Using Dairy Slurry for Sustainable Crop Production: Short Term and Long Term Effects

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▪ Take Home Messages

- Use manure as the main source of nutrients for your grass crops.
- Test manure for mineral N content with the Agros or Nova Meter.
- Apply manure with surface banding equipment such as the sleighfoot or Aerway SSD applicators.
- Apply manure at about two thirds of recommended rates of mineral N according to the Agros meter.
- Conduct test strips with contrasting rates of manure and/or fertilizer to compare response.
- Soil sample fields in Oct. for residual levels of nitrate, phosphorus and potassium.
- For crops to be fed to livestock sensitive to high K, replace some manure with fertilizer N, apply dolomitic limestone to increase Mg content of feed, and use species and varieties with high Mg/k ratios

▪ Introduction

Historically, dairy farmers have found it convenient to dispose of large quantities of slurry manure onto arable land, especially corn (*Zea maize* L.) and cereal fields, before planting in spring and after harvest in autumn. Application of manure on bare land in the autumn often leads to contamination of water systems over winter due to leaching and surface runoff (Paul and Zebarth, 1997). Heavy manure applications in spring before planting may lead to high levels of residual soil nitrate in the autumn, which is prone to leaching particularly in regions with high rainfall (Zebarth et al., 1996).

Perennial grass crops offer certain advantages for utilization of slurry compared with annual crops and associated bare arable land: grasses use large quantities of nutrients, especially nitrogen; manure can be administered to perennial grasses several times through the growing season; grasslands pose less of a risk of leaching or runoff losses because the ground is always covered; and, there is less risk of pathogenic contamination of grasses than edible crops. Grassland application of manure during the growing season can increase the efficiency of storage facility utilization and reduce fall application requirements.

By applying manure to grassland over the growing season, storage facilities can be emptied before autumn so that less capacity is required, and there will be reduced requirement to dispose of the manure on bare land in the autumn.

Unfortunately, it has been difficult for farmers to effectively utilize slurry rather than fertilizer on grassland as the primary source of N (Whitehead, 1995). With commonly available slurry broadcasting equipment (splash plate applicators), spreading must be done before there is any growth in spring or soon after harvest to avoid fouling or burning the regrowth. Uniform application is difficult to achieve with broadcasters, especially in windy conditions. Slurry applied with the conventional splash plate applicator may lose up to 80% of its ammonium-N so crop response is inconsistent (Amberger, 1990). Injecting manure beneath the soil surface has been shown to reduce ammonia-N loss compared to surface application, but injection systems have not been well received by grassland farmers. Injectors are expensive, require additional draft power, have slow application rates, are unsuitable for some soil conditions, and cause physical damage to sward especially under dry conditions and when repeated several times a year (Van Der Meer et al., 1987).

To avoid the problems of injection, yet deliver manure uniformly and with minimum air contact, European workers developed a slurry applicator that exudes the slurry in bands directly on the sod surface with individually floating shoes that slide on the ground giving the applicator its name ‘drag-shoe’ or 'sleigh-foot’. Several recent European studies have shown that application of manure in bands directly on the soil surface, beneath the grass canopy, reduces ammonia loss compared to broadcast spreading (Lorenz and Steffens, 1996; Frost, 1994; Huijsmans et al., 1996). However, other studies have reported similar total ammonia loss from banded and broadcast manure (Thompson et al., 1990) or inconsistent results (Pain and Misselbrook, 1996). The relative effectiveness of the techniques appears to depend on weather conditions (Lorenz and Steffens, 1996).

We started our research on manure by asking the question “why do farmers apply more manure on corn than on grass?” Logically more manure should be applied to grass than corn because:

- grass takes up more soil nutrients than corn
- grass produces almost twice as much protein on a given land area compared to corn
- grass can receive manure all summer long, not just spring and fall
- grass provides a permanent cover that resists wintertime losses by leaching, runoff and erosion.

Our initial studies were designed to test the efficacy of manure nitrogen relative to fertilizer for grass production. We also wanted to determine if efficacy of manure is affected by the method of application.

Why manure on grass?

