Published online September 23, 2005

Alfalfa and Reed Canarygrass Response to Midsummer Manure Application

JoAnn F. S. Lamb,* Michael P. Russelle, and Michael A. Schmitt

ABSTRACT

Perennial forages like alfalfa (*Medicago sativa* L.) or various perennial grasses, which are cut several times during the growing season, could provide an alternative land base and time management strategy for manure applications. Our objectives were to evaluate the response of two forage species to increasing rates of swine manure slurry applied in midsummer and to compare commercially available alfalfa cultivars for tolerance to swine manure applied during the growing season. The first experiment, hereafter referred to as the rate experiment, included four entries, two N_2–fixing (UMN 3097 and 'Agate') and one non-N_2–fixing (Ineffective Agate) alfalfa and reed canarygrass (*Phalaris arundinacea* L.), grown at two locations in Minnesota. Liquid swine manure was applied at five rates (0, 23.4, 32.7, 42.1, and 93.6 kL ha^{-1}) within 4 d after the second forage harvest in July 1998 and 1999. In the second experiment, hereafter referred to as the cultivar study, six alfalfa cultivars, Magnagraze, 5312, Rushmore, Wintergreen, Winterstar, and WL 325 HQ, were evaluated for response to manures applied at three rates (0, 37.4, and 93.6 kL ha^{-1}) as described above. Manure slurry containing less than about 3300 kg ha^{-1} organic solids applied 4 d after cutting in July improved reed canarygrass yields and had no effect or slightly improved yields of normal N_2–fixing alfalfa. Ineffective Agate yields improved with increasing manure rates, but insufficient N was applied to keep this entry productive. Alfalfa cultivars did not differ in yield response to manure applications. Organic solids in the manure slurries at one of the locations compromised forage yields and stand scores at the highest application rate by completely coating and smothering the plants. Results emphasized the importance of manure testing to reduce adverse effects on alfalfa and reed canarygrass yields.

Livestock manures can be a source of N and other plant nutrients for crop production but must be managed properly to avoid negative impacts on the environment (Eghball and Power, 1994). Manure is usually applied to fields cropped to corn (*Zea mays* L.) or other annual crops, but farmers often have more manure than should be applied to those crops. In addition, it is difficult to apply manure to annual crops during the growing season. Perennial forages, like alfalfa or various perennial grasses, which are harvested several times during the growing season, could provide an alternative land base and time management strategy for manure applications.

Many farmers are reluctant to apply manure to established alfalfa (Lanyon and Griffith, 1988; Russelle, 1997), even though some research has shown no negative economic impacts (Daliparthy et al., 1995; Lloveras et al., 2004). Reasons for avoiding manure applications to alfalfa include increased weed incidence, stand damage by equipment tires, lack of sufficient manure, and lower palatability of the forage. Most of these concerns can be alleviated by manure application before seeding alfalfa, but manure application during the growing season offers farmers a window of opportunity to utilize manure when other farming activities either have been completed (e.g., seedbed preparation, planting, and pesticide application) or are yet to come (e.g., harvest and soil tillage in autumn). Manure applications to established alfalfa usually are made as soon as possible after forage harvest to reduce damage to the crop or in winter when the plants are dormant. Preplant application of manure has not been detrimental to alfalfa production (Mathers et al., 1975; Schmitt et al., 1993, 1994), whereas manure applications to established alfalfa fields have produced variable results. Winter applications of manures were not damaging to the crop and increased dry matter yield on low-fertility soils in Spain (Lloveras et al., 2004). Dry matter yield was depressed by manure slurry application in Minnesota when regrowth was present (Lory, 1993). Increased dry matter yield over the control plot was found at one of two locations in Massachusetts (Daliparthy et al., 1995), but N applications (manure or fertilizer) to established alfalfa only rarely improve yield (Raun et al., 1999; Lloveras et al., 2004; Russelle, 2005). Recommendations are to use moderate rates of slurry or solid manure that will not smother the crop and to apply as soon as possible after harvest (Lory et al., 2000; Kelling and Schmitt, 2003).

