Dairy effluent – composition, application and release
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Executive summary

Dairy effluent – composition, application and release

Wallace DF & Johnstone PR, July 2010, SPTS No. 4287

Intensification of New Zealand’s dairy industry has resulted in increased volumes of nutrient-rich effluent being collected from the dairy shed, feed pad and holding areas that need to be disposed of. Application of effluent to land is now common and offers both environmental and economic benefits for farmers. A recent industry-funded project (SFF 07/037 Maize to manage dairy effluent) has demonstrated that applying effluent to maize crops can result in yields that are similar to those produced when inorganic fertiliser is applied to maize.

This report describes the findings of a literature review on dairy effluent conducted on behalf of the Foundation of Arable Research in association with the above project. The literature review focused on the nutrient composition of dairy effluent, methods available for its application, factors that control the release of nutrients in the soil, and the use of tools to predict nutrient release and required application rates. Increased understanding of these factors will improve the profitability of applying effluent to maize crops and its environmental sustainability.

The review has found that the nutrient composition of dairy effluent is highly variable. Factors such as age and breed of cows, seasonality, supplement feeding and volume of wash down water used all affect the nutrient content of effluent. Therefore, to accurately match the effluent applied with crop nutrient demand the nutrient content of effluent must be tested before it is applied.

Two broad application methods were reviewed in this study: surface application and sub-surface application. Sub-surface application is the most efficient method of the two as it allows immediate losses of N due to volatilisation to be reduced. Sub-surface application involves either incorporating effluent or injecting it directly into the soil. Incorporation involves initial surface spreading followed quickly by cultivation. Directly injecting effluent into the soil is the most efficient method for reducing volatilisation losses, although this practice does not appear widespread in New Zealand.

Nutrient release from the applied effluent occurs slowly via mineralisation. This biological process is controlled predominantly by soil temperature, soil moisture, soil pH and aeration. Due to the number of factors that can influence the nutrient release rate, it is difficult to predict precisely when nutrients will become available. To date, most indications are that between 20 and 50% of the total N applied in the effluent may be released during the first year after application. Spreading effluent during autumn when soil temperatures are higher and the soil is easier to work may allow the quick release of nutrients. However, studies are necessary to confirm if winter losses from leaching are significant. Overall, understanding of nutrient release from effluent in New Zealand conditions is still relatively poor (especially for P and K). Further work would allow greater confidence in the use of effluent for maize cropping in New Zealand.

Internationally, tools are available to model crop responses to effluent application. Two tools have been identified (APSIM and MANNER). Both offer a base from which to develop a tool suitable for predicting the response of maize to dairy effluent application in New Zealand. Work would first need to be conducted to calibrate these tools to local conditions. The development of such a tool has the potential to increase farm profitability and improve the sustainable disposal of farm effluent.
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1 Overview

Managing nutrients on intensive dairy farms is an ongoing challenge for the industry as it strives to remain profitable and minimise potential environmental impacts. Nutrient loading can be particularly high on soils that are regularly treated with dairy effluent collected from the milking shed, feed pad and holding areas. These soils can become highly enriched in nitrogen (N), phosphorus (P) and potassium (K), especially where the area treated with effluent is small or the farming system has intensified. Negative effects on animal health and the environment can occur as a consequence. These are major concerns for farmers, regional councils and the wider community.

In 2007 a project commenced to investigate management practices that reduce these risks and enhance nutrient use efficiency (SFF 07/037 – Maize to manage dairy effluent). One approach that was studied was the application of effluent to soils with a history of regular maize cropping. In many cases these soils have low natural fertility (especially N) due to years of nutrient removal in crops. For example, a silage maize crop that produces an average yield removes approximately 250 kg N, 40 kg P and 250 kg K/ha/season. The work confirmed that effluent has strong potential to replace bagged fertiliser in part or full (Johnstone et al. 2009, 2010). These findings were consistent with several previous cropping trials here in New Zealand and Australia (Roach et al. 2001; Houlbrooke et al. 2004; Hawke & Summers 2006; Jacobs et al. 2008). However, uncertainty remains around the general composition of dairy effluents, ideal application techniques, factors controlling nutrient release from effluent, and how to predict the ideal effluent application rates for successful maize production (Houlbrooke et al. 2004; Wang et al. 2004). An understanding of these factors will help improve the profitable and sustainable use of shed effluent in arable crops.

