

Manure: Enhancing Crop Production and the Soil Resource

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Livestock production in Western Canada has expanded over the past decade with substantial increases in both cattle and hog production. With this expansion has come increased economic activity and more value added industries. The volume of livestock waste has also gone up considerably and while these levels are still low relative to regions such as North Carolina or the Netherlands, they have become high enough in some locales to raise environmental concerns. These concerns have driven considerable research in a number of agronomic and engineering aspects of manure management. The objective of this paper is to use some recent work performed in Alberta to reinforce some old and illustrate new concepts in manure management. The work drawn on for this task is only a small proportion of the manure work performed on the prairies in the past decade. None-the-less it is a considerable body of work encompassing a number of field and laboratory experiments performed by Alberta Agriculture, Food and Rural Development staff over a period of five years. The main people involved in these projects are listed in the acknowledgements. It is not my intention to provide the detailed methodologies and complete data from these experiments. The details, should the reader care to pursue them, can be obtained in Zhang et al (2003) and Wright et al. (2003). Rather I will use data to illustrate concepts and issues concerning manure management on the Canadian prairies.

The main concepts discussed will be manure variability, the changes manure affects on soil nutrient levels and other soil properties, how these changes impact performance of the cropping system, and finally a look at the cost benefit relationship of manure compared to fertilizer systems. Along the way, there will be a slight detour in the realm of soil testing for phosphorus as this has been a subject of some controversy over the past decade. The controversy largely driven by the struggle to set soil based regulatory limits for phosphorus application.

Manure Variability

Unlike fertilizer, manure is a highly variable commodity and this adds an increased level of complexity to any cropping system using manure as a nutrient source. While there are a number of standard references showing the wide range of N, P, K etc. in liquid or solid manures, many producers assume that manure in their operations is relatively consistent. A comparison of liquid hog and solid beef manure from the same operation over three years shows that there is considerable variation from year to year (Table 1).

Table 1. Variability in moisture and nutrient content of liquid hog manure and beef feedlot manure sampled from same source over three years.

Year	Moisture %	Total N ^x %	Total P %	Available N mg kg ⁻¹	Available P mg kg ⁻¹
<i>Liquid Hog Manure</i>					
1998	96.1	0.56	0.13	2560	569
1999	96.2	0.57	0.16	3490	379
2000	92.2	0.63	0.19	3927	662
<i>Beef Feedlot Manure</i>					
1998	64.4	0.78	0.19	18	951
1999	55.8	0.59	0.20	145	495
2000	43.1	0.69	0.21	173	232

^x Nutrient values reported on a wet basis.

The end use of the manure in this case was incremental treatments in a series of agronomic field experiments. The manure was obtained from the same source at close to the same time of year and following the same procedure. For example, the lagoon was stirred just prior to sampling. These data illustrate that manure varies considerably within an operation in moisture content and both total and available nutrients. Since manure is generally applied on a wet weight basis, even reasonable care and attention to the tonnage applied can still result in major differences in the amount of solids and nutrients that end up in the soil.

The solution to the problem of manure variability is conceptually simple, test the manure before application. In practice, this proves more difficult as manure is difficult to sample representatively, and in some cases, changes considerably during the application process. There is also a time delay of from one to several days between when samples are taken and the results returned. Despite these drawbacks, testing would provide for better management decisions as the producer would know how much total and immediately available nutrient was being applied. The cost of applying 40T ha⁻¹ of beef manure to a quarter section would likely be in the range of \$4,000-\$6,000. The marginal revenue from the additional crop, assuming a 1-2 T ha⁻¹ yield increase for barley through providing adequate N, would be in the range of \$6500 to \$13,000 for a quarter section. The cost of routine testing of that manure and the soil receiving it for nutrients would range for \$60-\$100 depending on how complete an analysis was requested.

Changes in Soil Properties following Manure Application

Manure contains the un-digestible components of livestock feed as well as an array of metabolic waste products excreted in the urine and feces. When the manure is collected in solid form, as is the case with feedlot animals, it can also contain the remnants of bedding material such as straw or sawdust. Since manure is itself an organic material, it directly increases soil organic matter (SOM). In addition, it acts as a substrate for microbial growth and microbial activity transforms manure over time into a more recalcitrant and condensed form of soil organic matter. Finally, manure enhances crop growth and can increase soil organic matter by increasing the amount of crop residues returned to the soil.

Increases in SOM with manure application are illustrated using data from two black soil in Central Alberta (Table 2). When these sites were sampled in the fall of 2000, the one in three year treatments

Table 2. Changes in soil properties following manure application for six years^x.

