in sediment loss

2. We can model these systems and their resultant nutrient losses

These systems were designed with pre-experimental modelling based on DairyNZ's Whole Farm Model, and also Farmax and OVERSEER. The N leaching reductions were in line with those predicted by the models. This confirms our understanding of some of the fundamental principles that govern N cycling and losses in pastorally-based grazing systems such as the importance of the amount of feed N flowing through the herd, and the amount and timing of urinary N deposited onto the paddocks, as outlined in reviews by Ledgard (2001), Di & Cameron (2002) and de Klein et al. (2010).

3. How N leaching reductions were achieved

This followed a two-pronged attack:

- Firstly, strong emphasis was placed on maximising pasture utilisation, pasture quality, and the efficiency with which inputs of feed and fertiliser were converted to milk. For example, reduced total annual N fertiliser inputs meant that the timing of fertiliser application, and the amount of N applied on each occasion, was governed by the changing balance between feed supply and demand during the year, rather than applying N in regular amounts after each grazing. It also meant that less pasture and N were consumed; for example, see Roach et al. (2016). Decreasing the stocking rate to match the available feed grown, combined with increased per cow milk production, meant that less feed went in to animal maintenance and more went into milk production. Shepherd et al. (2017) demonstrated in the Waikato study that the 9% reduction in pasture eaten per ha resulted in a c. 14% reduction in urinary N production per ha.

- Secondly, cows were removed from the paddock at critical times to capture urinary N in autumn and winter. A range of facilities were used to achieve this. Although the focus at Manawatu was to develop a housing facility to test the practicalities at scale, the use of woodchip pads in the Waikato and South Otago systems was more about establishing the principle that removing cows had benefits for N loss.

- *Importantly, the tools to help manage these systems are available now*. They include: weekly farm walks and use of feed wedges to allocate pasture; spring rotation planner; autumn management tool; and feed budgets (see https://www.dairynz.co.nz/feed/feed-management-tools/); as well as off-paddock facilities (https://www.dairynz.co.nz/farm/off-paddock-facilities/) and effluent management (https://www.dairynz.co.nz/media/2832537/farmers-guide-to-managing-fde.pdf).

4. How P loss reductions were achieved

Strategies were targeted towards protecting vulnerable areas of landscapes that contribute the greatest amount of sediment and P loading i.e. critical source areas (CSAs). For grazed winter forage crops, sediment, phosphorous and *E. coli* were reduced considerably through protection of the CSA, (which accounted for less than 2.5% of total paddock area) when the cows strip-grazed from the top of the catchment and moved downslope, with restricted access to the CSA in the bottom of the paddock (Orchiston et al., 2013; Monaghan et al. 2017). A number of factsheets have been produced to promote the practice across the Southland and South Otago regions (e.g. DairyNZ, 2015).

5. Implications for profit?

Although production was slightly down in three of the four Future systems compared with Current, the profit delivered by the systems is a more important metric of performance. A key driver of profit is milk price, which varied widely over the duration of the programme. In general terms, relative profits between the Control and Future systems at a site changed with milk price, with the lower input systems out-performing higher input systems at low pay-out and *vice versa*. Increased profit in the Future systems at low pay-out was generated through: reduced costs (fewer cows, fewer inputs e.g. fertiliser N); maximising the use of pasture for feeding; and increased per cow production (as a result of the system changes); for example, see Chapman et al. (2017). Gains from saved inputs offset some of the extra Standoff costs but, clearly, building infrastructure impacted on profit.

6. The role of standing cows off paddock

Standoff managements played two roles in the systems. The first was to reduce N leaching risk by decreasing urine N deposition to paddocks in autumn and winter. A second role was to protect wet, fragile soils from treading damage, particularly around the autumn and spring shoulders. The benefits of implementing this second approach were two-fold: more pasture was grown on protected paddocks, and the risk of surface runoff in autumn and spring was likely decreased (although this was not directly measured). The timing of implementing these standoff managements varied regionally according to climate and the practicality of using the off-paddock facility.

Realising the above benefits required the capture and recycling of dung and urine deposited in the barn or standoff pad facility. Applying effluent and manures back to pasture at the right time and at the right rate were other important considerations to ensure that the nutrients in these materials were used by pasture, and direct losses via run-off and leaching were minimised.

7. Winter forage crops

Grazed winter forage crops have been identified as a significant source of N, P, sediment and faecal microorganisms. While the strategic grazing strategies developed within P21, as described above, provide solutions for reducing losses via surface run-off, N leaching remains a challenge. Use of fodder beet as an alternative to brassicas was evaluated in the Canterbury system. Urinary N concentrations were low for animals grazing both brassicas and fodder beet (Edwards et al., 2014) and further evaluation of the consequences on N leaching risk are being worked through. The use of a 'catch crop' post grazing shows some promise for reducing subsequent N leaching losses (Carey et al., 2016). Research on fodder beet post P21 will continue in the Forages for Reduced Nitrate Leaching (FRNL) programme (DairyNZ, 2016).