- **High nutrient uptake**
- **Season-long application**
- **Year-round vegetation cover (less risk of nutrient loss)**
- **Soil organic matter build-up**
- **Low risk of contamination**

▪ Phase 1. Short Term Efficiency of Manure on Grass

We carried out 9 trials in 1994-96 to compare the response of grass (tall fescue) to dairy slurry relative to fertilizer. The slurry was either broadcast with a conventional splash plate or surface-banded with the sleighfoot (drag shoe) applicator. The trials were conducted in spring, summer and fall so that all weather conditions and grass conditions would be taken into account.

A summary of these trials is presented in Figure 1. Grass growth responded to N fertilizer in the usual manner. Note that yield response to fertilizer is greater in the spring than in the summer or autumn, showing that grass crops need more nitrogen in spring.

How well did the grass respond to manure? The figure shows that the grass receiving manure from the sleighfoot applicator (triangles) responded similarly to the fertilizer in most cases, whereas grass that received manure from the splash plate applicator often yielded less. Of the 9 trials conducted, manure applied with the splash plate performed well in 5 and poorly in 4. In contrast, the sleighfoot manure performed within a few percent of fertilizer in all trials! The significance of this finding is that with the technology available, farmers cannot expect to get reliable results by applying manure on grass. This may explain the reluctance of farmers to rely on manure as the main fertilizer source for their grass crops.

Keys to using manure as fertilizer

- **Reliable and predictable response**
- **Uniform application**
- **Adequate window for application**
- **Low risk of contamination**
- **Low nutrient loss/odour emission**

Why was the sleighfoot applicator more effective than the splash plate? The main reason is that banding manure on the soil surface conserves the nitrogen in the manure. Most of the readily available nitrogen in manure is in the ammonia form and ammonia is very volatile. We have recent data that shows that the new SSD manure applicator (manufactured by AERWAY, Norwich, Ont), which bands manure over openings made in the soil, reduces ammonia emission by 50%. There is also recent data from Texas A&M University that shows that the SSD substantially reduces odour emission.

To be effective as a nutrient source, manure must be applied uniformly. Splash plate applicators typically have variability of 30-60%, and under windy conditions, the variability is even greater. In contrast, the variability of the manure banding is typically less than 10%, even under windy conditions. In comparison to manure injectors which have the virtues of conserving ammonia and uniform application, the sleighfoot and SSD applicators band closer together, do not tear up the grass (allowing multiple applications), and require little additional horsepower. Also, manure can be spread faster by surface banding than injection; sleighfoot and SSD applicators that are 6 m (20 feet) wide, or more, are available.

Another impediment to the use of manure instead of fertilizer on grass is the amount of time it takes to spread all the fields. Often the grass starts to grow back before all the fields can be spread. Producers are concerned that the manure will contaminate and possibly burn the new growth. Banding applicators greatly reduce contamination because they deposit the manure beneath the canopy.

Since manure application is relatively slow, how does delayed application of manure affect grass response? In our studies, we found that an 8-10 day delay in application is similar with fertilizer or manure; there is a slight reduction in yield (see Fig. 1) but a slight gain in crude protein content. We were concerned that delayed application might cause high nitrate levels but this was not observed. Interestingly, workers in Denmark have shown that when manure is surface-banded under a grass canopy, more ammonia is conserved because there is less air movement and some of the ammonia is directly absorbed into the leaves.

It is important to stress that the short-term comparisons between manure and fertilizer described above are based on equivalent amounts of **mineral-N**, ignoring the **organic-N** portion of the manure. In dairy manure, usually half of the total N is in the mineral form. Hence the manured treatments received twice the amount of total N compared to the fertilized treatments. A comparison of the long-term effects of applying fertilizer and manure on grass is described below.

