Long term assessment of the dual manure steam concept for improving crop recovery of N and P from liquid dairy manure

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Abstract
This paper reports on two multi-year studies to assess the efficiency of N and P recoveries and crop responses to two manure streams resulting from solid-liquid separation of dairy slurry. The low-solids liquid fraction is tested as a primary N source for grass and the high-solids fraction is tested as primary P source for maize (*Zea mays* L.). The grass had higher yields and apparent N recovery rates when fertilized with the low-solids fraction than with the whole slurry. This can be attributed to lower concentrations of relatively unavailable organic N and higher infiltration rates for the low-solids fraction than for whole slurry. Apparent P recovery from the high-solids fraction injected near the corn rows was similar to that of commercial fertilizer side-banded with the planter. The results suggest that N and P in dairy slurry can be used more effectively when separated into low-solids and high-solids fractions with a simple method- settling.

Introduction
Manure processing is receiving a lot of research attention, but most manure is applied directly to land and this is likely to continue. While manure has advantages for crops over commercial fertilizer in diversity of nutrients and organic matter content, manure continues to be problematic in terms of unbalanced nutrient composition relative to crop needs, and poor nutrient recovery relative to fertilizers [1]. Poor recovery of nutrients by crops will inevitably lead to leakage of nutrients into the environment. In Canada and Western Europe most dairy cattle and pig manure is in the slurry form and methods have been developed to improve application efficiency and reduce losses, especially of ammonia. Solid liquid separation of slurry can help improve nutrient management but the technology is not well developed. Hence, efficient use of nutrients from slurry remains elusive for farmers. This paper reports on two multi-year studies to assess the efficiency of N and P recoveries and crop responses to two manure streams resulting from solid-liquid separation of dairy slurry. The liquid fraction is tested as a primary N source for grass and the sludge is tested as primary P source for maize (*Zea mays* L.).

Material and Methods
The multi-year study used slurry from commercial dairy farms with high-producing cows using sawdust bedding. The manure was passively separated (double lagoon or settling tank) giving low-solids and a high-solids (sludge) fractions with relatively high and low N:P ratios, respectively. The low solids fraction was compared with whole slurry as the sole N source for a permanent stand of tall fescue (*Festuca arundinacea* Schreb.) over 8 years. The low-solids fraction and whole slurry manures were applied in equal portions four times per year about 4-6 weeks prior to harvests made in early May, late June, mid-August and mid-October. The target total annual N rates (kg ha^{-1}) were 400 and 600 (both manures) and 800 (whole slurry only). The manures were applied by surface banding to minimize ammonia emission losses and to ensure uniform application.

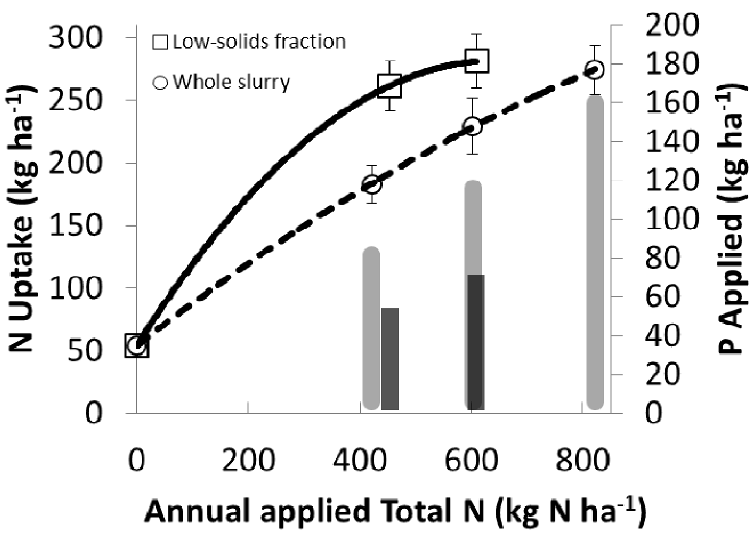
The high-solids fraction was compared to mineral fertilizer as a P source for maize on the same plots in 2010 to 2012. The sludge was applied by injection at 75 cm spacing (12-15 cm depth) and the injection furrows were immediately covered. Maize was precision-planted (72,000 seed ha^{-1}) with a commercial planter within ~10 cm of the centre of sludge furrows about one week after sludge injection. The delay allowed the sludge to fully soak into the soil. The sludge was applied to provide 16.3 and 32.5 kg P ha^{-1} (81 and 161 kg N ha^{-1}, with about half as mineral N) and ammonium nitrate was added by surface broadcasting to give total sludge + fertilizer rates of 161 and 250 kg N ha^{-1}. Fertilizer plots were treated with starter N and P (mono-ammonium phosphate at 20 and 32.5 kg ha^{-1} of N and P, respectively). The fertilizer was applied with the planter in a sideband placed at ~5 cm below and to the side of the maize rows, according to current farm practice. Additional N as ammonium nitrate was broadcasted at various rates to allow comparison with the sludge treatments. Maize was harvested at silage maturity stage.