Treatment	Organic Matter		Total Nitrogen		pH		Water Holding Capacity ^r	
	Calmar	Devon	Calmar	Devon	Calmar	Devon	Calmar	Devon
	%		%				%	
Check	6.5	3.9	0.28	0.16	5.9	6.1	28.9a	23.3a
60 N ^y	6.7	3.7	0.29	0.15	6.0	6.0	-	-
Annual Hog ^z	7.3	5.4	0.31	0.22	6.0	6.1	30.7b	27.0b
1/3 yr Hog ^{zu}	7.5	5.3	0.31	0.22	5.9	6	29.4a	27.7b
Annual Beef ^v	7.7	5.3	0.33	0.22	6.1	6.3	30.8b	30.9bc
1/3 yr Beef ^w	7.5	5.8	0.31	0.22	5.9	6.6	29.3a	31.9c
LSD	1.2	0.6	0.03	0.03				

^x Data from Zhang et al. 2003.

^y Fertilizer applied annually in the spring as urea at a rate of 60 kg N ha⁻¹.

^z Liquid hog manure applied annually at a rate 15 m³ ha⁻¹.

^u Liquid hog manure applied one year in three at a rate of 45 m³ ha⁻¹.

^v Solid feedlot manure applied annually at a rate of 15 T ha⁻¹.

^w Solid feedlot manure applied one year in three at a rate of 45 T ha⁻¹.

^r Means in columns followed by different letters are significantly different at P = 0.5% .

had been applied twice in 1995 and 1998. The data illustrates several concepts. First the increase in SOM is proportionally greater in the Devon soil, the soil that started out with the lesser amount of SOM. Second the method of application, whether annual or every third year, does not appear to have made a discernible difference. Third, by increasing SOM, manure has also increased the soil's reserve of nitrogen and again the proportional increase is greater in the Devon soil that started out with less. Similar results were obtained with total phosphorus as well as other total macro and micronutrients measured. Repetitive manure additions tend to increase SOM and the nutrient content of the soil and in most cases the nutrient supplying power of the soil. Proportionally these improvements to soil tend to be greater on soils that start out with less.

Manure tends to increase soil pH. This was more evident in the poorly buffered Devon soil than in the more strongly buffered Calmar soil (Table 2). This pH increase was observed in other experiments as well. For example, at an experiment conducted near Ponoka (Black SL) and Lacombe (Black SiCL), the treatments included high fertilizer N treatments as well as high annual feedlot manure treatments. Soil pH was reduced 0.3-0.4 units by the high fertilizer relative to the check after six years of application. It was increased 0.3-0.8 units in the high manure treatments. The ability of manure to increase pH is attributable to its relatively high concentration of basic cations like Ca and Mg. Whalen et al. (2002) found that feedlot manure could be used as a substitute for lime in raising pH of acid soils provided the hauling distances were less than 40 km and that precautions were taken to limit nutrient movement off site.

Manure additions can increase a soil's water holding capacity. At Devon, WHC was increased significantly in all the treatments while at Calmar increases were only evident in the annual treatments of hog and cattle manure. Increased WHC, particularly if coupled with a higher permeability allows a soil to store more water for crop use.

Manure additions lead to other important changes in soil system performance in relation to water. Soils collected from research sites at Lacombe, Ponoka, Highway 845, and Picture Butte that received high annual rates of manure over seven years illustrate these changes (Table 3). These samples were rained on in the laboratory under standardized conditions. Runoff volumes were reduced in the manure treatments compared to the checks in the Dark Brown but not the Black soils. The reduction in the Dark Brown soils is attributable to increased permeability and reflects improved aggregation rather than an increase in WHC. Water holding capacity did increase with manure application in these experiments, but as the soils were saturated from below prior to being rained on from above, increased flow into and through the soil rather than increased storage is responsible for reducing runoff. Sediment losses were reduced in all soils in the 120 T ha⁻¹ yr⁻¹ manure treatments and in the finer textured soils at the 60 T ha⁻¹ yr⁻¹ rate. Proportionally the reduction in sediment loss tends to be greater than the reduction in runoff. This suggests that manure reduced erosion in two ways, by increasing the amount of water flowing into rather than over the soil, and by increasing the durability of soil aggregates.

The phosphorus enrichment ratio (PER), the ratio of total P concentration in sediment removed with runoff to total P in the original soils varied with soil and in some case treatment. Multiplying the PER by the sediment loss and comparing the values would show that the reduced sediment loss more than offsets any P enrichment of the sediment in the manure treated soils. In other words, manure reduced loss of sediment P. At one time it was commonly thought that since P was so reactive and tightly held by the solid phase, preventing sediment loss would prevent any P movement into surface waters. This data shows that manure does reduce particulate P loss. However, the accompanying dissolved inorganic phosphorus data shows that manure increased P loss in the most bioavailable and potentially environmentally destructive form by an order of magnitude. To prevent environmentally damaging P loss from manured soils, runoff water not just the sediment has to be prevented from moving into surface waters.

Table 3. Changes in soil erodibility and P mobility following manure applications^x.

