Issues related to the management of nutrients on organic dairy farms: Nitrate leaching and maintaining soil nutrient levels

D. J.HORNE[1], E.F. DIJKSTRA[2], A. S. PALMER[1] and P. CAREY[3]
[1]*INR – PN433, Massey University, Private Bag 11-222 Palmerston North 4442*
[2] *EcoAgriLogic PO Box 190 Carterton*
[3]*Land Research Services Ltd, PO Box 84, Lincoln University*
D.J.Horne@massey.ac.nz

Abstract

It is often claimed that nutrient management in organic dairying is more environmentally sustainable than its conventional counterpart. Organic dairy farmers often focus on pH, trace elements and nutrient ratios rather than the major nutrients such as phosphorus. As a consequence of less nutrient input, the environmental impacts of organic dairy systems may be smaller than for conventional farms. Some of these issues were explored by surveying eight organic farms in the North Island. The objectives of the nutrient management plans along with trends in soil test values were examined. OVERSEER® Nutrient Budgeting software was used to quantify maintenance fertiliser requirement for the organic dairy farms and likely trends in nutrient status. Nitrogen leaching from the organic farms was also assessed using OVERSEER®. This study suggest that while the current nutrient status of organically managed soils is not dissimilar to that found on conventional farms, sustainable nutrient management on organic dairy farms is an emerging challenge. Of particular note here is a decline in phosphorus status. While organic dairy farms leach much less nitrogen than conventional farms, some of these advantages are eroded when efficiency indicators are invoked. A field trial has been established to identify products that will help organic farmers increase soil nitrogen and phosphorus nutrition.
Keywords: organic dairying, nutrient management, nitrogen leaching, nitrogen conversion efficiency, environmental efficiency.

Introduction

For some time there has been scientific evidence that organic management may enhance some soil physical and biological properties (Reganold *et al.* 1993). On the other hand, some researchers have raised serious questions about the ability of organic farms to sustain soil nutrient reserves (Condron *et al.* 2000). Apart from the ARGOS study (Carey *et al.* 2010), there has been relatively little research of the trends in the nutrient status of soils on organic dairy farms in New Zealand. As organic dairying is a relatively new enterprise in this country (Carey *et al*. 2010), it may be timely to take stock of some of the issues related to nutrient management on these farms. Nutrient management in organic dairying faces a number of challenges. Arguably the greatest difficulty is sourcing nutrients in a concentrated, readily available and cheap form. This is particularly the case for nitrogen where there is no real alternative to urea which is used so ubiquitously, and by many accounts, so effectively on conventional farms. Currently fertilisers and/or soil conditioners that are certified for use on organic farms tend to be either bulky, and therefore expensive, or very novel products that are largely unproven. There is concern that organic farmers may be trading on and depleting the nutrient reserves that they accumulated with the use of conventional fertilisers and management practices.

The other plank of nutrient management plans is reducing losses to the environment. Here, organic dairy farms may lead the way (Condron *et al.* 2000). If fewer nutrients are applied to an organic dairy farm then, all other things being equal, this system should leak smaller quantities of nutrients and have a smaller environmental footprint. Systems comparison research found that nitrogen leaching from an organic dairy farmlet in the Manawatu was approximately 50% less than a neighbouring conventional farmlet, and this was attributed to lower intensity, including smaller N inputs to the organic system (Horne *et al.* 2008). A reduction in leaching and runoff losses could be a major benefit of organic farming in this day of increasing environmental concern and regulation. Furthermore, so long as they can realise the premium for organic milk, converting to organics may be the most practicable and cost-effective way for some dairy farmers to comply with imposed nitrogen loss allocations.

In this paper, we seek to explore issues related to nutrient management on organic dairy farms using eight case study farms. These issues include: the likely trend in the status of some macro-nutrients, the impact of organic farming on the magnitude of nitrogen leaching, and relatedly, the effect of organic farming on some indicators of nitrogen use efficiency. Furthermore, some preliminary results from a large scale field trial which has been established to address some of these issues are reported.