Surface-banding manure

- **Consistent results – all seasons and weather**
- **Uniform application**
- **More time to apply**
- **Less crop contamination**
- **Less runoff - can apply closer to sensitive areas**
- **Less odour**

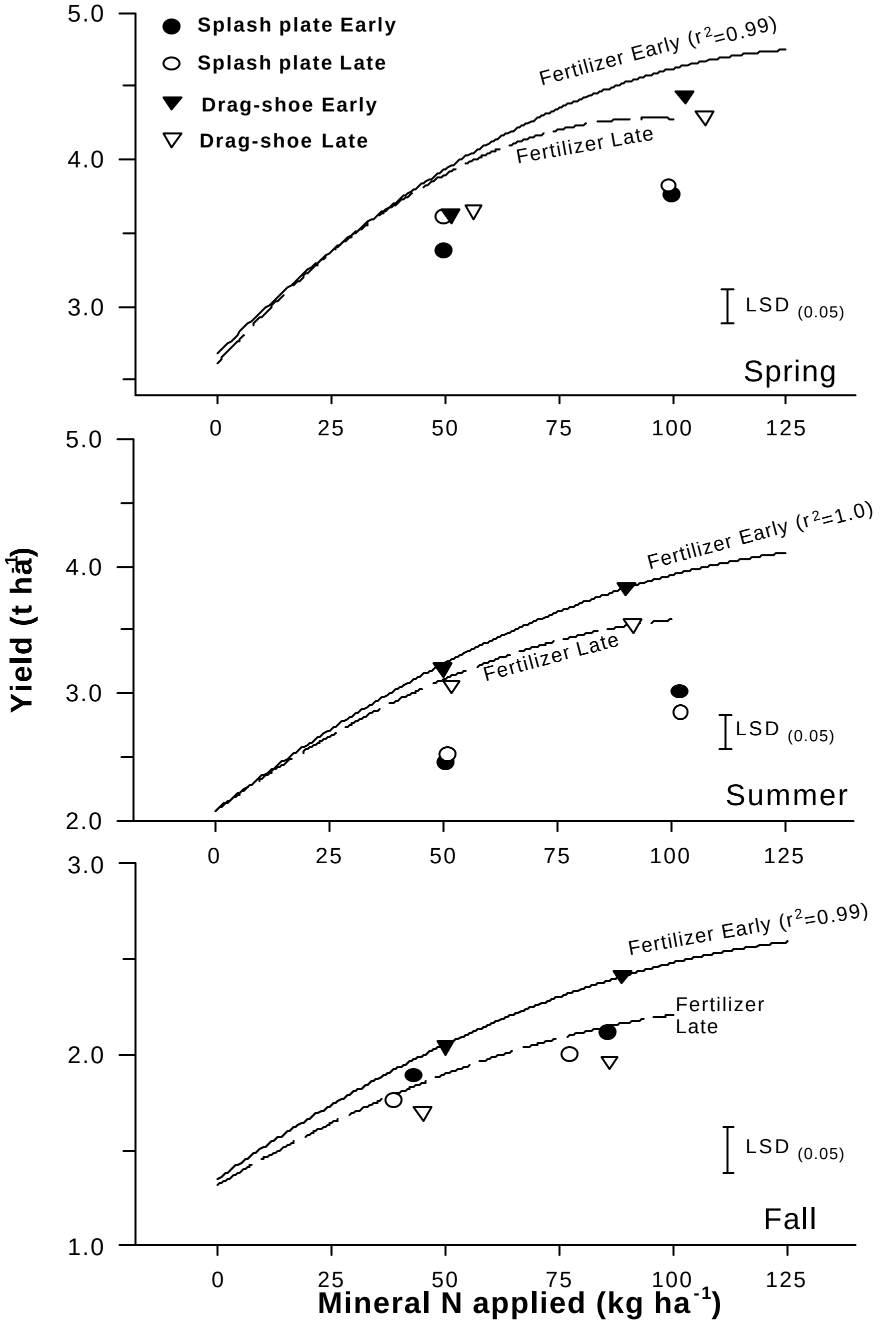

Fig. 1. Yield of tall fescue as affected by NH_4NO_3 fertilizer and dairy slurry spread with splash plate and drag shoe applicators in spring, summer, and autumn (1994-96)

▪ Phase II. Long-Term Effects of Manure Use on Grass

Having shown that, in the short term, manure can be used to replace fertilizer at equivalent rates of mineral-N, we set out to determine the long-term implications of applying manure at these rates. In this study, we compared the effects of multi-year applications of fertilizer and manure at equivalent rates of both **mineral-N** and **total-N**. To ensure uniform application, all manure was applied with the sleighfoot applicator in equal amounts for each harvest. The study examined a wide range of effects including grass production, soil chemistry, soil biology, and movement of nutrients.

