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Effect of Soil Nutrient Balance/Imbalance on Plant Uptake--A Soil Fertility Perspective

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Historically, livestock manure has been used for centuries to supply nutrients for crop production. There is a growing concern that the nutrient concentrations in home-grown feedstuffs are significantly higher than expected for ration formulation, thus, creating potential livestock health concerns. The most mentioned cause for these high nutrient concentrations is excessive manure applications onto fields. Manure contains not only the macro-nutrients of nitrogen (N), phosphorus (P), and potassium (K) but also significant quantities of the secondary nutrients [calcium (Ca), magnesium (Mg), and sulfur (S)] and micronutrients [iron (Fe), manganese (Mn), zinc (Zn), copper (Cu), and boron (B)]. Nutrients from the manure become available to the plant much like if applied as a chemical fertilizer.

Two primary differences exist, however, between adding nutrients as manure and as fertilizer. First, fertilizer can be purchased as a single nutrient or in various combinations of nutrients to meet a particular crop need, while all nutrients are contained in manure and the user can not adjust the nutrient ratios. Second, manure often exists in large quantities as a by-product of the livestock enterprise, is not valued highly by the farmer, and thus is "disposed of" with higher-than-needed land application rates. The combination of these two factors often leads to "over-application" of at least some nutrients. This can cause some concerns regarding the balance of nutrients in the soil and the effect on grain and forage production among livestock producers. The primary purpose of this paper is to describe the effects of manure and fertilizer application on soil test levels; nutrient uptake, and crop yields.

Corn

Corn yields and protein content can be greatly increased by prudent applications of hog manure. A study conducted in 1995 in Blue Earth Co. showed corn grain yield to be increased by about 110 to 115 bu/A over the control by as little as 3000 gal/A of hog manure from a finishing barn when corn followed a previous crop of millet (Table 1). Increasing the application rate to 6000 gal/A increased yield another 5 to 10 bu/A. Grain yields were about 15 bu/A higher with the optimum rate of manure compared to the optimum rate of fertilizer N. Grain protein (quality) was also increased significantly above the control and the fertilizer N treatments by the manure treatments. Silage yields and quality were also increased similarly to grain. Protein content in the silage for the control averaged 4.2%, 5.7% for the optimum fertilizer N rate, and 6.8% for the spring-applied 6000-gal manure rate. These data also suggest that a 4000 gal/A rate would have been optimum under these conditions.

A Waseca Co. study with liquid dairy manure applied to soybean ground showed somewhat similar, but not as spectacular responses (Table 2). Grain yield was increased 39 bu/A and protein content by 1.2 percentage points by the optimum rate (8000 gal/A) of spring-applied manure. The optimum fertilizer N rate gave slightly lower grain yields (7 bu/A) and protein content.

Protein content of the silage was increased from 4.6% in the control (no N) to 5.8% with both the optimum manure and fertilizer N treatments.

Table 1. Corn grain yield, grain protein, silage yield, and total N uptake as influenced by hog manure application rate and date and fertilizer N in Blue Earth Co. in 1995.

	Application		Grain		Silage	
N Source	Date	Rate	Yield	Protein	Yield	N Uptake
		gal/A	bu/A	%	T DM/A	lb N/A
-	-	0	71	5.9	3.3	44
Hog M.[1/]	9/29/94	3000	181	6.8	7.8	129
"	"	6000	191	8.4	8.0	163
"	4/5/95	3000	188	8.2	8.1	161
"	"	6000	193	8.9	8.1	176
Urea	4/27/95	50 lb N/A	110	6.0	5.3	71
"	"	100 lb N/A	176	7.4	7.2	131
"	"	150 lb N/A	171	7.2	7.3	127

[1/] All hog manure was sweep-injected.

Table 2. Corn grain yield, grain protein, silage yield, and total N uptake as influenced by dairy manure application rate and date and fertilizer N in Waseca Co. in 1995.

	Application		Grain		Silage	
N Source	Date	Rate	Yield	Protein	Yield	N Uptake
		gal/A	bu/A	%	T DM/A	lb N/A
-	-	0	124	6.4	5.7	84
Dairy M.[1/]	10/11/94	4000	141	6.9	6.0	100
"	"	8000	151	7.8	6.5	123
"	4/26/95	4000	149	7.5	6.4	112
"	"	8000	163	7.6	6.8	126
Urea	5/1/95	50 lb N/A	147	7.4	5.6	117
"	"	100 lb N/A	156	7.3	6.5	123
"	"	150 lb N/A	151	7.4	6.9	127

[1/] All dairy manure was sweep-injected.