Next generation solutions

We demonstrated reduction in N leaching of up to 40% in the systems comparisons. However, it is necessary to continue to develop new mitigation strategies:

- To provide farms with a wider range of options to give more flexibility
- To provide options that are more cost-effective than what is currently available

This second point is highly pertinent because P21 has been less successful at raising farm profitability; whilst we have created options for farming within environmental limits, profit is a key element of sustainability. Thus, more cost-effectiveness measures are required, especially more affordable options to replace stand-off facilities that are commonly used at the moment. Figure 2 shows an example of a range of options that have been or are being developed. Some of these were targeted in P21.

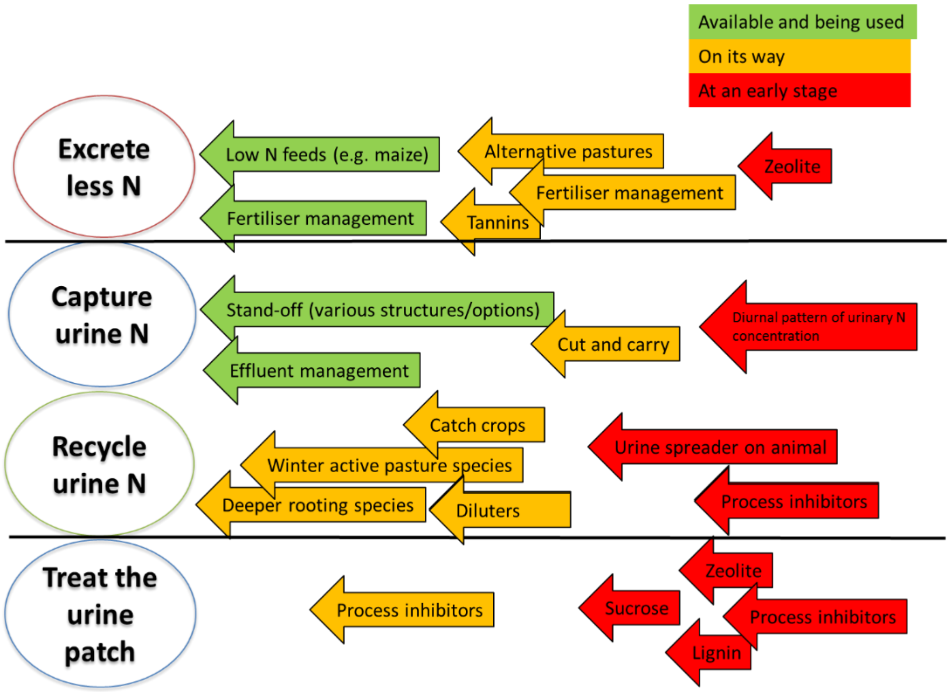

Figure 2. *An example of a development pipeline for a selected set of N mitigation approaches.*

One of the most promising N mitigation technologies coming from P21 was the use of salt supplementation of dairy cows to dilute the N concentration of individual urine patches (Ledgard et al., 2015). This is currently undergoing field evaluation. Other approaches include using N immobilising compounds to lock up urinary N. Treating urine patches may become more cost-effective now that technologies for easily identifying urine patches in the paddock are becoming available, such as SPIKEY ® (Quin et al., 2016).

To reduce P losses from CSAs, McDowell et al. (2014) demonstrated that replacing clover (with its higher soil P requirement) with grass (lower P requirement) in CSAs reduced P runoff, suggesting benefit from spatial separation of clover and grass in catchments rather than sowing as a mix. Furthermore, dilution of soil P by cultivation below 7.5 cm when establishing the grass further decreased P loss (Smith et al. 2016).

Relevance to the mixed livestock sector

As well as the research specifically addressed for Mixed Livestock systems (with some examples listed in the description of the research, above), other components of the research programme were directly applicable to these systems. Examples are listed in Table 3.

Table 3. *Examples of 'non-Mixed Livestock' research that are relevant to the Mixed Livestock sector.*

Topic	Example references
Winter forage crops including fodder beet for feeding cows - implications for N leaching	Edwards et al. (2014)
Husbandry of forage crops, including fodder beet	Chakwizira et al. (2014)
Strategic grazing of winter forage crops to decrease sediment and P run-off	Orchiston et al. (2013)
Separation of grass and clover, using grass (with low P requirements) in critical source areas and clover in other areas of the farm. Use of cultivation to 'dilute' surface soil P status in grassed areas.	McDowell et al. (2014) Smith et al. (2016)
Long-term: proof of concept for the potential to select hybrid germplasm with improved dry matter production under reduced P inputs	Nichols et al. (2014)
A protocol for measurement of pasture mass has been developed and tested with farmers and B+LNZ	Hutchinson et al. (2016)
Feeding salt to cattle to decrease N leaching	Ledgard et al. (2015)
Drought effects – N leaching risk and fertiliser N utilisation	Lucci et al. (2013)

Conclusions

- The dairy-focused component of the Pastoral 21 research programme clearly demonstrated a range of options are available for farmers to decrease N, P and sediment losses to water. These system options are can be successfully implemented with commercial scale herds (Pellow, 2017).
- We have been able to develop a set of evidence-based key messages from the research that can be shared with the industry, not just in the dairy sector.
- Although these results provide options for farming within limits, future research still requires
  - A focus on profit (solutions that decrease costs, increase production or value-add)
  - A focus on next-generation mitigation solutions that are able to achieve the gains at lower cost

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