Ineffectively nodulated alfalfa is incapable of fixing atmospheric N when grown in association with all tested strains of *Sinorhizobium meliloti*, and must meet its nutritional N demand through N uptake from the soil (Viands et al., 1979). In the presence of adequate inorganic N supply, ineffectively nodulated alfalfa was comparable to its effectively nodulated parent population in herbage yield and N content (Lamb et al., 1995). Research using ^{15}N has shown that these ineffectively nodulated alfalfas absorbed 30 to 40% more N from the subsoil than normal N_2–fixing alfalfas (Blumenthal and Russelle, 1996; Blumenthal et al., 1999). At the site of a train derailment where soil and ground water were contaminated by spilled fertilizer N, this non-N_2–fixing alfalfa removed greater than two-fold more N from the soil than annual grain crops. Ineffectively nodulated alfalfa might, therefore, be a better choice for manure applications than standard N_2–fixing alfalfa.

In contrast to N_2–fixing alfalfa, established perennial forage grasses, such as reed canarygrass, show marked yield improvement with manure slurry applications (Schmitt et al., 1999). A concern with reed canarygrass, which has a high demand for N (Niehaus, 1971; Vetsch et al., 1999), is that sufficient N is provided to promote stand persistence and herbage growth.

J.F.S. Lamb, USDA-ARS Plant Science Research Unit and Dep. of Agronomy and Plant Genetics, Univ. of Minnesota, 411 Borlaug Hall, 1991 Upper Buford Circle, Saint Paul, MN 55108; M.P. Russelle, USDA-ARS-PRSU and US Dairy Forage Research Center (Minnesota Cluster), 1991 Upper Buford Circle, Room 439, Saint Paul, MN 55108; M.A. Schmitt, Dep. of Soil, Water and Climate, Univ. of Minnesota, 1991 Upper Buford Circle, Room 439, Saint Paul, MN 55108. Received 15 Dec. 2004. *Corresponding author (lambx002@umn.edu).

Published in Crop Sci. 45:2293–2300 (2005).
Forage & Grazinglands
doi:10.2135/cropsci2004.0729

677 S. Segoe Rd., Madison, WI 53711 USA

Our objectives were to evaluate the response of reed canarygrass, standard N_2–fixing alfalfa, and a non-N_2–fixing alfalfa to increasing rates of swine manure slurry applied in midsummer, and to compare commercially available alfalfa cultivars for tolerance to applications of swine manure during the growing season.

MATERIALS AND METHODS

Manure Rate Experiment

This experiment included four entries, 'Venture' reed canarygrass, Agate alfalfa, released in 1973, Ineffective Agate, an experimental germplasm selected from Agate that is incapable of N_2 fixation (Barnes et al., 1990), and UMN 3097, an alfalfa cultivar blend created by mixing six recently released commercial cultivars (Magnagraze, 5312, Rushmore, Wintergreen, Winterstar, and WL 325 HQ) that are adapted to the upper Midwest. All were planted on 22 to 25 Aug. 1997 at two Minnesota locations, the Agricultural Experiment Station at Rosemount (44°43′ N, 93°06′ W) on a Waukegan silt loam (fine-silty over sandy-skeletal, mixed, superactive, mesic Typic Hapludoll) and the Southern Research and Outreach Center at Waseca (44°04′ N, 93°31′ W) on a Webster clay loam (fine-loamy, mixed, superactive, mesic Typic Endoaquoll). Liquid swine manure was applied at five target rates (0, 23.4, 32.7, 42.1, and 93.6 kL ha^{-1}) 3 to 4 d after the second forage harvest on 17 July 1998 and 9 July 1999 at Rosemount and 20 July 1998 and 13 July 1999 at Waseca. The manure application equipment was not driven over the control (0 kL ha^{-1}) plots. Manure slurries were sampled at each application to determine total N, P, K, and solids concentration. At both locations, soil test levels of P and K were adequate for high yields of perennial forages (Rehm et al., 2001).

The experiments were established with six replications in a randomized complete block design with a split plot arrangement of the treatments; manure rates were whole plots and entries were subplots. Entries were sown at a rate of 550 live seed m^{-2} in rows 15 cm apart in 1.8 by 6.1 m plots. All plots were mown in June 1998 and the forage was discarded. Yields were estimated from a 0.9 by 5.2 m swath cut through each plot on 14 July and 1 Sept. 1998 and 2 June, 6 July, and 5 Aug. 1999 at Rosemount and 16 July and 26 Aug. 1998 and 3 June, 9 July, and 11 Aug. 1999 at Waseca. The effect of manure on persistence was assessed in non-wheel-tracked areas in September of each year with a stand score based on ground cover, ranging from 0 with no cover to 100 with 100% cover. Total forage yield for 2 yr was calculated for the five harvests for which yield data were collected. Total yield as reported here does not, therefore, include the discarded first harvest after stand establishment.