The importance of using the correct rate of manure was shown in a longer-term study in Olmsted Co. (Table 3). Annual applications of 4550 gal dairy manure per acre were insufficient to optimize the 4-yr average corn grain yield, grain protein, and total N uptake in 1995. Although total N contained in the manure averaged 150 lb/A/yr, the amount of "available N" suggested by the grain yield was about 90 lb/A or 60% of the total N. This highlights the importance of a manure analysis. By determining the total N content of the manure and assuming 60%

availability, a farmer can then calculate the application rate of manure needed to optimize crop yield. In this case, an application rate of 6000 gal/A would have supplied about 120 lb available N/A, which should have been sufficient.

Table 3. Corn grain yield, grain protein, silage yield, and total N uptake as influenced by fertilizer N rate and dairy manure in Olmsted Co.

Application		1992-95 Avg. Grain	1995		
			Grain	Silage	
N Source	Rate	Yield	Protein	Yield	N Uptake
	gal or lb N/A	bu/A	%	T DM/Y	lb N/A
-	0	60	6.9	3.3	56
Urea	60 lb	106	7.7	4.5	83
"	90 lb	117	7.8	5.2	97
"	120 lb	128	7.8	5.2	102
"	150 lb	127	8.0	5.3	108
Dairy M.[1/]	5000 gal	120	7.5	5.3	93

[1/] Sweep injected annually in May.

From the data obtained in the three previous experiments, one quickly sees the value of manure in optimizing both corn yield and quality. Manure applied at rates greater than needed does not lead to further increases in corn yield or quality but does increase the potential for nitrate losses to ground and surface waters and P losses to surface waters. In addition, soil test P and K rise rather quickly with continued applications of high rates of manure. Questions often arise as to whether these high soil test levels (caused by the manure) contribute to nutrient imbalances in the soil or in the plant. For corn, we have little concern. First, secondary and micronutrients are also contained in the manure; thus, nutrient imbalances in the soil are unlikely. Second, corn is unlikely to take up increasing amounts of N, P, and K as amounts in the soil increase.

A 12-yr experiment at Waseca shows the relationship between P accumulated in the corn ear leaf and soil test P (Table 4). At soil tests between 5 (very low) and 18 (high) ppm P, leaf P increased up to a maximum (about 0.31%). Increasing soil test P from 18 to 40 ppm (very high) did not change the ear leaf P concentration.

In summary, high application rates of fertilizer or manure will definitely increase soil test levels. However, negative effects of these high rates on corn growth, production, and quality are very unlikely. The negative aspects of the higher-than-needed rates are: 1) poor economic return and 2) higher potential for environmental consequences. Thus, farmers are advised to utilize manure and/or fertilizer in a manner that optimizes corn yield and quality, which in turn improves economic profitability and minimizes negative environmental effects.

Table 4. Phosphorus concentration in the ear leaf of corn at sicking as influenced by soil test P at Waseca from 1974 - 1985.

Bray P_1 Soil Test	Leaf P Conc.
ppm	% of Max. P
5	77
10	92
15	99
18	100
20	100
30	100
40	100

Reed canarygrass

Reed canarygrass, a tall growing perennial grass, is being considered as an alternative forage for dairy enterprises for a variety of reasons. First, recently developed varieties have a low alkaloid content, contain high amounts of protein when cut properly, and are quite palatable to livestock. Second, once established, reed canarygrass is very winterhardy. Third, it is well adapted to wetland soils but is also very productive on upland soils. Fourth, due to deep-rooting, high yields can be obtained with optimum N fertilization, especially under moist conditions, while still being more productive than other cool-season grasses under dry conditions. Fifth, it appears to have a large capacity for receiving high rates of surface broadcast liquid dairy manure both in the spring and fall and after each harvest without stand damage. And sixth, leaching of nitrates from the soil profile is very unlikely unless extremely high rates of fertilizer N are used. The application rate of manure required to cause leaching would be so high that smothering of the crop would occur first.

Nitrogen fertilization studies on reed canarygrass were conducted at Waseca from 1992-1995. Optimum N rates during this period ranged from 200 to 300 lb N/A/yr. In 1994, yield was optimized at the 200-lb N rate, while protein (N concentration) in the 2nd cutting was optimized at between 300 and 400 lb N/A (Table 5). Nitrate-N concentration increased rather dramatically up to 4000 ppm (0.4%) with N rates of 400 to 600 lb/A. These high NO_3-N concentrations could be toxic to livestock and emphasize the need for caution when fertilizing reed canarygrass with high rates of N. Farmers will need to balance yield and economic return on one hand with NO_3-N accumulation in the forage on the other.