Grass yield

Based on equivalent rates of mineral-N, manured plots yielded 2-3 t/ha more than fertilized plots (Table 1). This was due, in part, to the manured plots receiving organic N, some of which gradually mineralized into ammonia. However, even based on equivalent amounts of total-N (400 kg/ha, shaded areas in Tables), the manured plots yielded 1 t/ha more than the fertilized plots. From the nitrogen perspective, this was surprising because some of the manure N was incorporated into the soil organic matter (see below).

The manure plots had higher soil pH, P, K, Zn and other nutrients. The fertilized plots were amended according to soil test (see below) but as discussed in the paper by Grant Kowalenko in this proceedings, it is hard to perfectly balance nutrient requirements with fertilizer. On a farm, such a loss of potential yield would not be apparent unless comparative test strips were employed. The benefit of the manure may include greater biological activity in the soil (see below), which contributes to soil tilth and perhaps other benefits.

Note that the high manure treatment yielded only 1.5 t/ ha (10%) more than the low manure treatment, although it was given 400 kg/ha more total N annually.

Table 1. Annual dry matter yield of tall fescue (1998-2000) as affected by manure and fertilizer applied since 1994. Fert/Man treatment received alternating applications of fertilizer and manure. Shaded rows are at equivalent values of applied total-N.

Treatment	Applied Mineral N	Applied Total N	Yield
	-------kg/ha-------		t/ha
Control	0	0	7.3
Low N			
Fertilizer	200	200	13.2
Manure	200	400	15.0
High N			
Fertilizer	400	400	14.0
Fert/Man	400	600	16.8
Manure	400	800	16.5

Grass stand

The high rate of manure reduced the density of the grass stand and increased the amount of bare soil (Table 2). Weeds were not affected by the treatments. As evident from Table 1, the thin stand of the high-manure plots yielded more that the thicker stands receiving less manure or fertilizer, showing that a thin but weed-free stand can yield well. Often the decline in stand density in manured fields is attributed to wheel traffic but this was not a factor in this study because measurements were made between the wheel tracks. The cause of the decline in stand is not known.

Table 2. Percent ground cover of tall fescue in1998 as affected by manure and fertilizer applied annually since 1994. Shaded rows are at equivalent values of applied total-N.

	Applied Mineral N	Applied Total N	Cover
	--------kg/ha-------		---%---
Control	0	0	65
Low N			
Fertilizer	200	200	72
Manure	200	400	73
High N			
Fertilizer	400	400	69
Fert/Man	400	600	63
Manure	400	800	58

Nitrogen uptake and protein content

At the same rate of applied mineral-N, manured plots took up 40-50 kg/ha more N than fertilized plots (Table 3). However, at equivalent rates of **total-N** (400 kg/ha), the fertilized plots took up 60 kg/ha more N than the manured plots. Also, the fertilized plots contained over 4% units more crude protein. Even at equivalent rates of mineral-N, crude protein was similar or better on the fertilized plots than the manured plots. Interestingly, the plots receiving both manure and fertilizer took up the most N.

These results show that manure favours yield but fertilizer favours N-uptake and protein content. Two factors may contribute to this: 1. manure-N is less available to plants than fertilizer-N because of competition by soil microbes which is enhanced by the carbon in the manure (see below) and 2. manure has benefits additional to N . That manure enhances yield more than protein may be an advantage because high concentrations of easily degraded grass protein are used inefficiently by dairy cows.

The yield and protein results taken together suggest that manure applied annually at 200 kg mineral N/ ha would be nearly adequate for yield but inadequate for protein production. These results suggest that the optimum manure application rate on a productive grass stand would be around 275 kg/ha of mineral N or 550 kg/ha of total N. At this application rate, the crop would remove between 340 to 440 kg/ha of N. Taking a mean value of 380 kg/ha of N removed, N use efficiency based on total-applied N would be about 70% which is quite realistic.