To help address these factors a review of relevant literature was undertaken. The review is split into five key sections. These include:

1. Nutrient value of dairy effluent and dairy pond sludge,
2. Surface and sub-surface effluent application techniques,
3. Primary factors controlling the release of effluent nutrients once applied to the soil,
4. Tools that can be used to model the release of nutrients from dairy effluent over time, and,
5. Final recommendations for future research.
2 Background to effluent use in cropping

New Zealand’s dairy industry has intensified significantly with total dairy cow numbers increasing by 87% between the 1988–89 season and 2008–09 season (Livestock Improvement Corporation 2009). Most recent estimates put the New Zealand dairy herd at approximately 4.25 million cows (Glassey pers. comm.). Common stocking rates are 2–3 cows/ha, though more farmers are operating increasingly intensive systems (>3 cows/ha) that rely heavily on feed supplements. The increase in dairy cow numbers and intensification of these farming systems has led to an increase in the national production of nutrient-rich effluent that is deposited in dairy sheds, feed pads and holding areas. A recent estimate put the volume produced annually at around 70 million m$^3$ (Saggar et al. 2004). Over the last 6 years the number of intensive dairy farms has increased as global demand for milk products has increased, likely resulting in an even higher volume of effluent. Shed effluent is a combination of dairy cow faeces, urine, teat washings and wash down water that is collected from the dairy shed and holding yards after milking (Longhurst et al. 2000; Hawke & Summers 2006). Historically, effluent has been treated via a two-stage aerobic and anaerobic pond system before being directly discharged to local waterways. However, land application of effluent has become the industry standard as the environmental and economic benefits have been identified (Cameron et al. 1997). Land application of liquid effluent forms is typically by a mobile irrigation system (e.g. k line, or overhead cannon), whereas sludges are often applied using spreading wagons.

Dairy and piggery effluent produced in New Zealand has been previously estimated to have a comparative fertiliser value of $21 million per annum (Bolan 2001). This is likely to underestimate the current comparative value because fertiliser prices and dairy cow numbers have both increased since 2001. The application of dairy effluent as a nutrient source for maize crops has been shown to produce similar (Roach et al. 2001; Johnstone et al. 2009, 2010; Macoon et al. 2002) or greater dry matter yields (Trindade et al. 2009) as those produced using common commercially available inorganic fertilisers. Dairy effluent has also been used to successfully produce a wide range of other forage, arable and pasture crops (Beckwith et al. 2002, Laws et al. 2002, Jackson & Smith 1997). Most studies have concluded that dairy effluent has obvious potential to provide a nutrient source for crop production, and the practice is widespread overseas. In New Zealand, the approach of applying effluent to cropping land can have win-win outcomes for the dairy industry because this resource can be used to improve the economic and environmental performance of the farm.

In a recent review, Houlbrooke et al. (2004) concluded that practices for applying dairy effluent to land could be improved. In order to maximise the benefits of effluent application to cropped land, its nutrient content must first be established. In practice, this presents a challenge as the nutrient content of dairy effluent is highly variable (Smith & Chambers 2003; Salazar et al. 2007). Once applied, factors such as soil temperature, soil moisture and soil pH can modify nutrient release from the effluent. Initial application of effluent to the soil also presents a challenge because the spreading method affects nutrient loss via volatilisation and leaching.

In this review we describe how these factors affect the efficient use of dairy effluent, and identify the research questions that must be addressed in order to devise ways to utilise this resource more successfully.
3 Effluent composition

In order to efficiently supply nutrients to crops, the nutrient composition of dairy effluent must first be considered. Chemically, nitrogen (N) and potassium (K) are the major nutrients present in most types of dairy effluent (dairy shed effluent [DSE], slurries and sludges). Phosphorus (P) is typically present in much smaller amounts. The most prevalent form of all of these nutrients is as organic N, P or K. To become ‘plant-available’ organic nutrients in effluent must first be converted to inorganic forms via mineralisation. Factors controlling this process are described in Section 5.