Application of liquid dairy manure to established reed canarygrass increased forage yield and N content (protein) with increasing annual rates up through 40000 gal/A (Table 6). Highest yields were obtained when 20,000 gal/A of manure was applied after the 2nd cutting with an additional 20000 gal applied in the spring prior to regrowth and when 300 lb fertilizer N/A was split applied. In addition, NO_3-N from the manure did not move below 12" in the soil profile (data not shown). These data demonstrate the tremendous capacity of reed canarygrass to receive very high rates of broadcast-applied dairy manure without stand damage and without leaching losses of N to ground and surface water.

Soil test P and K in the 0-6" layer were determined in November, 1995 after two years of these manure rates. Both Bray P_1 and exchangeable K were increased substantially by the increasing rates of manure (Table 7). This was especially true with the 80000 gal/A total application rate.

Table 5. Reed canarygrass yield and N concentration as affected by fertilizer N rate at Waseca in 1994.

N Application Rate			Total 3-cut	2nd Cutting	
April	June	Total	Yield	N Conc.	NO_3-N Conc.
------- lb N/A ------			T DM/A	%	ppm
0	0	0	2.3	1.6	85
100	0	100	2.9	1.8	215
200	0	200	3.9	2.6	1295
300	0	300	3.8	3.4	2415
200	200	400	3.5	3.8	4025
300	200	500	3.5	3.9	3870
300	300	600	3.6	3.8	4230

Table 6. Reed canarygrass yield, N concentration and protein in 1st cut forage as affected by rate of dairy manure application and fertilizer N at Waseca in 1995.

Total Annual Manure/N Rate	Application Time[1/]	Yield	N Conc.	Protein
gal/A or lb/A		T DM/A	%	%
0	-	1.6	1.8	11.2
10000 gal	After 2nd & 3rd Cut in 1994	2.6	1.5	9.4
20000 gal	"	3.6	1.8	11.2
30000 gal	"	3.9	2.2	13.8
40000 gal	"	4.7	2.5	15.6
40000 gal	After 2nd Cut & early April '95	5.4	3.4	21.2
100 lb N	Early Apr. '95	3.7	2.6	16.2
200 lb N	"	5.0	2.9	18.1
300 lb N	200 in April & 100 after 1st Cut	5.8	2.8	17.5

[1/] Total annual manure rate was split with 50% broadcast-applied at each time.

Table 7. Soil test P and K in the 0-6" layer as affected by rate of dairy manure application and fertilizer N at Waseca.

Annual Manure/N Treatment[1/]	Soil Test	
	Bray P_1	Exch. K
	ppm	
300 lb N/A as AN[2/]	28	166
10000 gal/A dairy manure	32	195
20000 "	38	234
30000 "	44	285
40000 "	60	441

[1/] Applied for two successive years.
[2/] AN = broadcast as ammonium nitrate.

In addition to increasing the potential for higher soluble P concentrations in the runoff water, concern also exists that these high soil test values may also affect the nutrient balance within the forage. Wisconsin researchers state "With the continuing increase in statewide soil test levels, potassium has been more frequently identified as a major contributor to ionic imbalance in rations. This can lead to increased potential for developing milk fever at freshening" (Peters and Kelling, 1996). High levels of K in the dry cow ration, especially in the close-up cow ration, can create a host of problems including milk fever, calving problems and metabolic disorders such as displaced abomasa (Flaherty, 1994; Munson, 1995). Ratios between Ca and P and between K and Ca and/or Mg become important in the forage. For instance, large amounts of K results in decreased absorption of magnesium (Mg) by plants. Ruminants consuming such forage may suffer from Mg deficiency, known as grass tetany or hypomagnesemia.

Selected forage samples from the reed canarygrass study that received manure were analyzed for their P, K, Ca, Mg, and micronutrient content. Differences in micronutrient content between the manure and fertilizer treatments were small and are not presented herein. Forage P, K, Ca, and Mg concentration data presented in Table 8 show K to be affected the most by the manure treatments, especially in the first cutting. Forage K was increased from 2.66% when fertilized with 100 lb N/A to 3.10% when 20000 gal/A was split applied after the 2nd cut in 1994 and in the spring. Moreover, forage Ca and Mg concentrations were reduced slightly. This resulted in K/Mg ratios being increased from 11.6 to 14.5+. The K/Mg+Ca ratios on a equivalent basis were raised from 2.05 to as high as 2.65, which may not be acceptable for quality forage. Concentrations of K, Ca, and Mg and the corresponding ratios in the second cutting were not affected by the manure and fertilizer treatments.