Location	Soil Type	Treatment ^y		
		Check	60 T ha ⁻¹ yr ⁻¹	120 T ha ⁻¹ yr ⁻¹
<i>Runoff Volumes (L)</i>				
Picture Butte	Dk. Brown CL	28.6	20.9	12.7
Hwy 845	Dk. Bown LS	24.8	20.4	16
Lacombe	Black SiCl	39.2	35.1	36
Ponoka	Black SL	39.5	38.4	39.5
<i>Sediment Loss (T ha⁻¹)</i>				
Picture Butte	Dk. Brown CL	2.20	1.38	0.84
Hwy 845	Dk. Bown LS	3.42	3.36	2.72
Lacombe	Black SiCl	3.96	2.6	2.26
Ponoka	Black SL	4.46	4.38	2.54
<i>Phosphorus Enrichment Ratio</i>				
Picture Butte	Dk. Brown CL	1.1	1.1	1.4
Hwy 845	Dk. Bown LS	1.3	1.5	1.1
Lacombe	Black SiCl	1.0	1.1	1.0
Ponoka	Black SL	0.9	0.9	0.9
<i>Dissolved Inorganic Phosphorus in Runoff (mg L⁻¹)</i>				
Picture Butte	Dk. Brown CL	0.12	0.89	1.84
Hwy 845	Dk. Bown LS	0.17	0.75	1.2
Lacombe	Black SiCl	0.10	0.61	0.91
Ponoka	Black SL	0.09	0.44	0.73

^x Data from Wright et al. 2003.

^y Treatments received manure from the same source at Lacombe and Ponoka but from a different source at Hwy 845 and Picture Butte. Rates are manure applied wet.

Soil Testing for Phosphorus on Manured Soil

Many different soil tests have been developed for soil P. Differences among tests relate to the chemical cocktail used to extract P from the soil and the end use of the data. Older tests like the Miller-Axley and Olsen tests were developed for agronomic purposes. They correlated to crop growth and could be used to predict nutrient deficiencies and formulate corrective fertilizer plans. In Western Canada, they have largely been replaced by the Modified Kelowna and Norwest tests, although the Olsen test is still used commonly on the high pH soils in Southern Manitoba. A second group of tests using extractants such as distilled water or iron impregnated strips were developed for environmental reasons. Their end use was to measure mobile and immediately bioavailable P in soil and surface waters. An important questions in P management in the 1990's was can agronomic tests be used in a system to asses P mobility or are specific environmental tests required. A second question was if agronomic tests can be used, which test should be used.

To answer the first question, a series of rainfall simulation studies were performed on manured soils. These studies indicate that under standardized conditions, the agronomic soil tests were actually better predictors of dissolved inorganic P (DIP) in runoff than the distilled water test (Table 4). Based on similar data from a number of lab and field projects across N. America, the idea that agronomic soil tests can be used in risk assessment tools for P has been widely accepted.

Table 4. Coefficient of determination between various soil tests and dissolved P in runoff^x.

Measure	Soil Test Method					
	Distilled Water	Miller-Axely	Norwest	Modified Kelowna	Kelowna	Mehlich III
FWMC DIP ^y	0.87	0.90	0.95	R^2 0.96	0.97	0.96

^x Data from Wright et al. 2003.

^y Flow weighted mean concentration of dissolved inorganic P.

The question remains of which test to use. Of the tests listed above all gave a significant correlation with DIP. The Norwest, Modified Kelowna, Kelowna, and Mehlich III group together as better predictors than the Miller-Axley or distilled water test. The different tests vary in extracting power as shown by the mean soil test P (STP) extracted from over 200 manured soils (Table 5). On these soils the Kelowna method extracted the most P and distilled water the least. The Norwest and Modified Kelowna were very similar in extracting power. The Miller-Axley was considerably weaker than the other chemical based extractants. Although, the different tests extracted differing amounts of P, they tend to correlate fairly well with each other. Data from the two tests used most widely in Western Canada, the Modified Kelowna and the Norwest, can be inter-converted with a fair degree of confidence.

Table 5. Comparison of different soil tests extracting P power and correlation between tests on manured soils^x.

	Soil Test					
	Distilled Water	Miller-Axely	Norwest	Modified Kelowna	Kelowna	Mehlich III
Mean STP	31	137	186	192	227	210
			$mg\ P\ kg^{-1}\ soil$			
			R^2			
Distilled Water		0.67***	0.78***	0.78***	0.72***	0.68***
Miller-Axely			0.85***	0.85***	0.88***	0.91***
Norwest				0.99***	0.96***	NA
Modified Kelowna					0.97***	0.99***
Kelowna						0.98***

^x Data from Wright et al. 2003.

*** Significant at $P < 0.001$

NA- value not reported in Wright et al. 2003.