Cultivar Experiment

In this experiment, the six alfalfa cultivars, Magnagraze, 5312, Rushmore, Wintergreen, Winterstar, and WL 325 HQ, which were blended to create UMN 3097 used in the rate experiment, were each planted on 22 to 25 Aug. 1997 in adjacent plots to those described in the rate experiments at both locations. Liquid swine manure was applied at three target rates (0, 37.4, and 93.6 kL ha^{-1}) 2 to 4 d after the second harvest on 17 July 1998 and 9 July 1999 at Rosemount, MN, and 20 July 1998 and 13 July 1999 at Waseca, MN. Manure slurries were sampled at each application to determine total N, P, K, and solids concentration. At both locations, soil test levels of P and K were adequate for high yields of perennial forages (Rehm et al., 2001).

The experiments were established with six replications in a randomized complete block design with treatments arranged in split plots, with manure rates as whole plots and cultivars as subplots. All cultivars were sown at a rate of 550 live seeds m^{-2} in rows 15 cm apart in 0.9 by 6.1 m plots. Experiments at both locations were mown in June 1998 and the forage was discarded. All plots were harvested on 15 July and 1 Sept. 1998 and 4 June, 7 July, and 5 Aug. 1999 at Rosemount, and on 16 July and 26 Aug. 1998 and 3 June, 9 July, and 11 Aug. 1999 at Waseca. Persistence was assessed as described in the rate experiment.

Statistical Analyses

Analysis of variance was conducted to estimate the effects of year, location, manure treatment, and entry or cultivar, and all interaction effects on forage yield and stand score in both the rate and cultivar studies (PROC GLM; SAS Institute, 2001). For both experiments, locations were considered random and manure treatments and either entries or cultivars were fixed. Regression analyses were conducted to describe the response in yield or stand score for each entry to the manure rates in the rate experiment (PROC REG; SAS Institute, 2001). Means and standard errors were calculated for third harvest forage yield, stand score, and total forage yield for each entry within each manure treatment in each year at each location in the rate study. Mean comparisons ($LSD_{0.05}$) were calculated for yield and stand score for each cultivar in the cultivar experiment.

To evaluate whether the effects of manure slurry solids could be generalized, we converted third harvest yield data to relative yield for each entry-site-year combination in both experiments. Yields from plots that responded positively to manure N were omitted, and the remaining data were fit to a plateau-linear decline model (PROC NLIN, SAS Institute, 2001). A similar approach was used for both total yield and fall stand score, but regression relationships were not significant.

RESULTS AND DISCUSSION

Manure Treatments

Swine manure from the same source was applied to both experiments within a location at each application date, but rates and manure characteristics varied (Tables 1

Table 1. Manure application rates, total N, and solids applied for the rate experiment.

Rosemount, MN						Waseca, MN					
17 July 1998			9 July 1999			20 July 1998			13 July 1999		
Rate	N	Solids	Rate	N	Solids	Rate	N	Solids	Rate	N	Solids
kL ha^{-1}	kg ha^{-1}		kL ha^{-1}	kg ha^{-1}		kL ha^{-1}	kg ha^{-1}		kL ha^{-1}	kg ha^{-1}	
0	0	0	0	0	0	0	0	0	0	0	0
23	31	152	28	67	463	23	43	2 940	28	239	2 890
33	44	213	42	100	694	33	60	4 120	42	358	4 330
42	56	273	56	133	925	42	77	5 300	56	478	5 780
93	126	607	131	311	2160	93	171	11 800	112	955	11 600

Table 2. Manure application rates, total N, and solids applied for the cultivar experiment.

