# Effectiveness of dairy first pond sludge as a nutrient source for forage crop production

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## Abstract

First pond sludge from on-farm dairy effluent treatment systems contains relatively large amounts of agronomically useful nutrients. As a high proportion of these are in organic forms, there is uncertainty amongst dairy farmers of the effectiveness of sludge as a nutrient source and partial replacement of fertilisers for forage production. In this experiment, sludge was applied at three rates and incorporated into the soil before growing a series of three successive forage crops. Results demonstrate that sludge is an effective long-term, slow-release nutrient source for the growing of forage crops. Dry matter yield increases of 44%, 120% and 68% for the highest (85 mm) sludge rate compared to the untreated control were found for annual ryegrass and triticale (second crops in the rotation) and for the third crop (turnips) respectively. Despite increasing the total soluble salt content of the soil, sludge incorporation had a number of beneficial effects on soil chemical condition including increasing pH, organic matter content, plant available nutrient levels and the cation exchange capacity.

## Key Words

Dairy sludge, organic waste, recycling, nitrogen, soil effects, forage crops

## Introduction

The accumulation of excess sludge in the first ponds of on-farm dairy waste treatment systems is emerging as a major environmental risk to the dairy industry. Many farmers are reluctant to de-sludge their ponds due partially to the high cost and the need for specialised equipment. In addition, although this sludge contains large amounts of agronomically valuable nutrients that can be recycled back onto farm land (Cameron *et al.* 1996), there is widespread farmer uncertainty on the effectiveness of the sludge as a fertiliser replacement for forage production on farm and the cost:benefit of applying it to land. In Europe, farm yard slurry is commonly applied to and incorporated into the soil prior to the sowing of crops such as cereals and maize (Smith and Chambers 1992). Such slurry applications are used to supply a large proportion of the nutrient requirements of the crop, especially nitrogen for that year. The objectives of this experiment were to quantify the responses of a series of successive summer and winter forage crops to a range of application rates of sludge, determine the longevity of these responses and monitor the effect on soil health.

## Methods

### *Study site and trial establishment*

The trial was conducted on a commercial dairy farm (DemoDAIRY) (38$^{o}$14'S, 142$^{o}$55'E) in south west Victoria. The soil is a fine sandy clay loam described as a brown Chromosol (Isbell 1996) derived from quaternary basalt. Initial soil tests (0-0.1 m) indicated a soil $pH_{H20}$ of 5.4, electrical conductivity of 0.24 dS/m, Olsen P of 25 mg/kg, available K of 160 mg/kg and CPC S of 33 mg/kg.

The trial was conducted in a long-term (10+ years) perennial ryegrass (*Lolium perenne* L.) based dairy pasture paddock. The existing pasture was sprayed out with a knockdown herbicide, Roundup Max (540 g/L Glyphosate) at 3.0 L/ha on 26 October 2006. Seven days later the pasture was crash grazed with dairy cows and on 6 November cultivated using two passes of a large offset disc plough, leaving a cloddy seedbed.

Sludge, extracted from the bottom of the first pond of the farm's dairy effluent treatment system was spread using a commercial dairy effluent vacuum tanker with a splash plate giving an effective width of 6.5 m. The tanker was calibrated to give a target application rate of 15 mm of sludge per pass. Application of sludge commenced on 9 November and was completed by 21 November. After allowing the soil to dry, the trial areas were power-harrowed on 27 November to incorporate the sludge and to prepare a seedbed.

The trial was a randomised design with 4 replicates and 4 sludge treatments of a control (no sludge), 15, 42 and 85 mm of sludge. No fertiliser was applied for the duration of the trial.

*Site management and measurements*

A series of successive summer and winter forage crops were grown on the trial site. Turnips (*Brassica rapa* L. cv. Rival) were drilled in at 2 kg/ha on 27 November and grazed by the farm herd on 20-23 February 2007. For the following winter forage crop, the plots were split and half of each plot was direct drilled to Triticale (*Triticosecale* Wittm. exA. Camus. cv. Crackerjack) at 100 kg/ha and half to a tetraploid annual ryegrass (*Lolium multiflorum var westerwoldicum* Lam. cv. Winterstar) at 25 kg/ha on 14 April 2007. Neither crop was grazed and both were harvested for silage on 1 October 2007. The trial site was subsequently cultivated using a chisel plough and power harrowed in the week commencing 4 November. The pre-emergence herbicide trifluralin (480 g/L) was applied at 1.7 L/ha, incorporated and the trial sown (2 kg/ha) to the second crop of Rival turnips on 13 November 2007. This crop was grazed by the farm herd during the week of 11 February 2008.