For both trials, we measured crop yield and concentrations of N and P to determine crop nutrient uptake. Apparent N recovery was determined as: (N uptake - N uptake by control)/ N application rate; similarly, apparent P recovery was: (P uptake - P uptake by control)/ P application rate. Nitrous oxide (N_2O) was measured using passive flux chambers. The methods are described more fully in [2] and [3].

Results

Yield of grass was 12 to 26% higher, and apparent N recovery was 8 to 15% higher (mean of 8 years) for the low-solids fraction compared to whole slurry, based on equivalent application rates of total N (Figs. 1 and 2). Based on equal rates of available ammonium N application rate, the liquid fraction increased apparent N recovery by 10 to 17%. (not shown). These differences can be attributed to two factors: more available N and to lower viscosity (hence faster infiltration into soil) for the liquid fraction than for the whole slurry. The effect was greater in summer than in spring or fall. Historical organic N from whole slurry did not diminish the advantage of the separated liquid fraction. The apparent N recovery rate of separated manure of 35 and 45% is low but this calculation subtracts the value of the control. If steady state had been reached in this trial, then the apparent recovery of applied N would be simply N uptake divided by N applied, which in this trial equals about 60% for the low rate of low-solids fraction. New work is beginning on trying to improve this rate of recovery.

The vertical bars (Fig. 1) show that the P loading was much lower in the separated manure than the whole manure and suggests that separated liquid manure may be applied as the sole N source without significantly overloading P. Effect of the manure separation on N_2O emissions is not yet clear after two years of analysis with occasions of greater and lower emissions. Work is continuing on long term effects of manure separation on soil C, N, P and soil biology, and on nitrate leaching.



Fig, 1. Annual N uptake by tall fescue receiving different N rates as whole and separated liquid (low-solids) dairy slurry (curves) for 8 years. The bars show annual P application rates (loadings) at the respective N application rates of the whole slurry (light bars) and low-solids fraction (light bars).

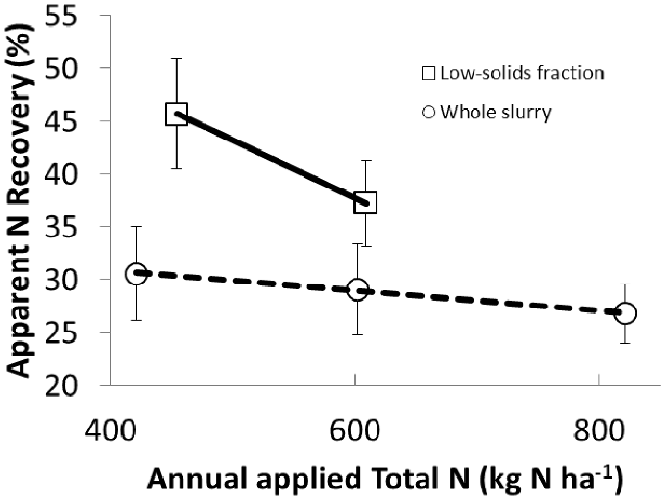


Fig. 2. Apparent N recovery by tall fescue receiving different N rates as whole and separated liquid (low solids) dairy slurry (average for 8 years).

The effect of total N rate on apparent P recovery by corn receiving separated high-solids fraction, (sludge) or commercial fertilizer is shown in Fig 3. It is evident that the P uptake was improved by increasing rates of N for both the high-solids fraction and fertilizer. At a given P rate of high-solids fraction application, the higher N rates were due to added commercial fertilizer, which is more available to the crop than the mix of organic and mineral N forms present in the high-solids fraction. At equal levels of total N applied, the apparent P recovery was similar for high-solids fraction and fertilizer. At equivalent rates of available N (for high-solids fraction: available N = fertilizer N plus high-solids fraction ammonium N), the efficiency of the high-solids fraction P was somewhat higher than that of commercial fertilizer P (not shown). The concentration of P in whole maize plants ranged from 13 to 15 g kg^{-1} P in all treatments. The highest apparent P recovery for high-solids fraction was nearly 50% for the 32.5 kg ha^{-1} P application rate but over 90% at the 16.3 kg ha^{-1} rate. The latter treatment received about 85% of its N in mineral form and almost 70% as commercial fertilizer. The P efficiency for the low rate of the high-solids fraction with no added fertilizer was almost an order of magnitude lower than the high N rate, underlining the importance of N for achieving P recovery from applied high-solids fraction.