Rosemount, MN						Waseca, MN					
17 July 1998			9 July 1999			17 July 1998			9 July 1999		
Rate	N	Rate	N	Rate	N	Rate	N	Rate	N	Rate	
kL ha^{-1}	— kg ha^{-1} —		kL ha^{-1}	— kg ha^{-1} —		kL ha^{-1}	— kg ha^{-1} —		kL ha^{-1}	kg ha^{-1}	kL ha^{-1}
0	0	0	0	0	0	0	0	0	0	0	0
37	55	239	37	100	611	28	76	3540	37	354	3820
93	138	602	93	251	1535	75	203	9500	93	888	9582

and 2). The manure source at Rosemount in both years contained less solids than slurries used at Waseca. The amount of total N applied in the swine manure treatments also varied for each application for both the rate and cultivar studies, with maxima ranging between 126 and 955 kg N ha^{-1}, depending on year and location. Slurry N concentrations were lower at Rosemount than at Waseca for both years and greater in 1999 at both locations than in 1998. Similarly, maximum application rates of manure solids ranged from 600 to 11 800 kg ha^{-1}. These results point out the importance of manure testing for on-farm nutrient management planning and, as will be discussed, for consideration of manure use on growing vegetation.

Weather conditions also varied among years and locations. During the first week after slurry application at Rosemount, less than 1.5 mm of rain fell both years. In the first week after slurry application at Waseca no rain fell in 1998, but 63 mm fell in 1999. Air temperatures were cooler (t test $P < 0.02$) during the week after manure application at both locations in 1998 (mean maximum = 26°C; mean minimum = 14°C) than in 1999 (mean maximum = 28°C; mean minimum = 19°C).

Manure Rate Experiment

Third harvest forage yield, taken after the midsummer manure applications, fall stand score, and total forage yield demonstrated that N_2–fixing and non-N_2–fixing alfalfa and reed canarygrass responded differently to the increasing rates of manure applied in each year and location (Tables 3 and 4). Differences in the manure characteristics and response to the application procedures for the manure treatments in each year and location contributed to the complex yield and fall stand score responses we observed. Wheel traffic damage from the manure application equipment was apparent in all manure-treated plots, with the greatest plant damage occurring at the highest rate because the manure applicator and tractor had to be driven over the plots twice to apply the desired amount of manure slurry. Based on our observations, driving over the plots a second time when the plants and soil surface were wet from the first pass of the application caused greater plant damage than the other manure rate treatments. Perennial forages exhibit compensatory growth when small gaps or openings in the plant stands occur from physical (winterkill) or mechanical (wheel traffic) damage. Plants adjacent to these small open areas grow larger (less competition for light, nutrients, and water) and compensate in forage yield for the plants that were lost. Compensatory growth occurred in all plots with wheel traffic damage. Yields were measured in strips perpendicular to wheel tracks from manure application and therefore represent the combined effects of manure, wheel traffic, and compensatory growth. In contrast, we scored plant stand in areas without wheel track damage to evaluate the independent effects of manure rate on plant persistence.

Amounts of N and solids applied to the plots for all manure treatments was on average over twofold and eightfold, respectively, greater at Waseca than at Rosemount (Table 1). At Waseca the plants were completely coated at the highest application rate by the manure slurry, which clung to the plants for several days, particularly in 1998. At Rosemount, most of the manure slurry ran off the vegetation within a day or two. Variation in the physical and chemical composition of the manure slurries contributed to the disparity in third harvest yield, fall stand score, and total forage yield response for the entries between the two locations.

N_2–Fixing Alfalfa

Forage yields and fall stand scores of two N_2–fixing alfalfas, UMN 3097 and Agate, differed in response to increasing rates of manure applications between locations (Fig. 1–3). At Rosemount, manure rate did not affect third harvest yield, fall stand score, or total harvest yield for either UMN 3097 or Agate. UMN 3097 out-

Table 3. Rate experiment analysis of variance for fall stand score and forage yield from harvest after manure was applied (third harvest), for two years, two locations, five manure treatments, and four entries.

		Mean squares	
Source	df	Third harvest forage yield	Fall stand score
Year (Y)	1	217.02***	410.60***
Location (L)	1	11.41***	90.74***
Y × L	1	0.11	1.57
Rep within L	10	2.43**	2.17
Error a	10	0.31	2.56
Manure rate (M)	4	1.51	0.23
Y × M	4	0.38	0.47
L × M	4	7.92***	1.72
Y × L × M	4	0.95	2.93
Error b	80	0.67	1.33
Entry (E)	3	20.81***	352.49***
Y × E	3	6.36***	146.79***
L × E	3	11.91***	35.66***
M × E	12	1.32***	1.99***
Y × L × E	3	2.94***	13.75***
Y × M × E	12	0.18	0.40
L × M × E	12	0.29*	1.48***
Y × L × M × E	12	0.38**	0.60
Error c	295	0.13	0.47

* Significant at the 0.05 level of probability.
** Significant at the 0.01 level of probability.
*** Significant at the 0.001 levels of probability.