Methods

Eight case study, organic dairy farms were identified. The certified, organic farms were from the Waikato (5 farms), Taranaki (2 farms) and Manawatu (1 farm) regions and were part of the "Grow Organic Dairy" Project.

A survey was sent to the farmers canvassing their views on nutrient management, soil testing and fertiliser. In follow-up, semi-structured interviews, numerous features of the nutrient management plan (such as they were) of the eight organic dairy farmers were probed.

The survey results were supplemented with measurements of soil nutrient status on the case study farms. These samples were collected during the spring of 2011. Soil fertility analyses were conducted on a bulked sample of soil (taken from 0–7.5 cm depth) from at least three paddocks on each farm. Soil chemical analyses discussed here include pH, Olsen-P, resin-P, and exchangeable cations (Blakemore *et al.* 1987). Five of the case study organic farms had detailed historical information which allowed a comparison between present-day soil nutrient status and the values measured in 2005.

OVERSEER® (Version 5.4.10) was used to estimate the maintenance nutrient requirements, N leaching and nutrient use efficiency on the case study organic farms. The environmental efficiency (kg N leached/tonne of milksolids) as defined by Tillman *et al.* (2008) was calculated for each farm.

A series of field trials has been established on four of the farms (Manawatu, Taranaki and two Waikato farms). The trial sites span a range of climates and soil types. The objective of this research is to evaluate the performance of four, commercially available, fertilisers or soil conditioners. The products being assessed include; agricultural lime, reactive phosphate rock, chicken compost and a relatively new product known as ROK Solid. At each site, these treatments are replicated six times. There are 30 plots at each site. Plots are 6 × 5 m and set out according to a complete randomised block design. The allocation of treatments to plots is identical at all four sites. The treatments have been applied three times: October 2009, March 2010 and September 2011. This trial is ongoing. Preliminary results are summarised here.

Results and Discussion

Organic dairy farmers often have quite different aspirations for soil and nutrient management than their conventional counterparts. The case study organic farmers invariably articulated the (sole) importance of "soil biology" to soil properties and function. While this undoubtedly refers, in part, to the well understood importance of soil organic matter as a source of nutrients and biologically mediated processes in nutrient supply, the case study farmers were often unclear as to exactly how "biology" is so efficacious, nor were they able to substantiate their argument with quantitative information. However, the latter point undoubtedly reflects the paucity of measures for biological activity that are commercially available for whole-farm testing. The organic farmers also prioritise pH management, many claiming that it is important to have pH values in the range of 6.3 to 6.5. The other features of the nutrient management plans of the survey group of organic farmers is the emphasis placed on trace elements, nutrient balances e.g., base saturation, and calcium and magnesium levels. The emphasis placed on trace elements on organic farms is noteworthy. However, the survey also revealed that the major nutrients are not given the same attention on the organic farms that they receive on conventional farms. Some of the organic farmers seemed to be of the view that by attending to soil biology, pH and trace elements, a soil environment or ecology capable of providing the major nutrients, would be created.

Organic farmers tend to use a wide range of fertilisers and/or soil conditioners and they are also prepared to try new products. However, they admitted to some confusion and concern, even scepticism, about the claims made by the manufacturers of a plethora of new products that are actively marketed to organic producers.

Examination of the soil test results suggests that currently there are no major soil nutrient deficiencies – or for that matter, toxicities – on the case study organic farms. Indeed, most of the soil test values looked remarkably similar to values commonly observed on conventional farms. For example, the mean Olsen P value across the seven organic farms in 2011 was 27 (σ = 5). While not large by the standards of modern dairy farming in New Zealand, this value falls in the range that is often stated as being "biologically optimum for dairying and posing a smaller environmental risk". The mean pH and QT potassium values were 6.4 (σ = 0.2) and 11 (σ = 6), respectively. Carey *et al.* (2010) also reported that soil nutrient values on organic and conventionally managed dairy farms are, in general terms, similar.