For turnip dry matter (DM) yield, 12 randomly placed 1.0 $m^2$ quadrats were collected per plot, separated into leaves and roots, weighed individually, and subsampled on a plot basis. Subsamples were taken to determine DM yield by drying at 100?C for 24 hours and for nutritive content analysis by drying at 60?C for 72 hours. Annual ryegrass DM yields were determined by cutting 12 randomly placed 0.25 $m^2$ quadrats across each plot, whilst for the triticale treatments 12 randomly selected 1 m lengths of sowing rows were cut. Herbage subsamples were collected and dried as for the turnip samples. The Apparent Nitrogen Recovery (ANR) was calculated for the crops at each sludge application rate using the definition of Schroder *et al.* (2005):

ANR = (N uptake of treated crop) - (N uptake of control crop)/Total N input from sludge.

## Results and Discussion

*Sludge composition*

The chemical composition of the sludge and the nutrients applied at each application rate are shown in Table 1. Despite the very large total N applications, only a small proportion of this N was in the ammonia form. This indicates that a high proportion of the total N in the sludge was in an organic form, and as such would require mineralisation in the soil for it to become plant available.

*DM yield responses*

For the first turnip crop (2006/07) and the triticale crop in 2007 there were linear increases ($P<0.05$) in DM with applied sludge (Table 2). Responses of the first turnip crop were low at 10 kg DM/ha/mm of sludge for what was essentially a failed crop due to drought conditions. Triticale responses were much higher at 83 kg DM/ha/mm during the more favourable growing conditions the following season. For the annual ryegrass crop in 2007 and the second turnip crop in 2007/08 there was a quadratic trend ($P<0.001$) in DM accumulation indicating reducing DM responses per mm of sludge at the high application rates. Annual ryegrass had a peak yield of 8.37 t DM/ha at 53 mm of applied sludge, whilst the 07/08 turnip crop had a peak yield of 4.93 t DM/ha at 76 mm sludge. Dry matter yield increases of 44% (ryegrass), 120% (triticale) and 68% (turnip) for the 85 mm sludge rate, compared to the control, were found for the annual ryegrass, triticale and 2007/08 turnip crops respectively.

**Table 1. The pH, electrical conductivity (EC), total solids, total carbon (C), total nitrogen (N), ammonia ($NH_3$), total phosphorus (P), phosphate ($PO_4^{5-}$), potassium (K), calcium (Ca), magnesium (Mg), sodium (Na) and sulphate ($SO_4^{2-}$) content of the dairy first pond sludge and amounts (kg/ha) surface applied and incorporated in November 2006**

| | Analysis | | Application Rate | | |
|---|---|---|---|---|---|
| | Mean | s.d. (n=5) | 15 mm | 42 mm | 85 mm |
| pH | 7.5 | 0.12 | | | |
| EC dS/m | 7600 | 0 | | | |
| Total Solids g/L | 79 | 1.73 | 11900 | 33200 | 67200 |
| Total C % | 26 | 2.0 | | | |
| Total N | 12.7 mg/g | 0.58 | 150 | 421 | 853 |
| $NH_3$ | 0.7 mg/g | 0.14 | 8 | 23 | 47 |
| Total P | 2.5 mg/g | 0.58 | 30 | 83 | 168 |
| $PO_4^{5-}$ | 30.7 mg/L | 4.16 | 5 | 13 | 26 |
| K | 7.9 mg/g | 0.29 | 94 | 262 | 530 |
| Ca | 27.5 mg/g | 0.95 | 326 | 912 | 1847 |
| Mg | 11.0 mg/g | 0.25 | 130 | 365 | 739 |
| Na | 9.5 mg/g | 0.28 | 113 | 315 | 638 |
| $SO_4^{2-}$ | 34.0 mg/L | 2.00 | 5 | 14 | 29 |

*Apparent nitrogen recovery*

The apparent nitrogen recovery (ANR) of the N applied in the sludge by the 2 crop sequences grown in the first year of the trial were similar. The ANR's for the 06/07 turnips plus annual ryegrass were 32% (15 mm), 20% (42 mm) and 12% (85 mm application). Corresponding figures for the 06/07 turnips plus triticale were 29%, 20% and 13% respectively. These ANR's are considerably lower than the 41 – 54% observed when sludge was applied directly to established pasture (Ward and Jacobs 2008). It is speculated that these ANR's are a result of the increase in mineralisation of N from the soil pool brought about by the cultivation of the soil. It is also likely for the 42 and 85 mm treatments that there are amounts of yet un-mineralised organic N from the sludge present in the soil that may become available for future crops.