3.1 Dairy shed effluent

The chemical characteristics of DSE are highly variable (Longhurst et al. 2000; Hawke & Summers 2003). However, it is commonly classified as having a dry matter content of less than 1%. Factors such as the breed and age of dairy cattle, seasonality, supplementation, fertiliser application regime, wash down policy and prior treatment of DSE can all modify the chemical composition of this form of effluent (Longhurst et al. 2000). The common land treatment option for this form of effluent is by irrigation to paddocks near the settling pond.

3.2 Dairy slurry

Slurry is the resultant effluent when a settling pond is mixed so that the sludge and effluent are incorporated into a spreadable liquid (Longhurst et al. 2000). The nutrient content of dairy slurry is difficult to determine, as the final composition depends both on the ratio of effluent to sludge and the method used to mix the pond before it is collected. An approximate nutrient content from an anaerobic settling pond in the Waikato is presented in Table 1. The NPK ratio in dairy slurry (in this study approximately 6:1:5) is closest to that of the N:P:K uptake by maize (approximately 5:1:5). Slurries typically have a dry matter content of between 5 and 21% (Longhurst et al. 2000). Depending on viscosity, slurries are commonly applied using irrigation equipment (as is DSE) or by spreading wagons.

3.3 Dairy pond sludge

The term dairy sludge is commonly used to describe effluent with a high dry matter content (>21%). It is typically collected from the bottom of settling ponds on an annual to 5-yearly basis and applied to paddocks using spreading wagons; the frequency of application depends on herd and pond size (Longhurst et al. 2000).

Table 1 Stratification of nutrients by effluent type within an anaerobic dairy pond, as measured by Longhurst et al. (2000).

<table>
<thead>
<tr>
<th>Effluent type</th>
<th>Dry matter (%DM)</th>
<th>N</th>
<th>P</th>
<th>K</th>
</tr>
</thead>
<tbody>
<tr>
<td>DSE</td>
<td>0.9</td>
<td>16</td>
<td>6</td>
<td>48</td>
</tr>
<tr>
<td>Slurry</td>
<td>5</td>
<td>830</td>
<td>135</td>
<td>700</td>
</tr>
<tr>
<td>Sludge</td>
<td>21</td>
<td>2400</td>
<td>250</td>
<td>500</td>
</tr>
</tbody>
</table>
3.4 Nutrient content

The nutrient composition of dairy effluent reported in a range of previous studies is displayed in Table 2. The three most agronomically important nutrients in terms of maize production (N P K) are discussed in the following subsections.

3.4.1 Nitrogen

The N content of effluent is highly variable and is affected by a number of management and seasonal factors. Salazar et al. (2007) collected 50 slurry samples from commercial dairy farms in Chile between 1995 and 1997 and found total N concentration varied between 2.2 and 64.9%. This is similar to that reported in previous studies of Smith & Chambers (2003). Roberts et al. (1992) measured N content in DSE throughout lactation and identified considerable variation. Nitrogen content in the DSE increased from the start of lactation until late spring (September/October) before declining towards the end of lactation.

As a result of farm intensification, the use of supplements and high energy feeds is now common. These supplements and feeds are frequently provided towards the end of lactation to improve body condition. This practice may significantly modify seasonal N contents of effluent since the early study of Roberts et al. (1992). Longhurst et al. (2000) provided evidence that the N concentration of effluents has increased over time with the mean total N concentration from a range of locations across New Zealand doubling from 200 to 400 mg/L between 1977 and 1997. They attributed this to the increase in dairy cow numbers per herd while the size of dairy sheds, holding areas and hence volume of wash down water used has changed little over time. This practice has increased the ratio of effluent to water, resulting in effluent with a greater nutrient concentration. Few recent studies appear to have published the seasonal N content of modern dairy effluent, although a current MfE project is underway to better describe slurries and sludges in particular (Houlbrooke, pers. comm.).