One possible concern is the decreasing trend, with time, in some of the values for the major nutrients, phosphorus and potassium, as revealed by inspection of the historical records (available on five of the case study farms). Since 2005, Olsen P values have declined on all of these farms: the mean decrease in Olsen P values over this period is 25%. This decline in P status cannot be easily accounted for by the claim that reactive phosphate rock is the fertiliser of choice on organic dairy farms and that the success of this product can only be monitored by the resin P test. While some of the farmers use RPRs, this fertiliser is not the defining feature of fertiliser applications to the case study organic farms. Furthermore, the resin P values have also decreased on two of the three case study farms that have historic and current resin P test results.

It is important to appreciate that some of this reduction in P concentration may have been planned and desirable where Olsen P values were greater (45–50) than optimum. Large values of soil nutrient status are particularly difficult and inefficient to maintain under organic management. It should also be acknowledged that one farm (Waikato A) clearly demonstrates that it is possible to increase soil P reserves on organic dairy farms. Having said this, the trend of decreasing Olsen P values on many of the case study farms may lend some credence to the claim that organic farmers need to be careful that they are not simply mining the soil nutrients that have accrued under applications of conventional fertilisers.

OVERSEER® was used to throw some light on this trend of decreasing reserves of the major nutrients. According to OVERSEER®, there is a mismatch between maintenance requirements of P fertiliser and the quantities of P being applied to the organic farms (Table 1). For the 7 years between 2005 and 2011, OVERSEER® predicts an average decrease of 20% in Olsen P values on the organic farms, which agrees closely with the measured reduction of 25%. OVERSEER® predicts that, in the absence of intervention, Olsen P values will continue to decline by an average of 1 unit per year across nearly all of the organic farms: on some of the farms, Olsen P status will deteriorate more rapidly.

Although not as marked as the decline in Olsen P values, potassium values have also fallen on the five organic farms (with detailed historical records) between 2005 and 2011 by a mean value of 9%. However, this

Table 1. The Olsen P value (measured in 2011) and the phosphorus applied as fertiliser to the case study farms along with maintenance phosphorus requirement and the annual change in Olsen P value as predicted by OVERSEER®.

Farm	Average Olsen P (µg P/ml of soil)	Calculated maintenance phosphorus requirement (kg P/ha)	Actual Phosphorus fertiliser applied (kg P/ha)	Predicted change in Olsen P value per year
Waikato A	31	27	35	+2
Waikato B	28	32	33	0
Waikato C	27	40	30	-1
Waikato D	23	25	22	-1
Central Plateau	33	35	11	-2
Taranaki A	19	26	0	-2
Taranaki B	33	35	11	-2
Manawatu	34	24	20	-1

Table 2. The potassium value (QTU) as measured in 2011 and the potassium applied as fertiliser to the case study farms along with maintenance potassium requirement and the annual change in potassium value (QTU) as predicted by OVERSEER®.

Farm	Average potassium QTU (µg K/ml of soil)	Calculated maintenance potassium requirement (kg K/ha)	Actual potassium fertiliser applied (kg K/ha)	Predicted change in potassium QTU per year
Waikato A	16	37	0	-0.5
Waikato B	5	6	0	0
Waikato C	21	80	0	-1
Waikato D	8	12	0	0
Central Plateau	8	34	47	0
Taranaki A	7	4	0	0
Taranaki B	8	1	12	0
Manawatu	6	0	49	1

may just be noise or variability in the soil test analysis as OVERSEER® suggests that there should be no change in potassium values on the majority of the farms (Table 2). Interestingly, five of the farms apply no potassium fertiliser.

Not all soil test values have declined during this period. For example, pH values have increased slightly on all farms (mean value of 7%), reflecting the importance that organic farmers often place on elevated pH values.

