STRATEGIES FOR MAXIMIZING CROP RECOVERY OF NUTRIENTS APPLIED AS LIQUID SWINE MANURE

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BACKGROUND

Since the demise in 1996 of the freight rate subsidy for transport of grains by rail from Western Canada to port, there have been increased efforts to develop a local livestock industry to utilize feed grains produced in Saskatchewan and other prairie provinces. This has led to an expansion in the number of intensive livestock operations, particularly swine production systems, on the Canadian prairies. The desire to develop responsible manure management strategies in concert with increased pork production on the prairies resulted in the instigation of several research trials in Saskatchewan in the mid to late 1990's to address the following questions:

1. What is the plant availability of nutrients in liquid swine manure applied to prairie soils?
2. What are sustainable rates of application that maximize crop production and minimize nutrient losses to water and air?
3. What are beneficial management practices for nutrient recovery with regard to method of application of liquid swine manure?
4. Can the benefit of added manure nutrients be improved by supplementing with commercial fertilizers?

The purpose of this paper is to review the progress that has been made in Saskatchewan in addressing these questions, and in so doing, indicate strategies that have been developed and that are now being used to manage manure nutrients for agronomic and environmental benefit.

PLANT AVAILABILITY OF NUTRIENTS IN LIQUID SWINE MANURE

In Western Canada, liquid swine manure from intensive swine operations (i.e. 600 + sow farrow-finish) is stored in earthen storage units (1 to 5 million gallon capacity) for approximately six months before it is agitated, pumped and land-applied. The solids content of the liquid manure is low, usually around 1% to 5% solids, and typically much of the nitrogen in the liquid manure is in the form of ammonium, with the remainder present as organic nitrogen. While the ammonium nitrogen is immediately available for plant utilization, only a portion of the organic nitrogen (20-30%) will mineralize over the growing season (Qian and Schoenau, 2000a). Laboratory assessments of organic and ammonium nitrogen contents in the liquid manure are therefore necessary to predict the plant availability of nitrogen in the manure and make corresponding rate recommendations to meet a crop nitrogen requirement.

Availability of nitrogen added as liquid swine manure in the year of application was reported to be around 60% of that observed with commercial urea fertilizer in Saskatchewan soils (Qian and Schoenau, 2000a). In field research trials in east-central Saskatchewan, cumulative crop recoveries of nitrogen added annually as swine manure for four years were around 50% at low rates of addition (Mooleki et al., 2002), and only slightly lower than that observed for urea at similar rates of added nitrogen. Crop recoveries of nitrogen from swine manure more closely approach that of urea fertilizer nitrogen, despite lower plant availability per unit of total nitrogen in the manure, may be explained by enhanced root growth from other nutrients such as phosphorus that are added in the manure. For some solid manure sources such as cattle pen bedding material, nitrogen availability can be very low in the year of application due to low ammonium nitrogen content and a high carbon : nitrogen ratio of the organic matter (>15:1) which limits nitrogen mineralization (Qian and Schoenau, 2002; Mooleki et al., 2004).

Many manure sources, particularly ruminant and poultry manure, are reported to have a high phosphorus content relative to nitrogen (low N:P ratio), which poses concerns about over-application of phosphorus when applying manure to meet a nitrogen requirement (Sims et al. 2000). For this reason, application of manure based on phosphorus requirement and supplementation with commercial fertilizer nitrogen to achieve optimum balance of N and P availability is advised with high phosphorus content manures. However, not all manures have low N:P ratios. For the liquid swine manure sources used in field research trials in Saskatchewan, the N:P ratio has been increasing in recent years. At one site the N:P ratio increased from 5:1 in 1999 to 12:1 in 2001. The decrease in phosphorus content relative to nitrogen content in the liquid swine manure at this site was attributed to the use of phytase enzyme in the diet, which increases the efficiency of feed phosphorus utilization by the animal, reducing the phosphorus excreted in manure. The prediction of plant availability of phosphorus added as liquid swine manure to prairie soils is that 50% of the total phosphorus will be available in the year of application (Tri-Provincial Manure Application and Use Guidelines, 2003). Mineralization of organic phosphorus makes a significant contribution as soluble inorganic P usually comprises much less than 50% of the total phosphorus in the liquid swine manure (Qian and Schoenau, 2000b).

Manures are effective sources of available potassium. We have found the potassium contents of liquid swine manure to be similar to the ammonium nitrogen contents and the availability of potassium in the liquid manure is generally considered to be 90 to 100%. For sulfur, the availability of sulfur in liquid swine manure can be low, with perhaps only 20% of the total sulfur present available for plant uptake in the year of application. High available N: available S ratios in liquid swine manure pose concern in creating N:S imbalances in high sulfur demanding crops like canola. A low availability of sulfur in liquid swine manure may be related to the anaerobic storage conditions that result in reduction of sulfate to sulfides that are then precipitated and end up on the bottom of the storage unit.

SUSTAINABLE RATES OF MANURE APPLICATION

A simple guideline that our research has proven to work in maximizing crop nutrient recovery while minimizing overloading and potential escape of nutrients from the system is *to balance the rate of applied manure nutrients with crop requirement and removal over time.* Ratios of N:P in the order of 10:1 in the applied liquid swine manure have resulted in minimal concerns over rising soluble, labile phosphorus levels in the soil when nitrogen needs are met entirely with swine manure, since the N:P ratio of 10:1 is close to the relative requirements by the crops grown. When the nitrogen is applied at a rate that is in balance with the crop requirements and removal (agronomic rate), accumulations of nitrate in the soil profile and deep migration are not evident (Table 1). However, when the rate of added manure nitrogen has exceeded the crop nitrogen requirement and removal year after year (excess rate), we observe accumulations of nitrate in the soil profile and evidence of migration of nitrate downward by leaching (Table 1).