Importantly, most N in dairy effluent is present as organic N. For example, Chadwick et al. (2000) reported that the organic fraction in dairy slurry could be as high as 94% of the total N present. The small pool of available N forms is commonly present as ammonium-N. Nitrate-N levels are often very low; it is this pool of N that is most readily absorbed by plants. So changes in the ratio of organic and available N forms will influence the amount and timing of N released.
Table 2. Concentration of nutrients in a range of different dairy effluents (adapted from Wang et al. 2004).

<table>
<thead>
<tr>
<th>Source</th>
<th>Country</th>
<th>Concentration (mg/L)</th>
<th>Total N</th>
<th>Ammonium (NH₄-N)</th>
<th>Nitrate (NO₃-N)</th>
<th>Organic N</th>
<th>Total P</th>
<th>Total K</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bolan et al. (2004)</td>
<td>NZ</td>
<td>135</td>
<td>22</td>
<td>231</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cameron et al. (1997)</td>
<td>NZ</td>
<td>190</td>
<td>30</td>
<td>220</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Di et al. (1998)</td>
<td>NZ</td>
<td>363</td>
<td>95</td>
<td>0.5</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Di and Cameron (2002)</td>
<td>NZ</td>
<td>246</td>
<td>58</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hawke and Summers (2003)</td>
<td>NZ</td>
<td>80</td>
<td>36</td>
<td>0.2</td>
<td></td>
<td>31</td>
<td>53</td>
<td></td>
</tr>
<tr>
<td>Jacobs et al. (2008)</td>
<td>Australia</td>
<td>146</td>
<td></td>
<td>34</td>
<td>439</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Longhurst et al. (2000)</td>
<td>NZ</td>
<td>269</td>
<td>48</td>
<td>2</td>
<td>219</td>
<td>69</td>
<td>370</td>
<td></td>
</tr>
<tr>
<td>Mahimairaja et al. (1990)</td>
<td>NZ</td>
<td>240</td>
<td>61</td>
<td>0.2</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Silva et al. (1999)</td>
<td>NZ</td>
<td>240</td>
<td>61</td>
<td>0.2</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sukias et al. (2001)</td>
<td>NZ</td>
<td>72</td>
<td>71</td>
<td>0.1</td>
<td>13</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Trindade et al. (2001)</td>
<td>Portugal</td>
<td>340</td>
<td>92</td>
<td></td>
<td></td>
<td>67</td>
<td>143</td>
<td></td>
</tr>
<tr>
<td>Zaman et al. (2002)</td>
<td>NZ</td>
<td>295</td>
<td>80.5</td>
<td>0.1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

3.4.2 Phosphorus

The P content of effluent is typically low compared to N and K (Table 2). This is ideal for maize as the crop has a relatively low P demand (< 50 kg P/ha) and many soils have sufficient reserves to meet some or all of this demand. Most studies have focused on the N component of dairy effluent and paid little attention to the P content (Hawke & Summers 2006). In particular, the rate of P release from effluent is not well understood under New Zealand conditions and requires further investigation.

3.4.3 Potassium

The K content of dairy effluent is often high (Table 2). This can make applying dairy effluent to soils that are low in K an excellent approach to reduce fertiliser costs. One potential concern about applying effluent to soils that are already enriched in K is that luxury uptake by the plant may occur. When maize to which effluent has been applied is fed back to dairy cows there may be an increased risk of grass staggers (hypomagnesaemia) and milk fever (hypocalcaemia). This is because high soil K levels can suppress the uptake of magnesium (Mg) and calcium (Ca) by the crop. To prevent this condition Wang et al. (2004) recommended that Mg and Ca are supplemented either directly to cows or by applying additional Ca and Mg fertiliser to grazed pasture. The content of K within dairy effluent is also more variable than either N or P. In previous studies K values ranged from 53 to 439 mg/L (Table 2).