According to OVERSEER®, relatively small quantities of nitrogen leach from the organic farms (Table 3). Given the very substantial differences between organic and conventional dairy systems, direct comparisons of N leaching from these types of farms need to be interpreted carefully. This cautionary note notwithstanding, N leaching from the case study organic farms is approximately 50–60% of the losses from conventional farms in their region. By way of illustrating this point, the mean N leaching of 18 kg N/ha from the Waikato organic farms is substantially smaller than the range of 35 to 55 kg N/ha leached from approximately 66% of the 706 farms in the region as surveyed by DairyNZ and Fert Research (Mladenov 2012). According to this data base, only 6% of farms leach less than 20 kg N/ha. In a long-term systems comparison trial, Horne *et al*. (2008) measured very similar differences in N losses in drainage under organic and conventional dairy management.

As alluded to above, these differences in N leaching are to be expected given the differences in nitrogen inputs, principally via fertilisers and supplementary feed, to the two systems. Larger N inputs to conventional farms will typically translate into higher stocking rates, greater nitrogen ingestion by the animals, greater N loads in excreta and subsequently larger quantities of leached N.

Given the differences in the quantities of milk produced by the two systems, it is often argued that the fairest way to compare their relative impacts on the environment is by using metrics of use-efficiency or a footprint approach i.e. linking the amount of N leached to the quantity of milk produced (Kirchmann & Bergström 2001). While organic farms still compete favourably with conventional farms, they lose some of their advantages when N leaching is adjusted for efficiency and/or yield. Two such indicators are discussed below.

There is an increasing focus on nitrogen conversion efficiency (NCE) on dairy farms. According to OVERSEER®, the case study organic farms used nitrogen efficiently (Table 3). Again, a comparison between the case study farms and conventional farms in their region is instructive. The mean NCE of 39% for the Waikato case study organic farms compares favourably with that of the conventional farms in the region as reported in the DairyNZ survey where only 20% of farms had NCEs greater than 37%.

Another indicator that has been proposed for benchmarking the environmental performance of farm systems is the "environmental efficiency of N leaching" which is defined as the quantity of N leached (kg N/ha) for every tonne of milk solids produced (Tillman *et al.* 2008). The mean value for the environmental efficiency of the organic farms is 24 kg N/t MS ($\sigma = 7$). In very general terms, this is comparable to a leaching loss of approximately 19 kg N/ha and a milksolids production of approximately 0.8 t/ha (i.e. 800 kg/ha). A conventional farm producing 1200 kg MS/ha could afford to leach only 29 kg N/ha if it is to match the environmental efficiency of organic farms. However, according to the DairyNZ survey (Mladenov 2012), leaching losses of *ca.* 35 kg N/ha are more likely from a conventional farm. Given these values, the environmental efficiency would be 29 kg N/t MS: a clear advantage to the organic farm, if only by approximately 20%.

In an attempt to address some of the nutrient management issues discussed above, a large scale field trial has been established on four of the case study farms. The treatments were selected to meet a range

Table 3. N leaching from the case study organic farms, N conversion efficiency as predicted by OVERSEER® and the Environmental efficiency index.

Farm	Milksolids production (kg MS/ha)	Predicted N leaching (kg N/ha)	N conversion efficiency (%)	Environmental efficiency index (kg N/t MS)
Waikato A	717	17	39	24
Waikato B	763	19	31	25
Waikato C	732	24	44	33
Waikato D	900	13	44	14
Central Plateau	843	25	38	30
Taranaki B	920	25	38	27
Manawatu	776	12	37	15

of different objectives including; identifying a reliable source of nitrogen and a fertiliser capable of increasing or maintaining Olsen P values. In addition, the organic farmers requested that we compare all treatments with lime. We were also asked to evaluate one new, alternative product (ROK Solid).

To date, only the chicken compost has significantly (mostly at P>0.05) and consistently increased pasture growth across all farms. Typically the compost has increased pasture growth by approximately 30 to 40% for the two month period after application. This translates into an average response of 10 kg DM/kg N.