**Table 2. Estimates and standard errors of regression coefficients *(Y=A + Bx)* for the relationship between herbage DM accumulation (t DM/ha) and the sludge application rate (mm) for the 2006/07 turnip and 2007 triticale crops and for herbage DM accumulation (t DM/ha) for the 2007 annual ryegrass and 2007/08 turnip crops ($Y=A + Bx + Cx^2$) and sludge application rate (mm)**

| | A (s.e.) | B (s.e.) | C (s.e.) |
|---|---|---|---|
| Turnip 2006/07 | 0.408 (0.0513) | 0.010 (0.0027) | |
| Triticale 2007 | 5.82 (1.070) | 0.0834 (0.0222) | |
| Annual Ryegrass 2007 | 5.785 (0.5160) | 0.097 (0.0338) | - 0.00091 (0.000374) |
| Turnip 2007/08 | 2.792 (0.236) | 0.0563 (0.0155) | - 0.00037 (0.000171) |

*Soil characteristics*

The application and incorporation of the sludge was found to have a number of effects on the chemical composition of the soil (Table 3). Soil $pH_{CaCl2}$ increased by up to 0.5 units at the 85 mm rate whilst the total soluble salt content was greatly increased, although this is likely to decrease under the influence of winter rainfall. The levels of available soil macro nutrients also increased appreciably with Olsen P levels increasing from 25 to 33 mg/kg at the 85 mm application, available K from 160 to 520 mg/kg and CPC-S from 33 to 133 mg/kg. The soil cation exchange capacity (CEC) also increased in response to the large applications of organic matter. These applications also increased the exchangeable sodium percentage (ESP) and decreased the Ca:Mg ratio, but both remained within normal and healthy limits.

**Table 3. Initial soil test (0-10 cm) [pH, electrical conductivity (EC), total soluble salts (TSS), Olsen P, available K, available S (CPC-S), total carbon, total nitrogen, C:N ratio, organic matter, nitrate-N, exchangeable cations (Ca, Mg, Na, K), sum of cations, Ca:Mg ratio and exchangeable sodium percentage (ESP)] before the study (November 2006) and in the following autumn (April 2007) after the spring application and incorporation of dairy sludge at varying rates (0, 15, 42 and 85 mm)**

| | November | April 2007 | | | |
|---|---|---|---|---|---|
| | 2006 | 0 | 15 | 42 | 85 |
| pH-$H_2O$ | 5.4 | 5.4 | 5.4 | 5.4 | 5.6 |
| pH-$CaCl_2$ | 4.9 | 5.0 | 5.0 | 5.1 | 5.4 |
| EC (dS/m) | 0.24 | 0.22 | 0.37 | 0.59 | 0.92 |

| | | | | | |
|---|---|---|---|---|---|
| TSS (% w/w) | 0.08 | 0.08 | 0.13 | 0.20 | 0.31 |
| Olsen P (mg/kg) | 25 | 25 | 25 | 31 | 33 |
| Available K (mg/kg) | 160 | 155 | 220 | 320 | 520 |
| CPC-S (mg/kg) | 33 | 31 | 44 | 74 | 133 |
| Total C (g/100g) | 5.1 | 4.9 | 5.1 | 5.3 | 5.9 |
| Total N (g/100g) | 0.39 | 0.36 | 0.38 | 0.40 | 0.46 |
| C:N ratio | 13.1 | 13.6 | 13.4 | 13.3 | 12.8 |
| Organic Matter (g/100g) | 9.3 | 8.9 | 9.3 | 9.7 | 11.3 |
| Nitrate N (mg/kg) | - | 65 | 98 | 148 | 210 |
| Exch. Ca (meq/100g) | 6.20 | 5.75 | 6.08 | 6.65 | 7.80 |
| Exch. Mg (meq/100g) | 1.60 | 1.40 | 1.73 | 1.93 | 2.38 |
| Exch. Na (meq/100g) | 0.10 | 0.09 | 0.12 | 0.16 | 0.23 |
| Exch. K (meq/100g) | 0.36 | 0.28 | 0.41 | 0.54 | 0.81 |
| 4 Cat. + (meq/100g) | 8.25 | 7.53 | 8.33 | 9.22 | 11.25 |
| Ca:Mg ratio | 3.9 | 4.0 | 3.6 | 3.5 | 3.3 |
| ESP | 1.21 | 1.19 | 1.44 | 1.74 | 2.04 |

**Conclusion**

The application and incorporation into soil of dairy first pond sludge is an effective, long-term, slow-release nutrient source for the growing of successive forage crops. Apparent nitrogen recoveries after 2 crops were still quite low, but may simply reflect large amounts of nutrients still remaining in organic forms in the soil. Despite increasing the total soluble salt content of the soil, sludge incorporation had a number of beneficial effects on soil chemical condition including increasing pH, organic matter content, plant available nutrients and the cation exchange capacity.

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