3.4.4 Approximate nutrient content

As the chemical composition of dairy effluent is highly variable, farmers should test the NPK concentration before using effluent as a nutrient source (Hawke & Summers 2006). These
effluent-specific results will allow the nutrient demand of maize crops to be met in a more
accurate manner than estimations derived from previous studies under variable conditions.
Importantly, recent data collected by R J Hill Laboratories (Corban, pers. comm.) shows a
strong positive correlation between dry matter content of effluent and its N and P content
(Figures 1–2). K concentrations are less well correlated with dry matter content (Figure 3).
These data were collected across several years from a wide variety of New Zealand dairy farms
and management practices. Selecting a higher dry matter effluent may be one approach
farmers can adopt to minimise the cost of application while maximising the amount of nutrient
applied (particularly N and P).

![Figure 1. Effluent total nitrogen content plotted against dry matter content.](image1)

![Figure 2. Effluent phosphorus content plotted against dry matter content.](image2)
Figure 3. Effluent potassium content plotted against dry matter content.
4 Effluent application

Dairy effluent is commonly applied to the soil surface or sub-surface in autumn or spring. Method of application can have a significant impact on the amount of nutrient (and N, in particular) that becomes ‘plant-available’ from effluent. Overall, the optimum application method selected must be economically viable and technically effective, limiting any potential loss of nutrients.

4.1 Surface application

A common form of surface effluent application to maize crops overseas is broadcasting across a paddock prior to crop emergence. However, other methods also exist, such as the surface banding of effluent between rows (Dosch & Gutser 1996). Using both approaches, effluent is not incorporated into the soil. Bittman et al. (1999) compared application of dairy effluent using a splash plate (broadcasting) with surface banding (drag-shoe) application in British Columbia. Yield response in tall fescue to the surface banding approach was similar to when the equivalent amount of inorganic fertiliser was applied. Yield response to splash plate application was up to 1.0 t/ha less than these approaches. Dosch & Gutser (1996) found a similar result, and also reported that there were lower volatilisation losses from effluent applied in surface bands (22.7 kg NH₃/ha) than when it was broadcast (35.8 kg NH₃/ha). Surface banding is performed by trailing hoses behind a tanker, which allows effluent to be applied with greater accuracy and control (Dosch & Gutser 1996). This method of application may, however, be difficult when using thick sludges, which can block hoses and reduce application speed.

Most studies indicate that surface broadcasting of effluent (without any immediate soil incorporation) is the least efficient method of application because large losses of inorganic N occur due to volatilisation (Dosch & Gutser 1996; Bittman et al. 1999). Volatilisation occurs when ammonium-N is transformed into ammonia gas. This is most common when soil temperature is high and pH and atmospheric conditions are dry and turbulent (McLaren & Cameron 1996). Under such conditions, losses can be very rapid. Dosch & Gutser (1996) measured total loss of ammonium-N via volatilisation over 7 days. They found that more than half of the total loss of ammonia occurred during the first day. Overall, surface application of slurry resulted in volatile losses of 31% of the total ammonium-N that was applied.

4.2 Sub-surface application

Sub-surface application involves either the direct injection of effluent into the soil profile or incorporating the effluent that has been applied to the surface. Incorporation is typically by some form of cultivation, which should occur quickly after spreading (taking care not to damage soil structure). This latter approach is most common in New Zealand where effluent is applied to cropping soils. Sorensen (2004) compared the response of barley and ryegrass to three different forms of effluent application, including mixing (surface applied and incorporated), direct injection and surface banding. The study found that there was no significant difference in crop N uptake between the mixing and direct injection approaches. However, both of these sub-surface application techniques resulted in significantly greater uptake of N by the crop in the first year of the study than the surface banding application of effluent. They attributed this result to reduced losses of N via volatilisation. During the following 2 years there was no significant difference in crop N uptake from the three treatments. The study did not measure dry matter yield. Cameron et al. (1996) compared surface and sub-surface application of effluent to pasture and found that there was no significant difference in dry matter yield produced under either method. These contrary observations suggest that field-specific factors during application can strongly influence
subsequent nutrient availability from dairy effluent. This appears at least in part to reflect the factors that control initial losses (especially in the case of N), which Houlbrooke et al. (2004) linked to the quantity of effluent applied, the management of the effluent and soil moisture conditions at the time of applications. They concluded that the original nutrient content was less of an issue.