Nutrient management of reed canarygrass appears to be much more sensitive than for corn. Although this forage crop can physically tolerate very high application rates of manure and fertilizer without allowing leaching of nitrates from the profile, it is quite susceptible to these treatments in terms of forage quality. Nitrate-N concentrations can become very high if N inputs are not managed carefully. In addition, high rates of manure especially if applied early in the spring can lead to elevated K concentrations and reduced Ca and Mg concentrations. This imbalance could be significant to livestock producers if rations were not managed carefully.

Table 8. Nutrient concentrations in reed canarygrass forage in 1995 as affected by dairy manure and fertilizer N at Waseca.

Treatment		Nutrient					
Rate	Application Time	P	K	Ca	Mg	K/Mg Ratio[1/]	K/Ca+Mg[2/]
gal or lb/A		-------- % ---------					
		1st Cutting					
0	-	.36	2.43	.32	.18	13.5	2.01
100 lb N	April '95	.36	2.66	.28	.23	11.6	2.05
20000 gal	Split between after 2nd Cut in '94 & April '95	.41	3.10	.25	.21	14.8	2.65
30000 gal	Split between 2nd Cut & 3rd Cut in 1994	.38	2.76	.26	.19	14.5	2.46
		2nd Cutting					
0	-	.52	2.28	.41	.22	10.4	1.51
100 lb N	April '95	.44	2.56	.40	.25	10.2	1.61
20000 gal	Split between after 2nd Cut in '94 & April '95	.55	2.62	.35	.25	10.5	1.75
30000 gal	Split between 2nd Cut & 3rd Cut in 1994	.58	2.67	.37	.24	11.1	1.78

[1/] Ratio of K conc. (%) ÷ Mg conc. (%).
[2/] Ratio of K conc. (meq.) ÷ Ca conc (meq.) + Mg conc. (meq.)

Alfalfa

Alfalfa is a legume crop that has recently gained attention as a crop that may be environmentally suitable for sizeable manure applications, if applied prior to planting, based on its N uptake and removal. A multiyear project examined alfalfa's N, P, and K removal from fields receiving various rates of manure. Treatments consisted of a control, three manure rates (3,000, 6,000, and 12,000 gal./acre), and three P and K fertilizer rates (calculated to supply equivalent rates of P and K supplied with the manure treatments).

Manure and fertilizer applications increased alfalfa dry matter yields by an average of 8% during the first production year at the Rosemount sites compared with the unfertilized control (Table 9). In addition, the manure treatments increased yields by an average of 0.3 tons/acre when compared with the fertilizer treatments.

Table 9. Alfalfa dry matter yield in the first full production year as influenced by preplant manure and fertilizer applications.

Treatment		Location		
		Rosemount-South	Rosemount-North	Waseca
		ton/acre		
Control		3.81	4.67	2.84
Manure	-Low	4.31	4.72	3.40
	-Medium	4.60	5.09	4.12
	-High	4.55	5.22	4.49
Fertilizer	-Low	3.87	4.89	3.28
	-Medium	3.97	4.83	3.71
	-High	4.17	4.80	4.57

The lack of a yield response to increasing P and K fertilizer rates at Rosemount is probably related to the "very high" soil P and K levels. Therefore, when the preplant manure applications did increase yields over the control or fertilizer treatments, the response was probably due to factors other than the P and K. Manure contains all secondary and micronutrients needed for crop growth, although none were recommended based on soil tests for these sites. There is also the probability that the observed yield response may be related to the N contained in the manure.

At Waseca, commercial fertilizer and manure increased alfalfa yields compared with the control (Table 9). Manure rates of 3,000, 6,000, and 12,000 gal./acre increased alfalfa yields 20, 45, and 58% respectively, compared with the control. Similarly, the low, medium, and high rates of P and K fertilizer increased yields by 15, 31, and 61% respectively. The responses to the manure and fertilizer were similar. With the "medium" soil test levels for P and K at Waseca, and the equivalent amounts of P and K being added from both sources, similar alfalfa yield increases were expected.

Alfalfa herbage N concentrations were not affected by manure application rates in this study (Table 10). Because alfalfa is a legume, its nodules produce plant available N as needed in conjunction with plant uptake of soil inorganic N. For our research, while there were varying levels of soil inorganic N present in the soil, it is hypothesized that the plant used whatever soil N quantities were present and fixed atmospheric N for any additional N needed. With this type of a system, the nodulating ability of the alfalfa acts as a buffer such that the plant uses what available in the soil before adding more N into the system.

