Sustainable nutrient management for pig and cattle manure applied to annual and forage cropping systems (NCLE Long Term Field Laboratory Report for 2007-2010)

Introduction
Application of livestock manure provides nutrients for crop production and can also improve soil quality. However, the availability of nutrients in manure is difficult to predict. Therefore, livestock manure is frequently under or over-applied with respect to crop nitrogen and phosphorus requirements. In cases where the availability of nutrients is less than expected, application rates may be insufficient to meet a crop's nutritional requirements, whereas application of manure nutrients in excess of crop requirements can result in excessive accumulation of nutrients in soil and an increased risk of nutrient loss to ground or surface water. Therefore, an accurate estimate of nutrient availability from manure is required, not only to decrease fertilizer requirements and costs to producers but also to minimize risk to the environment.

Guidelines have been developed in Manitoba to maximize the benefits and minimize the risks associated with application of livestock manure to agricultural soils. Within these guidelines, factors that are considered include the manure's nutrient content (total N, ammonium-N, total P), the overall nutrient strategy for the manure application rate (N-based or P-based), manure application and incorporation methods, and the manure application timing (spring, summer or fall). However, many of these guidelines have not been evaluated rigorously and quantitatively with Manitoba manures and soils, and under Manitoba environmental conditions.

The present study was conducted as part of a continuous, long-term field trial at the NCLE field laboratory, established near Glenlea, MB, by the University of Manitoba's National Centre for Livestock and the Environment (NCLE) as a component of its holistic-multidisciplinary research approach. The mandate of NCLE is “To further the economic and environmental sustainability of integrated livestock and crop production through multidisciplinary whole system based research”. Towards this goal, the NCLE field laboratory provides infrastructure for investigating various management practices to optimize the economic, agronomic and environmental sustainability of nutrient and energy cycling in integrated livestock and crop production systems.

The specific objectives and research questions for this particular research project at the NCLE long term field lab were:
1. Determine the availability of annual and intermittent application of manure nutrients to crops, e.g.
   - Do all types of manure release 25% organic N to the subsequent crop, as estimated by Provincial guidelines?
   - What effect does manure organic N have on crop requirements for synthetic fertilizer N in years between manure applications?
   - Is P in all types of manure 50% less available to crops than synthetic phosphorus fertilizers, as currently estimated?
   - Do intermittent applications of manure P adequately substitute for annual applications of synthetic P fertilizers?

2. Determine the impact of annual and intermittent manure application on post-harvest residual accumulation of soil nutrients, e.g.
   - After several years of applying manure organic N, does the release of nitrate-N increase after harvest?

3. Determine the impact of annual and intermittent manure application on long term trends in soil test nutrient concentrations, e.g.
   - How quickly does soil test P build up in clay soils when different types of manure are applied annually to meet crop N requirements?
   - How stable is soil test P when different types of manure P are applied intermittently for crop P removal?
**Project Procedures and Activities**

The present study was conducted as part of a continuous, long-term field trial at the NCLE field laboratory. The field lab has two cropping systems, annual and perennial (Table 1). Within each main block of cropping system treatments, there are twelve nutrient management treatments (Table 2). For this particular study, the focus on nutrient dynamics in soil and crops necessitated a variety of measurements, including annual soil sampling at various depths as deep as 3.6 metres for N, P and K; manure sampling for total and ammonium N, P, K, moisture and electrical conductivity; crop measurements for seed, straw, and biomass yield; N, P content in grain, straw and forage; K, Ca and Mg in forage, only.