4.3 Application timing

Schroder (1999) compared the effect of applying a half rate of effluent prior to crop emergence and the other half once the crop had emerged to the traditional full application prior to crop emergence. No significant difference could be identified between the two treatments. However, the method of application in these trials was by broadcast surface application and no account of potential volatilisation losses was given. Houlbrooke et al. (2004) found that applying dairy effluent during the spring resulted in greater concentrations of available N in the soil, a fact they related to warmer soil temperatures and a higher rate of mineralisation. The efficiency of autumn effluent applications is less clear. Ghani et al. (2005) suggested that applying effluent in autumn resulted in less leaching than when it was applied in spring, while Zaman et al. (2002) found the likelihood of leaching was greater from autumn than spring applications.

Leaching losses will clearly vary depending on intrinsic soil properties and rainfall during these periods. The practical advantage of autumn application for farmers is that spreading can be done under optimal field conditions. In spring, soils are often wet and there are tight time constraints on cultivating land and sowing crops. One approach to ensure N released from effluent applied in autumn is not leached during winter would be to sow a catch crop (e.g. annual ryegrass). This practice is already common for many maize silage crops.
5 Nutrient release from effluent

Nutrients are released from effluent during mineralisation processes. These processes are influenced by several soil factors. Most of the literature on mineralisation processes has focused on N release from effluent. Given the importance of N in maize cropping systems (the most common yield-limiting nutrient), this section largely addresses factors that affect N release. However, the lack of information on the release of P and K from effluent is a concern as the supply of these nutrients from effluent is highly relevant to crop fertiliser decisions.

5.1 Nutrient release and relative fertiliser equivalent

The rate of nutrient release from effluent is a key factor that influences yield outcomes in maize. Nutrient availability must be adequate during key periods of high demand and plant biomass accumulation. One of the benefits of effluent is that the release of nutrients like N (which can be easily leached) is slower than that from inorganic fertilisers. The use of such inorganic fertilisers is common practice at the start of the season when plant nutrient demand is in fact quite low.

This low plant demand was highlighted in a series of recent trials by Johnstone et al. (2009, 2010). Across five sites, nutrient removal in maize crops was found to be less than 1 kg N/ha at 4 weeks after sowing and only about 30 kg N/ha at 8 weeks after sowing. Contrasting this demand, a common fertiliser practice on cropping soils is to apply rates of about 180 kg N/ha either at sowing or within 6–8 weeks of sowing. In an effluent trial Johnstone et al. (2010) found that at 8 weeks after sowing about 10% of the total effluent N that had been applied (in this case 300 kg N/ha) was released and available to maize, better matching N demand to this point. Total seasonal release from the effluent was estimated to be approximately 30%, though no account of potential losses was provided. This estimate agrees with the recent study of Carter et al. (2010) who found that between 34 and 44% of N was released from cattle effluent applied to orchard grass and reed canary grass within the first season.

If dairy effluent is repeatedly applied to cropping soil, residual effects can accumulate and significantly increase the availability of N. Schroder et al. (2005) estimated the impact of long-term cattle effluent application and found that the relative N fertiliser value of the applied effluent increased from about 60 to 80% after 6–8 years of application. This study also identified that the annual relative decomposition rate of effluent estimated by several previous studies ranged from less than 10% decomposition per year (Chambers et al. 1999) to 50% (Beauchamp & Paul 1989). This suggests that long-term measurements of effluent behaviour under New Zealand conditions should be considered in order to predict nutrient release from effluent over time.