This work was done in Alberta, where the Olson test was never used extensively, so comparison of the Olson test to other tests was not performed. The soils used in these tests have been archived and may be available for further analysis if correlation of these tests with the Olson test is required.

Yield and Economic Benefits from Manure

Many producers can estimate the operational cost of manure handling in their operation with reasonable accuracy, but most are much less sure when it comes to putting numbers to the benefit. This is not surprising as costs for manure handling are incurred immediately and the economic benefits of manure accrue from a diversity of effects over several rather than a single growing season. Manure does increase yields and it is ultimately the extra crop that is converted into dollar benefit. In the Calmar and Devon

plots, average barley yields over the three growing season 1998, 1999, and 2000 were higher in the manured plots relative to the controls (Table 6). Of the four different manure systems tested in this experiment, annual application of liquid hog manure gave the largest yield response at both sites. Yield responses for triticale and wheat, also grown in this experiment, followed the same pattern as barley. Triticale yields were 10-15% higher than barley and wheat yields 15-20% lower.

Table 6. Barley yields and marginal benefits at two sites receiving manure from 1999-2000 ^x.

Site	Treatment					
	Check	60 N ^y	Annual Hog ^z	1/3 yr Hog ^u	Annual Beef ^v	1/3 yr Beef ^w
	<i>Average Grain Yield T ha⁻¹ yr⁻¹</i>					
Calmar	2.67	3.77	4.74	3.85	3.53	3.72
Devon	2.21	3.12	4.69	4.32	3.14	3.53
	<i>Cumulative Marginal Benefit \$ ha⁻¹</i>					
Calmar	0	248	687	349	281	336
Devon	0	196	914	728	306	439

^x Data from Zhang et al. 2003.

Cumulative marginal benefits, added benefit minus added costs, over the three crop years 1998, 1999, and 2000 was calculated using feed barley at \$115 T as a starting point. Price was adjusted downward to reflect farm price FOB at a local elevator. Costs for fertilizer in the 60N treatment was based on the spring price of urea in each of the respective years. Manure spreading costs were first approximated from discussions with the producers providing the manure. Calculations were based on average 0.8 km haul and set at \$1.87-\$2.50 m⁻³ for liquid hog manure depending on year and \$1 T⁻¹ for solid beef manure. Based on these parameters, annual hog manure provided the greatest marginal benefit at both sites, followed by the one in three hog manure treatment. The one in three year beef manure application outperformed the annual beef manure application at both sites. Interestingly all the manure systems outperformed the fertilizer system at these sites.

The economic benefit shown above for manure reflect the costs for the particular case illustrated. Individual producers need to approximate their own benefit-cost relationships based on the yields they obtain on their farms and their own manure application costs. Costs will of course vary with hauling distance and handling system. Benefit will depend on yield increase and crop prices. Producers need to keep in mind that reducing hauling costs by continually adding manure to the fields closest to the manure source will also reduce benefits to zero when those fields are no longer responsive to manure additions. This concept is rather simplistically illustrated using barley at \$115 T⁻¹ in a series of example calculations (Table 7). In this example costs go up with hauling distance but so do benefits as manure is applied to a more responsive soil. The bottom line is adding manure to fields which are not responsive is all cost and no benefit. Hauling to a more responsive field will be a paying proposition as long as the value of the added yield is higher than the added spreading costs. While marginal benefit:cost analysis can provide insight on the value of manure in a producers operation, we shouldn't confuse it with price, which is what someone might actually pay you to haul it away.

Table 7. Projected marginal benefit based on responsiveness of different fields to manure.

	Field		
	Barley 1	Barley 2	Barley 3
Previous Manure History	Heavy	Moderate	Light
Yield Response to 40 T ha ⁻¹ manure	No response	1 T ha ⁻¹	1.5 T ha ⁻¹
Haul Distance	0.8 km	1.2 km	1.6 km
Spreading Cost	\$1.80 T ⁻¹	\$2.20 T ⁻¹	\$2.60 T ⁻¹
Spread Cost for 40 T ha ⁻¹	\$72 ha ⁻¹	\$88 ha ⁻¹	\$104 ha ⁻¹
Value Extra Yield	\$0 ha ⁻¹	\$114 ha ⁻¹	\$171 ha ⁻¹
Net Benefit	(\$72 ha ⁻¹)	\$26 ha ⁻¹	\$124 ha ^{-1s}
Marginal Benefit:Marginal Cost		7.1	5.3

Summary and Conclusions

Judicious manure application result in improved soil quality and increased crop yields. However, there can be too much of a good thing and over application or misapplication can result in poor crop performance and environmentally damaging loss of nutrients to surface or groundwater. Producers are encouraged to characterize both manure and the soils they are applying it to. This can be achieved with a modest sampling program. Understanding the yield response, costs and benefits of using manure on their farm will also help producers develop more profitable and environmentally friendly cropping systems.

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