Table 3. N-uptake and crude protein concentration of tall fescue (1998-1999) as affected by manure and fertilizer applied from 1994. Shaded rows are at equivalent values of applied total-N.

	Applied Mineral N	Applied Total N	Nitrogen Uptake	Crude Protein
	-------kg/ha-------		--kg/ha--	---%---
Control	0	0	136	11.7
Low N				
Fertilizer	200	200	292	14.0
Manure	200	400	336	13.9
High N				
Fertilizer	400	400	395	18.2
Fert/Man	400	600	474	17.3
Manure	400	800	443	16.6

Biological activity in the soil

Application of manure greatly increased microbial populations in the soil whereas fertilizer either decreased or had no effect on microbial populations (Table 4). The bacteria compete with plants for mineral nitrogen so less is available for crop growth in the short term (referred to as immobilization). Immobilization may help to explain the relatively low uptake of N in manured plots. When bacteria are consumed by protozoa, and when both bacteria and protozoa are consumed by nematodes, mineral N is released and available again to plants and bacteria (called mineralization). This ‘microbial food web’ mitigates against nitrogen leaching from manured grassland soils (see below).

Table 4. Bacteria, protozoa, and nematodes in the soil (1998) as affected by manure and fertilizer applied from 1994. Shaded rows are at equivalent values of applied total-N.

Treatment	Applied Mineral N	Applied Total N	Bacteria	Protozoa	Nematodes
	-------kg/ha-------		cells/micro-g soil	cells/mg soil	/100 g soil
Control	0	0	600	168	246
Low N					
Fertilizer	200	200	---	---	---
Manure	200	400	763	263	1017
High N					
Fertilizer	400	400	521	107	268
Manure	400	800	931	533	1092

High rates of manure also favour populations of earthworms and carnivorous ground beetles that feed on earthworms and other insects (Table 5). The increased populations of invertebrates improve soil tilth and distribution of nutrients.

Table 5. Earthworms and ground beetles (1998) as affected by manure and fertilizer applied from 1994. Shaded rows are at equivalent values of applied total-N.

Treatment	Applied Mineral N	Applied Total N	Ground beetles	Earth-worms
	--------kg/ha--------		/trap	/sample
Control	0	0	24	30
Low N				
Fertilizer	200	200	30	25
Manure	200	400	26	31
High N				
Fertilizer	400	400	27	23
Fert/Man	400	600	34	38
Manure	400	800	38	43

Build-up of total nitrogen, carbon and organic matter in the soil

Manure application produced an increase of soil organic matter, total soil carbon and total soil N compared to fertilizer and control (Table 6). The increase in organic matter and carbon signifies an improvement in the quality of the soil and shows that the soil can help store carbon which may have implications for reducing greenhouse gases. Most of the nitrogen is organic and represents a stable pool in the soil.

Table 6. Percent total soil carbon, nitrogen and organic matter (1998) in the upper 15 cm of soil as affected by rate of manure and fertilizer applied since 1994. Shaded rows are at equivalent values of applied total-N.

Treatment	Applied Mineral N	Applied Total N	Total Soil Carbon	Total Soil Nitrogen	Organic Matter
	-------kg/ha-------		-------------------%-------------------		
Control	0	0	3.45	0.29	8.1
Low N					
Fertilizer	200	200	3.21	0.27	7.8
Manure	200	400	3.82	0.31	8.7
High N					
Fertilizer	400	400	3.56	0.30	7.8
Manure	400	800	3.81	0.31	8.7

Effect of Manure and Fertilizer History on Uptake of Nitrogen From the Soil

The amount of nitrogen released from the soil was determined in 1998 from plots that did not receive any nutrients in that year. The historically unfertilized (control) plots released 133 kg/ha of N while the historically fertilized plots (200 and 400 kg/ha annually) released only 10-15 kg/ha more N than the unfertilized plots (Table 7). In contrast, the manured plots released 60-110 kg/ha more N than the fertilized plots at equivalent rates of mineral-N. At equivalent rate of total-N, the manured plots released 60 kg/ha of N more than the fertilized plots.