Table 1. Nitrate –N distribution in the soil profile in the fall of 2000 at a site in east-central Saskatchewan (Black Chernozem) after four annual additions of liquid swine manure at agronomic and excess rates: 1997 canola, 1998 spring wheat, 1999 barley, 2000 canola.

	0-30cm	30-60cm	60-90cm	90-120cm
	---------------kg/ha soil nitrate-nitrogen-------------------			
Manure Agronomic Rate (~100 kg N/ha/yr)	15	3	4	9
Manure Excess Rate (~400 kg N/ha/yr)	78	74	18	17

The agronomic rate of about 100 kg N/ha/yr of liquid swine manure was achieved by injecting about 3000 gallons per acre of liquid swine manure in the late fall each year. Rates of liquid swine manure nitrogen of 100 to 200 kg N/ha/yr were observed to maximize yield, protein and crop nitrogen recovery, without leaving large amounts of residual inorganic nitrogen in the soil profile (Mooleki et al., 2002). Excess rates of liquid swine manure were found to result in high nitrous oxide fluxes from the soil surface that may arise due to nitrification of added ammonium as well as denitrification of residual accumulated nitrate.

BENEFICIAL MANURE APPLICATION PRACTICES

The susceptibility of manure nitrogen to loss by volatilization when surface - applied to soils has been well documented (Zhu et al., 1997; Sanderson and Jones, 1997). In our field trials, we have compared broadcast and incorporating liquid manure to injecting the liquid manure in bands at 30 cm spacing and at a 7 to 10 cm depth using sweep, chisel and disc type openers. Regardless of opener type, injecting the manure in bands was found to give higher crop yield and nitrogen recovery compared to broadcast and incorporate. For example, over four years at one site in east central Saskatchewan, the cumulative nitrogen use efficiency for liquid swine manure applied at a rate of 100 kg N/ha/yr was 43% when injected in a band versus 31% when broadcast and incorporated. Injecting of the manure also reduces odor compared to surface placement. Although it has not been evaluated under prairie conditions, it may be anticipated that surface dribbling of liquid manure in a band would be more efficient than a splash or spray broadcast surface application. Today the majority of liquid swine manure in Saskatchewan is soil applied by sub-surface injection in bands, much of it using low disturbance configurations.

Low disturbance injection using disc-type openers has been successfully used in application of liquid swine manure to established forages, zero-till fields and post-emergent to annual crops to boost yield and protein (Fig. 1).

Figure 1. Low disturbance disc systems for injecting liquid manure.

Forage stands, especially grass pastures, have been very responsive to low disturbance injected liquid swine manure, with doubling, tripling or even quadrupling of hay yields in wheatgrass and bromegrass stands from 100 to 200 kg N/ ha of injected liquid hog manure. Post-emergent applications of liquid hog manure to spring-seeded cereals to boost yield and protein have produced more variable results, with stand damage from the injection sometimes not being compensated for by the fertilizing effect of the manure. Generally, negative effects from post-emergent injection were greatest when conditions were dry and application was delayed beyond the tillering stage.

COMMERCIAL FERTILIZER TO COMPLEMENT MANURE NUTRIENTS

The concept of adding nutrients as commercial fertilizer to lands receiving manure is based on the need to provide the appropriate balance of available nutrients to meet the crop's requirements. Manures in themselves often cannot supply the correct proportions of different nutrients that are required by crops as they are not an "off the shelf" fertilizer. While high phosphorus availability relative to nitrogen availability is not as great an issue with liquid swine manure as it is for some other manures, one important nutrient balance consideration that we have identified for liquid swine manure is the nitrogen:sulfur ratio. Because of their generally high C:S ratio, animal manures have been reported to have a variable and sometimes limited effect on increasing available sulfur (Tabatabai and Chae, 1991), and the available nitrogen : available sulfur ratio of liquid swine manure can be high (Charles, 1999). Using a fertilizer of low available sulfur relative to nitrogen is of particular concern with high sulfur demanding crops like canola grown on sulfur deficient soils, with the potential for severe N:S imbalance. This was revealed in a field study in Saskatchewan with canola grown on a sulfur deficient Gray Luvisolic soil (Table 2).

Table 2. Canola yield and straw sulfur concentration in 2001 on a Gray Luvisol receiving injected liquid swine manure.

Manure (gallons per acre)		*2001 Canola Crop*		
2000	2001	Grain kg/ha	Straw kg/ha	Straw S %
0	0	1155 b	3225 b	0.41
3000	3000	1975 a	4355 a	0.28
6000	0	1190 b	3850 ab	0.27
9000	0	918 bc	4720 a	0.25

Yields in a column followed by the same letter are not significantly different.

Carry-over of available nitrogen but not sulfur from the single, year 2000 only applications of swine manure resulted in a N: S imbalance and sulfur deficiency which inhibited seed yield in 2001. The establishment of supplemental sulfur fertilizer (40 kg S/ha) sub-plots across the site in 2002 and 2003 revealed significant yield responses of the crops grown these years to the supplemental sulfur fertilizer addition. These results indicate that to get good crop recovery from the soil of applied manure nutrients such as nitrogen, the availability of other nutrients must be considered and the appropriate balances achieved by supplementing with commercial fertilizer, if necessary.

CONCLUSION

Crop responses and recovery of added nutrients in liquid swine manure can be optimized by first predicting the plant availability of the manure nutrients and then adding a rate that is in line with crop needs, using equipment that will apply the manure in-soil in a band, and also consider the need for any additional nutrient to ensure a balanced availability.

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