Table 4. Total forage yield analysis of variance for both the rate (two locations, five manure rates, and four entries) and cultivar (two locations, three manure rates, and six cultivars) experiments.

Rate experiment			Cultivar experiment		
Source	df	Mean squares Total yield	Source	df	Mean squares Total yield
Location (L)	1	400.26***	Location (L)	1	335.92***
Rep within L	10	15.61**	Rep within L	10	9.18**
Manure rate (M)	4	14.28**	Manure rate (M)	2	14.91***
L × M	4	7.54	L × M	2	7.82**
Error a	40	3.59	Error a	20	1.03
Entry (E)	3	766.25***	Cultivar (C)	5	1.86
L × E	3	106.11***	L × C	5	0.82
M × E	12	6.81***	M × C	10	2.41
L × M × E	12	3.99*	L × M × C	10	0.78
Error b	148	1.61	Error b	145	1.53

* Significant at the 0.05 level of probability.
** Significant at the 0.01 level of probability.
*** Significant at the 0.001 levels of probability.

yielded Agate in the control plots (no manure) for third harvest yield in 1999, and in three out of the five manure rate treatments for total yield (Fig. 1 and 3). UMN 3097 is a mixture of modern cultivars with improved resistance to diseases and pests compared to Agate and appeared to have some yield advantage at Rosemount. Fall stand scores for the two N_2–fixing alfalfas were similar for all manure rate treatments at Rosemount in 1998 and 1999 (Fig. 2). Yield and stand longevity of the two N_2–fixing alfalfas were unaffected by the addition of manure in midsummer at Rosemount.

At Waseca, third harvest yield in both years and total forage yield of UMN 3097 and Agate were similar and declined linearly as the rate of the manure slurry in-