**Table 1. Cropping system treatments.**

<table>
<thead>
<tr>
<th>Year</th>
<th>Cropping Systems</th>
<th>Perennial/Annual</th>
</tr>
</thead>
<tbody>
<tr>
<td>Prep Year (2007)</td>
<td>Winter Wheat (straw removed for convenience)</td>
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<tr>
<td>1 (2008)</td>
<td>Barley silage</td>
<td>Barley silage + underseeded forage</td>
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<tr>
<td>2 (2009)</td>
<td>High erucic acid rapeseed</td>
<td>Grass mix: Timothy, Orchardgrass, Tall Fescue, Meadow Brome</td>
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<tr>
<td>3 (2010)</td>
<td>Feed wheat</td>
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</tbody>
</table>

**Table 2. Manure/nutrient management treatments.**

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Nutrient Source</th>
<th>Rate of Application</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Control (Check)</td>
<td>No nutrients applied</td>
</tr>
<tr>
<td>2</td>
<td>Synthetic fertilizer</td>
<td>Crop N and P requirements based on soil test</td>
</tr>
<tr>
<td>3</td>
<td>Liquid pig manure (LPM)</td>
<td>Crop N requirements based on soil test</td>
</tr>
<tr>
<td>4</td>
<td>Solid pig manure (stockpiled)</td>
<td>&quot;</td>
</tr>
<tr>
<td>5</td>
<td>Solid pig manure (stockpiled)¹</td>
<td>&quot;</td>
</tr>
<tr>
<td>6</td>
<td>Solid dairy manure (stockpiled)</td>
<td>&quot;</td>
</tr>
<tr>
<td>7</td>
<td>Liquid pig manure</td>
<td>Crop P removal for 5 years based on past yield²</td>
</tr>
<tr>
<td>8</td>
<td>Solid pig manure (stockpiled)</td>
<td>&quot;</td>
</tr>
<tr>
<td>9</td>
<td>Solid pig manure (stockpiled)¹</td>
<td>&quot;</td>
</tr>
<tr>
<td>10</td>
<td>Solid dairy manure (stockpiled)</td>
<td>&quot;</td>
</tr>
<tr>
<td>11</td>
<td>Liquid pig manure²</td>
<td>Crop N requirement rate (same as #3)</td>
</tr>
<tr>
<td>12</td>
<td>Liquid pig manure³</td>
<td>Crop P removal (same as #7)</td>
</tr>
</tbody>
</table>

¹Reserved for composted solid pig manure to be introduced at a later date;
²Based on estimated removal for 1st 5 yr cycle; N is applied as urea fertilizer between manure applications;
³Reserved for effluent from solid-liquid separation to be introduced at a later date;
⁴Reserved for solids from solid-liquid separation to be introduced at a later date.
Key Findings
The availability of annual applications of manure nutrients clearly varies with the type of manure, not just its nutrient content. The standard formula for estimating the availability of N from solid pig and dairy manures is not accurate, probably because much less than 25% of the manure’s organic N becomes available in the first few years after application. We could not determine whether the release of organic N is slower or simply lower than predicted; however, after three successive applications of solid pig and cattle manure at N-based rates, there was very little improvement in N uptake by crops or late-season increases in residual N measured in soil tests.

The agronomic value of manure phosphorus applications was difficult to evaluate in this study because the research site had high background concentrations of P, the liquid pig manure was unusually low in P and the solid dairy and pig manures did not release enough nitrogen to meet crop requirements. However, the variation in relationships between P surpluses into changes in Olsen P demonstrate that some manures, such as solid dairy manure, seem to have relatively stable P compared to solid pig manure, for example.

Potassium availability was very difficult to predict, probably due to exchange reactions between ammonium and potassium in soil. Treatments with no or low rates of K seemed just as likely to increase exchangeable K as those where large amounts of K were added. Similarly the impact of the treatments on plant uptake of K and measures of excess K such as grass tetany index, showed that predicting the impact of manures and fertilizers on soil and plant K is complex and unpredictable.

Detailed Results and Discussion
Soil nutrient characteristics – Prior to initiating the study, this site would be regarded from an agronomic perspective as low in available N, but very high or greater in plant available P and K. Therefore, the vast majority of crop responses to the nutrient treatments were governed by the availability of N from the fertilizer or manure, and crop response to additional P or K provided by manures, in particular, would be very unlikely at this site.