Table 10. Effect of preplant manure and fertilizer applications on first cutting alfalfa herbage N concentrations.

Treatment		Production Year		
		Rosemount-South	Rosemount-North	Waseca
			%	
Control		3.4	3.5	3.2
Manure	-Low	3.4	3.5	3.0
	-Medium	3.3	3.5	3.1
	-High	3.2	3.4	2.9
Fertilizer	-Low	3.4	3.5	3.3
	-Medium	3.3	3.5	3.1
	-High	3.3	3.5	3.1

Phosphorus concentrations in the herbage from the first cuttings were not consistently affected by fertilizer or manure applications at any of the sites (Table 11). Potassium concentrations in the alfalfa herbage at all site-years were increased with applications of manure or inorganic K fertilizers compared with the control treatments. Also, for all site-years, the response to commercial K fertilizer resulted in a linear increase in herbage K concentrations. At the medium K-testing Waseca site and at Rosemount-North in 1990, K concentrations increased almost equally for each increment of either manure or fertilizer when compared with the control. This confirms our estimates of the amount of K supplied from each of the nutrient sources were similar.

Summary

Nitrogen concentrations in the nonlegume crops increase with increasing N application rates, which also generally increases dry matter yields as well (Table 12). With legumes, increasing N applications had no effect on N concentrations, presumably due to a compensation in symbiotically fixed N when higher soil N levels were present.

From a crop management perspective, several conclusions can be made. Although alfalfa acreage may provide the highest average N removal rates, the risk of stand injury with topdress applications (Schmitt and Kelling, 1996) delegate this crop option for preplant manure applications. Corn, harvested for silage, and reed canarygrass can both respond with higher N plant concentrations in high fertility situations (Table 12), the main difference being that reed canarygrass provides in-season manure application options. With both non-legume crops, although the average N removal per ton of plant material was very close to common rules-of-thumb.

Phosphorus concentrations were not significantly affected by manure application rates for the crops we analyzed for P (Table 12). However, P concentrations were affected by soil P test level with alfalfa, thus, P concentrations of feedstuffs should be measured for different fields. While the specific application strategies did not have an effect on the immediate plant P concentrations, there could be a long-term effect of P applications on soil P test.

Potassium concentrations were greatly affected by the immediate fertilizer application strategy. As manure (and N fertilizer) rates increases, so did K concentrations (Table 12). Thus, to properly account for all of the various concentrations of K possibly present in the forages, it is very important to test the forages.

From a risk management perspective, excessive manure applications are often made due to uncertainties in manure application rates, nutrient concentrations, and uniformity. As a result, many producers are trying to maximize their crop removal of nutrients to minimize any potential pollution concerns. However, the nutrient concentrations of these crops/feedstuffs can be very dependent of specific manure management, thus the rations must be determined accounting for the possible elevated plant nutrient concentrations.

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Table 11. Effect of preplant manure and fertilizer applications on annual first-cutting alfalfa phosphorus and potassium concentrations.

	Rosemount-South				Rosemount-North				Waseca	
	1989		1990		1990		1991		1990	
Treatment	P	K	P	K	P	K	P	K	P	K
	%									
Control	0.30	2.09	0.32	1.92	0.30	1.92	0.33	1.68	0.22	1.51
Manure -Low	0.30	2.43	0.33	2.38	0.30	1.99	0.37	1.69	0.21	1.64
-Medium	0.31	2.56	0.36	2.30	0.28	2.31	0.35	1.83	0.21	1.73
-High	0.31	2.65	0.35	2.51	0.30	2.56	0.37	1.73	0.22	1.99
Fertilizer -Low	0.30	2.07	0.30	2.06	0.30	2.04	0.34	1.70	0.22	1.68
-Medium	0.31	2.20	0.32	2.16	0.30	2.35	0.35	1.73	0.17	1.79
-High	0.29	2.54	0.35	2.58	0.30	2.55	0.36	2.18	0.23	1.97

Table 12. Alfalfa, corn, and reed canarygrass nutrient concentrations as affected by nutrient application sources and/or rates.

Alfalfa	Manure Application Rates			
	None	Low	Medium	High
	%			
N	3.5	3.5	3.4	3.3
P	0.3	0.3	0.3	0.3
K	2.0	2.2	2.4	2.6

Reed Canarygrass	Control	Manure	N Fertilizer
	%		
N	1.94	2.18	3.14
P	0.44	0.47	0.41
K	2.36	2.74	2.72

Corn	Manure Application Rate			
	None	4000	8000	150#N
	%			
N	0.87	0.99	1.07	1.11