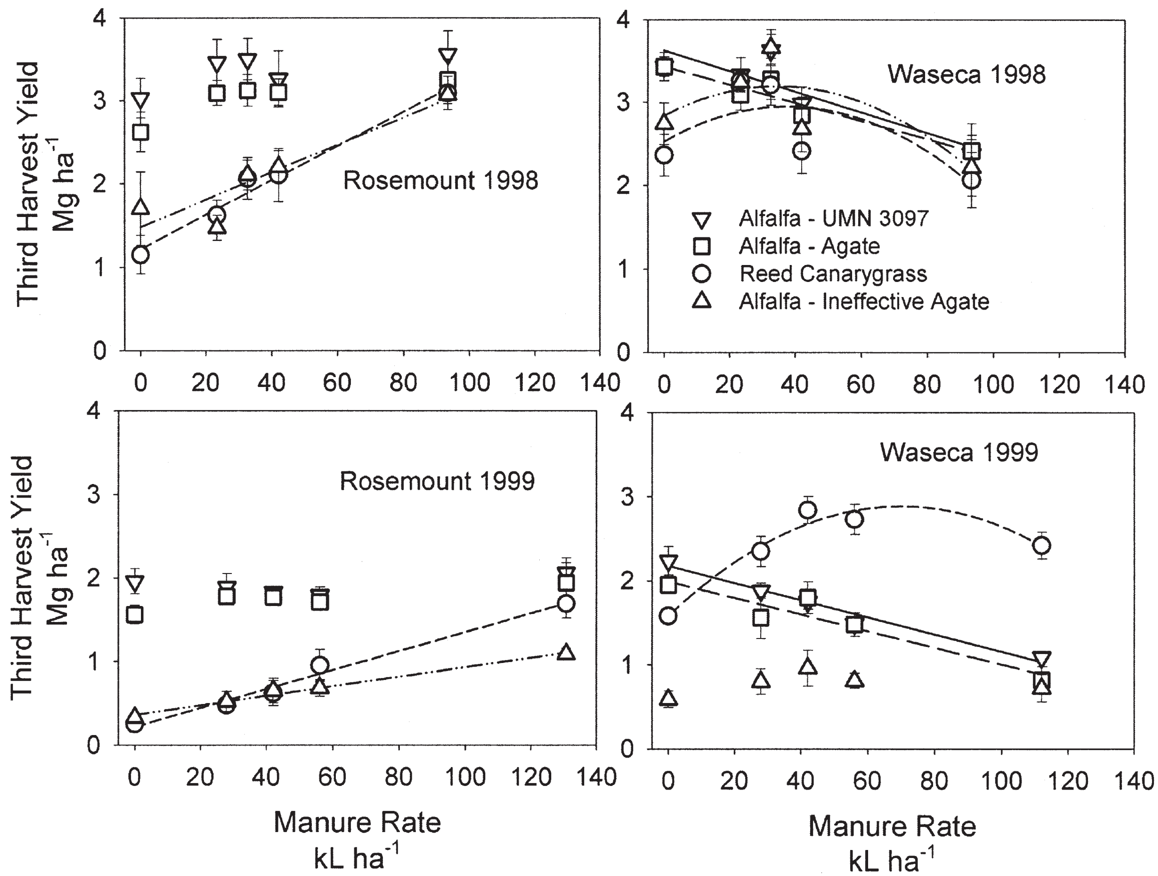

Fig. 1. Third harvest yield response to midsummer swine manure slurry applications for each entry in each location and year in the rate experiment. Ineffective Agate third harvest yield increased linearly with increasing manure rates at Rosemount in 1998 ($y = 1.47 + 0.02x$, $P \geq 0.0001$) and in 1999 ($y = 0.36 + 0.01x$, $P \geq 0.0001$), but demonstrated a quadratic response to increasing manure rates in 1998 at Waseca ($y = 2.84 + 0.02x - 0.0003x^2$, $P \geq 0.02$). Reed canarygrass third harvest yield increased linearly with increasing manure rates at Rosemount in 1998 ($y = 1.21 + 0.02x$, $P \geq 0.0001$) and in 1999 ($y = 0.22 + 0.01x$, $P \geq 0.0001$), but demonstrated a quadratic response to increasing manure rates at Waseca in 1998 ($y = 2.52 + 0.02x - 0.0003x^2$, $P \geq 0.03$) and 1999 ($y = 1.58 + 0.03x - 0.0003x^2$, $P \geq 0.0001$). At Waseca, third harvest yield declined with increasing manure rates for both of the N_2–fixing alfalfas: UMN 3097 (1998, $y = 3.63 - 0.01x$, $P \geq 0.0001$; 1999, $y = 2.18 - 0.01x$, $P \geq 0.0001$) and Agate: (1998, $y = 3.43 - 0.01x$, $P \geq 0.003$; 1999, $y = 1.10 - 0.01x$, $P \geq 0.0001$).

creased (Fig. 1 and 3). Fall stand scores at Waseca in 1998 for UMN 3097 and Agate were similar and declined as manure application rates increased. In 1999, plant stands for Agate did not change with manure rate, but again showed a negative linear response for UMN 3097 as manure rate increased. Rate of manure application at the two locations was essentially the same, yet yield and in some cases fall stand score declined at Waseca but not at Rosemount. Differences in the chemical and physical makeup of the manures resulted in this yield disparity between the two locations.

Non-N_2–Fixing Alfalfa

Third harvest forage yield of Ineffective Agate had a positive linear response to increasing manure application rates in both years at Rosemount (Fig. 1). At Waseca in 1998, Ineffective Agate showed a quadratic response to increasing manure rate, reaching a maximum yield at the intermediate manure application rates and then declining at the highest rate. In 1999 at Waseca, Ineffective Agate yields did not change as manure rates increased. Fall stand score of Ineffective Agate improved with increasing manure application rates at Rosemount in 1998 and at Waseca in 1999 (Fig. 2). Fall stand scores were lower compared to the N_2–fixing alfalfas for all manure rate treatments in both years at Rosemount and at Waseca in 1999. At both locations, total forage yield of Ineffective Agate was lower than the other three entries and did not change as manure rates increased (Fig. 3).

Ineffective Agate was included in this experiment because in previous research it proved to be an excellent scavenger of subsoil nitrate (Russelle et al., 2001). However, by midsummer 1998 at Rosemount the Ineffective Agate plants were chlorotic and stunted, typical symptoms of N deficiency. Very little N was added in the manure at Rosemount in 1998 (Table 1). These ineffectively nodulated plants had low productivity in the summer of 1999, which increased slightly in third harvest yield with increasing manure rates, but by November 1999 most plants had died, presumably from lack of adequate N.