Manure characteristics – The solid pig and dairy manures were quite typical in their dry matter and nutrient composition, with N:P ratios of 1.0-1.7:1. Conversely, the liquid pig manure was very dilute, with abnormally low concentrations of dry matter and P, along with a much higher N:P ratio (7.5-15:1), compared to typical manure from commercial pig farms in Manitoba. This manure could be regarded as "gravitationally settled liquid manure" because part of the dilution problem was due to a malfunctioning manure agitation system in the earthen manure storage.

Crop Yield Response to Synthetic Fertilizer and Livestock Manures
Yield response to manures - The most notable feature is that after three years of applying solid dairy and pig manure to meet crop N requirements, the yields from these treatments have barely exceeded the yields of the control treatments in most cases. This lack of crop response illustrates that the current formula used to estimate N availability from solid manures is not accurate for these sources of solid manure. Liquid pig manure performs much closer to expectations than the solid manures, but still falls short of the yields from synthetic fertilizer for the annual crop system, even though it matched synthetic fertilizer in the perennial forage system.

Nitrogen Availability, Uptake and Utilization
N uptake by crops - In both cropping systems, the patterns for N uptake were parallel to the trends in seed and dry matter yield. For annual crops, the trends for seed and total dry matter N uptake showed that solid manure applications do not significantly increase N uptake over that of the control. Nitrogen uptake by perennial crops receiving solid manures was greater than uptake in the control, but the yield increases were 74% and 76% lower than for synthetic fertilizer for N-based solid pig and dairy manure, respectively.
In contrast to the poor performance of solid manures, N-based liquid pig manure generally increased N uptake in seed and total dry matter of annual crops over that for the control. However, increases in absolute uptake of N and increased uptake of N were still smaller than for synthetic fertilizer in most cases, partly because a slightly lower rate of available N was applied for the liquid manure treatment. In the perennial system, N-based liquid pig manure treatments were not significantly different from the synthetic fertilizer treatment for N uptake or N uptake increase, in spite of the smaller amounts of total available N for the liquid pig manure treatments. The increase in N uptake for N-based liquid manure in the perennial rotation was 91% of that for synthetic fertilizer.

Crude protein content in forages - Crude protein was relatively unaffected by nutrient applications until the second cut. Second cut crude protein concentrations were lowest for the control and highest for the synthetic fertilizer treatment. N-based solid dairy manure failed to increase protein content while N-based liquid pig manure was generally as effective as synthetic fertilizer. The reasons for the larger influence of nutrient treatments on second cut than first cut are not known, but may be related to the forage crop's depletion of soil reserves for the first cut, leaving it increasingly dependent on applied nutrients for the second cut.

Fall residual nitrate-nitrogen – After initiating the study, residual NO₃-N concentrations in the top 60 cm of soil were generally low in all treatments and years. All NO₃-N concentrations decreased over time to extremely low concentrations (i.e., soil nitrate was virtually exhausted in all treatments every year), so changes in soil NO₃-N values were not significantly different between treatments for either rotation. Trends for soil NO₃-N in the 60-120 cm depth of the perennial rotation were similar to those in the 0-60 cm depth. The small amounts of residual NO₃-N at all depths, as well as the trend for decreasing amounts of residual NO₃-N with time demonstrate that following MAFRI's recommendations for fertilizer and manure application is unlikely to result in substantial accumulations of NO₃-N in soil. Therefore, current recommendations are unlikely to cause any significant agronomic or environmental problems with excess nitrate, even after several years of applying solid manures with large amounts of organic nitrogen.

Nitrogen balances and nitrogen use efficiencies – The trends for N balance in the annual and perennial rotations were similar, with a large deficit for the control, moderate surpluses for synthetic fertilizer and N-based liquid pig manure, and large surpluses for N-based pig and dairy manure. This is not surprising considering that a large proportion of N in solid manures is in the form of organic nitrogen, most of which is considered unavailable to plants. The majority of the "surplus" for the N-based solid manure treatments would be accounted for as applied organic N that could remain stable in the soil for several years. Therefore, large amounts of solid manure N must be applied to provide adequate amounts of plant available N for meeting crop requirements.