In order for applied N to be released in a plant-available form, mineralisation must first occur. Mineralisation is a biological process during which heterotrophic micro-organisms (bacteria, fungi, protozoa, etc.) convert organic N into inorganic (plant-available) forms. A net increase in the amount of mineral N available to plants requires that the mineralisation of N (conversion of organic N to mineral N) exceeds the amount of mineral N that is taken up (immobilised) by microbes. In general, the net mineralisation of N requires a C:N ratio (in the organic form) of less than 25:1 and is strongly influenced by soil moisture and temperature. Azeez & Van Averbeke (2010) investigated the rate of mineralisation and immobilisation of N from animal effluent. Initial release of N was rapid followed by slow constant release. Barkle (2001) studied mineralisation and immobilisation on a typical dairy soil and found that effluent loading rate influenced the subsequent release of N. At low loading rates (68 kg N/ha) no mineralisation occurred. However, there was a significant increase in net N mineralisation at high loading rates (345 kg N/ha).
5.2 Moisture

Release of N from organic forms to inorganic forms occurs under aerobic conditions. Because of this, soil moisture content can influence the rate of nutrient release. Maximum mineralisation rates typically occur when soils are at or slightly below field capacity (McLaren & Cameron 1996). Ghani et al. (2005) found that mineralisation rate was greatly reduced when soil moisture exceeded field capacity and net immobilisation occurred. This was particularly evident during the colder months when soils were saturated. However, the study also found that this reduction in mineralisation also resulted in a reduction in nitrate leaching, which is beneficial in terms of safe effluent disposal. In soils that become drier than permanent wilting point, the release of N is greatly reduced (McLaren & Cameron 1996).

5.3 Soil temperature

Soil temperature directly affects the rate of microbial activity, which in turn drives mineralisation processes in the soil. Ghani et al. (2005) measured the effect of soil temperature on the concentration of mineralisable N from a sandy loam that was maintained at field capacity. The study found that at temperatures of 10°C and less, mineralisation rate was reduced while maximum mineralisation occurred at soil temperatures between 20 and 30°C. This agrees with the earlier summary of McLaren & Cameron (1996). Average soil temperatures in the main regions where maize is grown in New Zealand range from about 10 and 19°C during spring and summer to about 17 and 8°C during autumn and winter respectively (National Institute of Water & Atmospheric Research 2010).

5.4 Cultivation

Cultivating soil increases soil aeration and soil contact with organic residues (either of plant or effluent origin) (McLaren & Cameron 1996). Collectively, these factors can accelerate N mineralisation processes. Johnstone et al. (2009b) provided evidence of this cultivation effect on several dairy and cropping soils. They found that at 8 weeks after sowing maize, soil mineral N levels were up to 75 kg N/ha higher under a full cultivation approach than under a reduced cultivation approach (strip tillage). Similar findings have been reported elsewhere (Johnson & Hoyt 1999; Catt et al. 2002; Pearson & Wilson 2002). It is important to note that these combined studies did not describe the effects of cultivation on N release from effluent directly. However, because mineralisation is a biological process, the overall patterns of N release from effluent should be similar to those from organic matter in the soil.

5.5 Soil pH

The optimal pH range for nitrifying bacteria is between 4.5 and 7.5 (McLaren & Cameron 1996). If soil pH falls below or above this range then N release from effluent is likely to reduce. Relatively few cropping soils in New Zealand have pH levels outside this range due to the regular use of acidic fertilisers like urea and/or lime. Under most conditions then, soil pH is unlikely to limit mineralisation rates from effluent.
6 Tools that predict nutrient release from effluent

Several tools exist for predicting nutrient release from effluent.

6.1 Agricultural production systems simulator

The agricultural production systems simulator (APSIM) is an Australian framework for modelling biophysical processes within farming systems. The simulator was designed to combine accurate yield estimates in response to management with the prediction of long-term consequences of farming practices on soils (Keating et al. 2003). To date, the modelling framework of APSIM has been applied to model the response of forest production to different levels of effluent application (Snow et al. 1999; Tillman & Surapaneni 2002). No such studies appear to exist for the application of dairy effluent in maize. However, the guiding components that determine N release in this model should be adaptable to suit maize production. These components include inputs that describe the initial amount and characteristics of the effluent (including effluent type and the composition of C and N in carbohydrate, cellulose and lignin pools) and factors that affect its subsequent decomposition rate (including the temperature, moisture and contact factors).