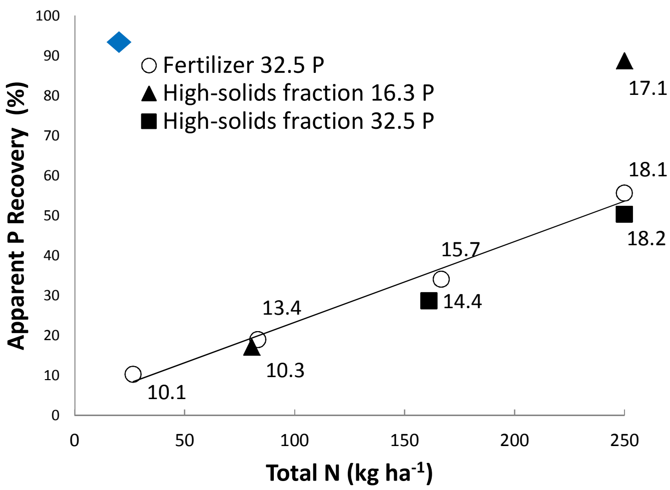


Fig. 3. Apparent P recovery by silage maize (mean of 2010-2012) treated with either commercial fertilizer and/or injected separated dairy slurry (high-solids fraction) applied at 16.3 or 32.5 kg P ha^{-1} (see legend). Total slurry N applied in high-solids fraction was 80.5 and 161 kg ha^{-1} at the low and high application rates, the remaining N coming from commercial fertilizer. The numerical values near the points on the graph indicate total dry matter yields (t ha^{-1}) for the associated treatments.

There was a positive relationship between yield (numerical values associate with P recovery points (shown on Fig. 3, in t ha^{-1}) and P recovery which is not surprising as these values are not independent. Highest yields with mineral fertilizer (18.1 t ha^{-1}) at the 250 kg ha N rate was matched with the corresponding high-solids fraction treatment which included about 100 kg ha of commercial fertilizer. These results show that high yield and high P efficiency can be achieved by providing all of the P as precision placed high-solids fraction. Highest apparent P recovery was achieved at half rate of high-solids fraction but the lower rate of P probably was responsible for the 1.1 t ha^{-1} drop in yield. Optimum high-solids fraction rate in this trial may be around mid-way between the 16.3 and 32.5 P rates of P. This would be very close to the 26-29 kg P ha^{-1} annual removal rates observed for the low and high high-solids fraction rates at 250 kg N ha^{-1}, respectively. This would be both agronomically and environmentally sustainable for P conservation.

While it is possible for maize to obtain all of its P from manure high-solids fraction, it does not appear equally possible for maize to obtain all of its N from this fraction, even from multi-year high-solids fraction injection. Our study shows that while P recovery increased, N efficiency declined with increasing N application rates. Over the three years of the trial, N recovery from the high-solids fraction treatments receiving fertilizer was about 10% units lower than from fertilizer alone. While the injected high-solids fraction N is unlikely to be lost by volatilization, leaching and denitrification, losses may be important and some N may be accumulating in the soil. Slurry injection doubled N_2O emissions (emission factor of ~2%) likely due to moist, anaerobic conditions in the injection furrow,

We have measured high rates of N_2O emission from the injected high-solids fraction (not shown) and this suggests high rates of denitrification. We are currently measuring leaching from the injected high-solids fraction. Evidently, optimizing both N and P efficiencies is difficult.

Conclusion and perspectives

This study shows that N and P in dairy slurry can be used more effectively when separated into low-solids and high-solids fractions with a simple method- settling. We refer to this as the dual manure stream approach. Removing the solids makes the remaining manure less viscous so it can rapidly infiltrate into the soil without adhering to plants or residue. Removing solids improves N efficiency as there is likely to be less ammonia loss and there is less slowly available organic N. Since this fraction has a higher N:P ratio, it can be applied at agronomic rates without over-loading the soil with P. The P-rich high-solids fraction can be applied effectively to maize before planting provided that it is placed near the seed row so that it can be accessed by the juvenile maize plants. The uptake of P from manure high-solids fraction equals that from fertilizer but depends on supplementing N fertilizer. The dual stream approach gives dairy farmers a strategic method for utilizing manure nutrients more efficiently.

References

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