Over the 3-year study period, the overall nitrogen use efficiency (NUE) of synthetic fertilizer was 59% for the annual cropping system and 56% for the perennial cropping system, a little higher than the 50% value often experienced in these types of fertilizer trials. The relatively high NUE for fertilizer indicates that the application rates and losses at this site were not excessive. The manure NUE values for annual and perennial cropping systems respectively were largest for N-based liquid pig manure (41%, 74%), followed by N-based solid dairy manure (11%, 4%), and N-based solid pig manure (6%, 7%). The increased NUE of liquid manure for the perennial rotation may be related to timing and time of uptake which may be different for perennial crops with a longer season.

Overall, when all data for N uptake and utilization are considered, this study clearly demonstrates that the plant availability of N from solid manures is not accurately predicted by the standard formulas used in Manitoba and may also require adjustments to different types of cropping systems. Also, although the standard formulas for estimating available N in manure worked reasonably well for the dilute liquid pig manure used in this study, our study does not provide much information about the validity of the standard formula for estimating the availability of organic N in liquid manure with a higher dry matter and organic N content.
Phosphorus Uptake and Utilization

Phosphorus uptake by seed and straw of annual crops (i.e., yield multiplied by P concentration) was increased over that of the control by synthetic fertilizer and manure treatments. However, N-based solid manure treatments did not significantly increase P uptake in the annual crops, in spite of adding large amounts of manure P. For the perennial rotation, all N-based manure treatments increased P uptake over that for the control. However, only N-based liquid pig manure increased P uptake as much as for synthetic fertilizer, even though very little P was added with synthetic fertilizer or this particular source of liquid pig manure, compared to the solid manures.

The main reason for greater crop uptake of P for synthetic fertilizer or liquid manure than for solid manures is probably because yields for N-based solid manure treatments were severely limited by N deficiency. As mentioned earlier, benchmark and yearly soil test nutrient concentrations indicated that this site was low in N and rich in P; therefore, the availability of N was much more important than P as a yield-limiting factor. In spite of adding much less P, with their relatively large supply of plant available N, synthetic fertilizer and liquid pig manure enabled greater yields and greater uptake of P than for N-based solid manure treatments.

Phosphorus balance – Trends in P balance for annual and perennial cropping systems were similar to each other and somewhat similar to the N balance trends, as well. Over the 3-year period, N-based solid manure treatments resulted in large surpluses of P, applying much more P than liquid manure or synthetic fertilizer applications. Furthermore, uptake and removal of P by crops was limited by N deficiency in the N-based solid manure treatments, further adding to the P surplus. Phosphorus balances for the control, synthetic fertilizer and N-based liquid pig manure were negative, indicating net export of P from these treatments. An important note of caution is that due to the unusually low P and solids content of the liquid pig manure used in this study, the N:P ratio for this manure was unusually high, compared to typical pig manure. Therefore, the net export of P from N-based liquid pig manure in our plots may contradict what would be observed for typical commercial hog operations.

Soil test P – Treatment differences in P balance were generally reflected in changes in Olsen extractable soil test P, with P surpluses generally resulting in increases in Olsen P and P deficits generally resulting in decreases in Olsen P. For example, in later years, 0-15 cm soil test P concentrations for N-based solid pig manure were substantially greater than at the beginning of the experiment in both cropping systems. However, N-based solid pig manure was the only treatment to consistently show a significant increase in Olsen P over the 3-year study period.

Applications of synthetic fertilizer in accordance with recommendations from the Manitoba Soil Fertility Guide did not increase Olsen P concentrations above those for the control. In fact, in the perennial cropping system, the amount of Olsen P for synthetic fertilizer P was significantly less than for the control at 15-30 and 0-30 depths. These results demonstrate that following P recommendations in the Manitoba Soil Fertility Guide is unlikely to result in soils with excessively high concentrations of Olsen P and, in cases where Olsen P is already high, following these recommendations will reduce those concentrations.