The only significant and consistent response in the soil analysis is an increase in pH under lime. However, there is a hint in the latest results that the RPR based product may be increasing Olsen P values. This is encouraging as it could be a solution to the problem of declining P status discussed above. The alternative soil conditioner has not improved either pasture production or soil properties. Results to date would suggest that providing that there are adequate nutrients in the fertiliser, and that they are plant available, the nutrient source *per se* is not important. Organic, and for that matter conventional, farmers need to proceed with extreme caution when contemplating the use of "alternative" fertilisers.

A further implication of the results presented here is that, given that they are prohibited from using the wide range of quick release fertilisers that conventional farmers can apply, organic farmers need to look (years) ahead and seek to accumulate or "aggressively" maintain soil fertility using larger rates of slow release fertilisers. Converting farmers need to be made aware of this i.e., that it may take a longer time for organically certified fertilisers to act.

Conclusions

While current soil test values for organic and conventional farms may not be that different, there is some evidence that the levels of some of the major nutrients are trending downwards on organic farms. Use of nutrient budgeting software such as OVERSEER® suggests that many of the organic farms are not applying "maintenance" fertiliser requirements.

According to OVERSEER®, the organic dairy farms leach only 50 to 60% of the quantity of nitrogen that is lost from conventional farms. There may be some important management lessons here for conventional farmers. However, some of the environmental advantages of organic dairy production are reduced when yield is factored in.

Protecting and increasing their productive capacity, i.e., milk yield, is a priority issue for organic dairy farms. To this end, sustainable nutrient management will be a challenge. In terms of protecting their environmental advantages, organic dairy farmers are caught on the horns of a dilemma: how to increase nutrient inputs to their system so as to increase production while, simultaneously, holding nutrient losses to water ways to a minimum.

REFERENCES

Blakemore, L.C.; Searle, P.L.; Daly, B.K. 1987. Methods for chemical analysis of soils. Report No. 80. NZ Soil Bureau.

Carey, P.L.; Moller, I.H.; Norton, S.; Benge, J.R.; Lucock, D.L.; Manhire, J.B.; Meenken, E.D.; Jiang, S. 2010. A perspective on differences in soil properties between organic and conventional farming in dairy and sheep and beef sectors. *Proceedings of the New Zealand Grassland Association 72*: 35-42.

Condron, L.M.; Cameron, K.C.; Di, H.J.; Clough, T.J.; Forbes, E.A.; McLaren, R.G.; Silva, R.G. 2000. A comparison of soil and environmental quality under organic and conventional farming systems in New Zealand. *New Zealand Journal of Agricultural Research 43*: 443-466.

Horne, D.J.; Thatcher, A.; Brookes, I.; Palmer, A.S.; Harrington, K.; Kelly, T.C.; Kemp, P.D.; Shadbolt, N. 2008. The impact of organic dairy farming on the aquatic environment. *In:* Proceedings of the 6th Dairy3 Conference. 235-242.

Kirchmann, H.; Bergström, L. 2001. Do organic farming practices reduce nitrate leaching? *Communications in Soil Science and Plant Analysis 32*: 997-1028

Mladenov, P. 2012. Regional nutrient management indicators. http://www.fertresearch.org.nz/resource-centre/regional-nutrient-management-indicators (accessed 18 July 2012)

Reganold, J.P.; Palmer, A.S.; Lockhart, J.C; Macgregor, A.N. 1993: Soil quality and financial performance of biodynamic and conventional farms in New Zealand. *Science 260*: 344-349.

Tillman, R.W.; Horne, D.J.; Hedley, M.J.; Yates, L.J.; Hanly, J.A. 2008. Is "environmental efficiency" a useful concept in improving and regulating the environmental performance of pastoral farming systems? *In:* Carbon and Nutrient Management in Agriculture (Eds. L.D. Currie and L.J. Yates) Proceedings of the 21st Annual Workshop held by the Fertilizer and Lime Research, Massey University, Palmerston North, NZ (13-14 Feb 2008). 531-538.