6.2 Manure nitrogen evaluation routine

The ADAS manure N evaluation routine (MANNER) is a decision support system that predicts the fertiliser N value of farm manures following their application to land (Chambers et al. 1999). MANNER has been designed for use on both arable crops and grassland. The system allows users to define specific effluent characteristics for cattle manure and slurry (manure type, total N, DM, ammonium-N), and specific manure application information (application rate, soil type, date of application, delay to incorporation). Nitrogen mineralisation from the effluent is then predicted based on these factors and meteorological information (rainfall and evapotranspiration). No studies have reported the application of MANNER to maize crops.

6.3 Other nutrient release models

Numerous studies have applied models in an attempt to understand nutrient release from different forms of effluent. The majority of these studies have concentrated on the release of N. Smith et al. (2009) produced a tool (Volt’Air) to simulate ammonium volatilisation following manure application. Volt’Air accounts for the influence of soil and manure characteristics, agricultural practices and meteorological conditions. The model was designed to be specific to eastern Canada. While successful over longer periods (> 5 days), it underestimates volatilisation at shorter time scales (< 5 days); this appears to be a critical period if conditions favour rapid losses. The model determined that the incorporation of effluent to greater depths followed by rainfall resulted in reduced N losses via volatilisation. However, combining increased incorporation depth and rainfall is likely to cause greater losses of N via leaching – an outcome not accounted for by this model.
7 Summary and recommendations

The potential for dairy effluent to be used on soils with low natural fertility appears to offer win-win outcomes for farmers. This approach can increase the area available for effluent disposal, which can prevent overloading of nutrients on soils that have historically received regular effluent irrigation. By applying effluent to soils that are regularly cropped, it may also be possible to reduce fertiliser costs.

Despite this potential, the application of dairy effluent to crops like maize has received limited attention in New Zealand in recent years. It is therefore difficult to define the optimum approach for utilising this valuable resource most efficiently. From this literature review the key factors farmers should consider include:

1. Nutrient composition in dairy effluent can vary greatly based on any number of inherent system properties or management practices. Because of this, the nutrient content of effluent must be tested prior to use. This will allow the correct amount of nutrient to be applied so that crop demand is met and excesses avoided, minimising potential nutrient losses to the environment. Most commercial analytical laboratories provide a rapid assessment of nutrient composition in effluent.

2. Method of effluent application can significantly affect nutrient losses. Of greatest concern to farmers should be losses associated with volatilisation, as these can occur quickly (particular in hot, turbulent conditions and/or if effluent is left on the soil surface for an extended period). Sub-surface application is the best approach to limit potential losses. To date there has been little or no work in New Zealand on the direct injection of effluent into the soil despite the potential of this method. Overall, the risk of N leaching can be reduced by ensuring that the correct amount of nutrient is applied (achieved by testing) and there is an active sink for plant-available nutrients (either a crop or winter cover).

3. The rate of nutrient release from effluent is driven by biological processes in the soil. In most situations, soil temperature and moisture appear to have the greatest effect on the rate of mineralisation. Not surprisingly then, it is difficult to accurately predict nutrient release ahead of the season. In the case of N (the nutrient that has received greatest attention in the literature), most indications are that between 20 and 50% of the total N in effluent is available in the first season after application.

4. Further research into the rate of nutrient release from a range of different New Zealand dairy effluents would provide farmers with greater certainty in use. This could be achieved relatively simply through a laboratory incubation study. Overall, the rate of nutrient release (including P and K) is an area of research that appears to require much closer scrutiny. Future trials should also incorporate the longer term supply of nutrients into the approach (from further effluent applications or in combination with inorganic fertiliser). Applying new effluent each year should, over time, allow a more constant nutrient supply.

5. Several tools exist that farmers can use to predict likely nutrient release from applied dairy effluent. These allow the direct input of measured nutrient characteristics and predict release during the year. Such tools would be ideal for farmers seeking to use their effluent resource more efficiently. However, calibration and refinement are required to ensure predictions accurately account for local conditions. Some existing data could be tested using these tools as an initial step.
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9 References