In spite of applying P in excess of crop removal, some of the P-based manure applications, especially those with solid dairy manure, showed decreases in Olsen P over the study period. After only three years of crop removal, P surpluses for P-based solid pig and dairy manures were still substantial, as would be expected since the initial applications of manure P were based on estimates for crop removal over a longer time period. The reasons why soil test P concentrations in the “P-based” solid manure treatments seem to be falling, in spite of those surpluses, probably include chemical and microbial stabilization of manure P with time, as well as continuing removal by crops. In addition, Olsen P for N-based solid dairy manure declined by 7.5 kg P ha⁻¹ in the annual cropping system and increased by only 1.9 kg P ha⁻¹ in the perennial cropping system, even though the P surpluses for this treatment were 265 and 236 kg P ha⁻¹ in the annual and perennial cropping systems, respectively. The reasons for the consistently and remarkably small effect of surplus dairy manure P on Olsen P are not known.
Potassium Uptake and Utilization

Low concentrations of potassium (K) may be a concern in some coarse-textured or organic soils in Manitoba, but at this site, the background concentrations of exchangeable K were agronomically very high. Even though high concentrations of K in soil are of little environmental concern, high concentrations of plant available K can cause nutrient imbalances such as milk fever or grass tetany in cattle.

Potassium balances and soil test K - Potassium balances for the annual cropping system could not be calculated since annual plant samples were not analyzed for K. However, when values for total K applied are compared to changes in exchangeable K, the changes in exchangeable K reflect the rates at which K was applied, except for a large number of K surpluses that were accompanied by unexpected decreases in exchangeable K. For the annual cropping system, the only situation where 0-15 cm exchangeable K increased was for N-based solid pig manure. Similarly, for the annual cropping system a decrease was observed in 0-30 cm exchangeable K for all treatments with the exception of N-based solid pig manure. This is opposite to trends for the perennial cropping system where all changes in exchangeable K were positive, with the exception of the N-based liquid manure.

In the perennial cropping system, N-based solid pig manure resulted in the largest K surplus, while synthetic fertilizer resulted in the largest K deficit. In the perennial cropping system, 0-15 cm exchangeable K generally increased slightly for all treatments, with the exception of N-based liquid pig manure which has, on average, remained stable. Although only significant when compared to N-based liquid pig manure, N-based solid pig manure for the perennial cropping system also appears to have increased 0-15 cm exchangeable K more than other treatments. Overall, the relationship between K balance for the perennial system was opposite to that for the annual crop system, with most of the treatments with K deficits showing unexpected increases in exchangeable K.

Grass tetany risk - From a forage quality perspective, the grass tetany index values (GT index) for all treatments, were almost always greater than 2.2, ranging from 1.9 to 6.2. The 2.2 threshold indicates the ratio of K to Mg+Ca, above which grass tetany or hypomagnesia is likely to occur in grazing cattle. The only exceptions where indices were lower than the 2.2 threshold were for the control and N-based solid dairy treatments for second cut in 2010.

Similar to the crude protein response in forages, increases in GT index from nutrient treatments were larger for the second cut than for the first cut, with the largest increases for synthetic fertilizer (N and P only) and N-based applications of solid and liquid pig manure. Even though the synthetic fertilizer treatment, in particular, did not include any additional K, the application of ammonium-N, such as urea, mono-ammonium phosphate, or liquid pig manure, probably resulted in release of exchangeable K from the soil’s cation exchange sites. Surprisingly, N-based annual applications of solid dairy manure had very little impact on GT index, even though large amounts of manure K were applied. This is a positive observation for dairy producers, since the risk of grass tetany and other nutritional imbalances is an important concern for highly productive dairy cattle.

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ACKNOWLEDGMENTS
We would like to thank the Canada-Manitoba Agri-Food Research and Development Initiative (ARDI) for providing financial support for this study. In addition, we would also like to express appreciation to the staff for the University of Manitoba’s Glenlea Research Station, as well as Clay Sawka, the original field technician for the National Centre for Livestock and the Environment (NCLE), Dr. Karin Wittenberg, Vice-Chair of NCLE, the Canada Foundation for Innovation, and the many other public and private partners that contributed to the development of NCLE’s field laboratory.