These results demonstrate the short-term immobilization of some manure N. The results also help to explain lower N uptake by the grass in the manured than in the fertilized plots and the increase in soil N (see above). Data not shown here demonstrate that the release of nitrogen is mainly from the manure applied in the previous year; manure applied two or more years prior contributed little to release of N, suggesting that it is stable.

Table 7. Effect of application of manure and fertilizer in previous years (starting 1994) on uptake of soil N by tall fescue in 1998. (No nutrients applied in 1998) Shaded rows are at equivalent values of applied total-N.

Historical Treatment	Applied Mineral N	Applied Total N	N-Uptake
	-------kg/ha--------		--kg/ha--
Control	0	0	113
Low N			
Fertilizer	200	200	123
Manure	200	400	186
High N			
Fertilizer	400	400	129
Fert/Man	400	600	223
Manure	400	800	241

Residual Soil Nitrate in the Fall and Movement of Nitrates in the Soil

Residual soil nitrate in Nov. 1999 was quite low for all plots, including those receiving high rates of manure (Table 8). The low levels may be the result of a number of factors such as immobilization, losses to the environment by denitrification and by dilution due to heavy rainfall. Plots receiving high fertilizer rates contained about twice the nitrates as plots receiving low fertilizer or manure at high or low rate.

Table 8. Residual nitrate in three soil layers on Nov. 1, 1999 as affected by application of manure and fertilizer starting in 1994. Shaded rows are at equivalent values of applied total-N.

Treatment	Applied Mineral N	Applied Total N	Soil Nitrate 0-15cm	Soil Nitrate 15-30cm	Soil Nitrate 30-60cm
	-------kg/ha-------		----------------ppm----------------		
Control	0	0	4	5	4
Low N					
Fertilizer	200	200	5	5	4
Manure	200	400	6	5	5
High N					
Fertilizer	400	400	11	12	8
Manure	400	800	6	5	5

The concentration of nitrates in the soil solution was tested in 1997 through the winter of 2000 using suction lysimeters placed at 60 and 90 cm depths in the soil. The concentration of nitrate in the soil solution was low most of the year, with peaks coinciding with the start of the rainy period around Nov (data not shown). Absence of leaching in the spring and summer was previously reported by Dr. Grant Kowalenko of our research centre.

The magnitudes of the peaks for the high manure and fertilizer treatments appeared to increase from year to year, suggesting that the nutrient application was gradually overtaking the stabilizing capacity of the soil. The peak in autumn of 1999 reached about 27 ppm for the high manure plots and 22 ppm for the high fertilizer plots.

Other Nutrients

Increasing levels of soil P and K are a concern when high rates of manure are applied over many years. Accumulating P levels can be seen in Table 9. Although P is not very mobile in the soil, there was some downward movement of P to the 15-30 cm depth in the high manure plots. There was no movement to the 30-60 cm depth.

Downward movement of K is also evident in the high manure plots (Table 10). Accumulation of K in the low manure plots is very small and the fertilizer plots have less K than the control. The potassium in the high manure plots has clearly moved to the 30-60 cm soil layer.

Table 9. Concentration of P in 3 soil layers sampled in Oct. 1999 as affected by manure and fertilizer applied starting in 1994. Shaded rows are at equivalent values of applied total-N.

Treatment	Applied Mineral N	Applied Total N	Soil Phosphorus		
			0-15cm	**15-30cm**	**30-60cm**
	--------kg/ha--------		----------------ppm----------------		
Control	0	0	135	89	25
Low N					
Fertilizer	200	200	133	94	21
Manure	200	400	162	102	32
High N					
Fertilizer	400	400	136	99	27
Manure	400	800	194	129	22

Table 10. Concentration of K in 3 soil layers sampled in Oct. 1999 as affected by manure and fertilizer applied starting in 1994. Shaded rows are at equivalent values of applied total-N.

Treatment	Applied Mineral N	Applied Total N	Soil Potassium		
			0-15cm	15-30cm	30-60cm
	-------kg/ha-------		----------------ppm----------------		
Control	0	0	108	82	101
Low N					
Fertilizer	200	200	33	31	90
Manure	200	400	122	99	112
High N					
Fertilizer	400	400	41	28	70
Manure	400	800	293	146	152

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