In contrast to Rosemount, the Ineffective Agate plots at Waseca in 1998 looked similar to the N_2–fixing alfalfa plots and did not show symptoms of N deficiency. More N was added to the plots from manure at Waseca than Rosemount in 1998, but a single application of manure in 1998 did not supply enough N to keep this non-N_2–fixing alfalfa germplasm as productive as the other three entries in 1999. Fall stand scores increased with increasing manure rate at Waseca in 1999, but both third harvest yield and total forage yield of Ineffective Agate were much lower than other entries evaluated in this study. We interpret these results as demonstrating that Ineffective Agate responded to the increasing N from

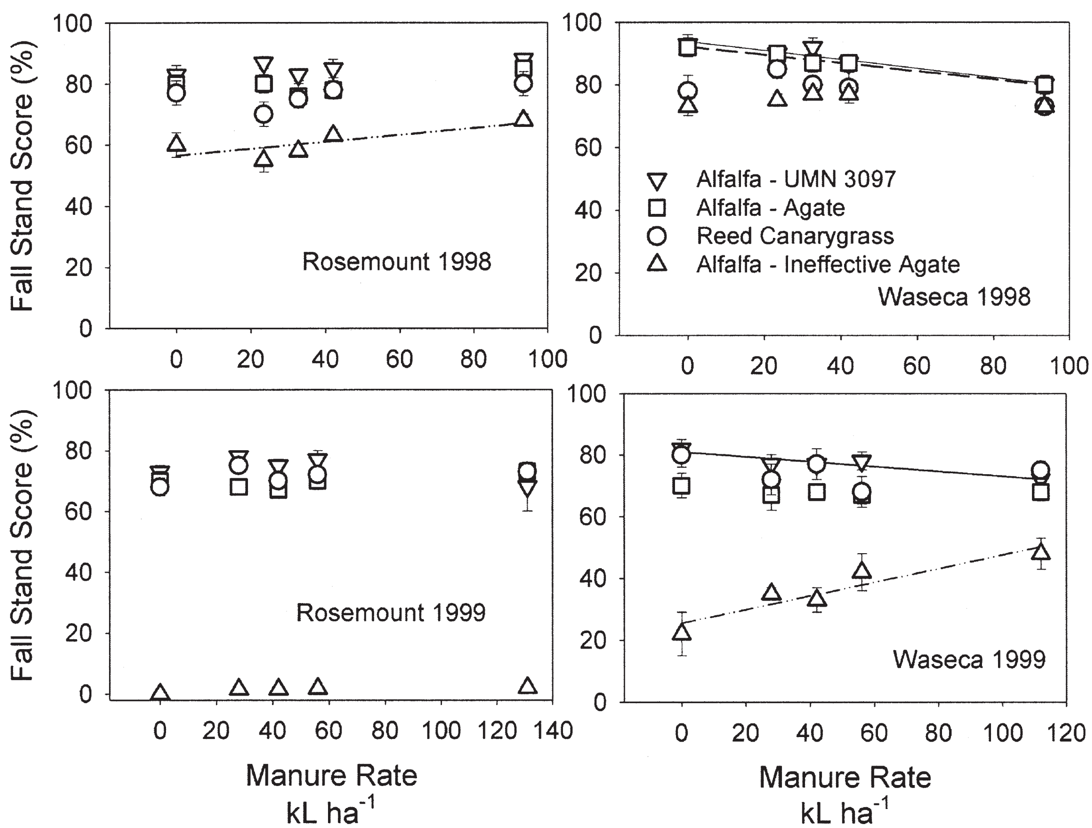

Fig. 2. Stand score response to midsummer swine manure slurry applications for each entry in each location and year in the rate experiment. Ineffective Agate stand score increased with increasing manure rates at Rosemount in 1998 ($y = 57 + 0.13x$, $P \geq 0.02$) and at Waseca in 1999 ($y = 25 + 0.23x$, $P \geq 0.001$). UMN 3097 stand score declined with increasing manure rates at Waseca in 1998 ($y = 94 - 0.15x$, $P \geq 0.0001$) and in 1999 ($y = 81 - 0.08x$, $P \geq 0.03$). Agate stand score declined with increasing manure rates only at Waseca in 1998 ($y = 92 - 0.13x$, $P \geq 0.001$).

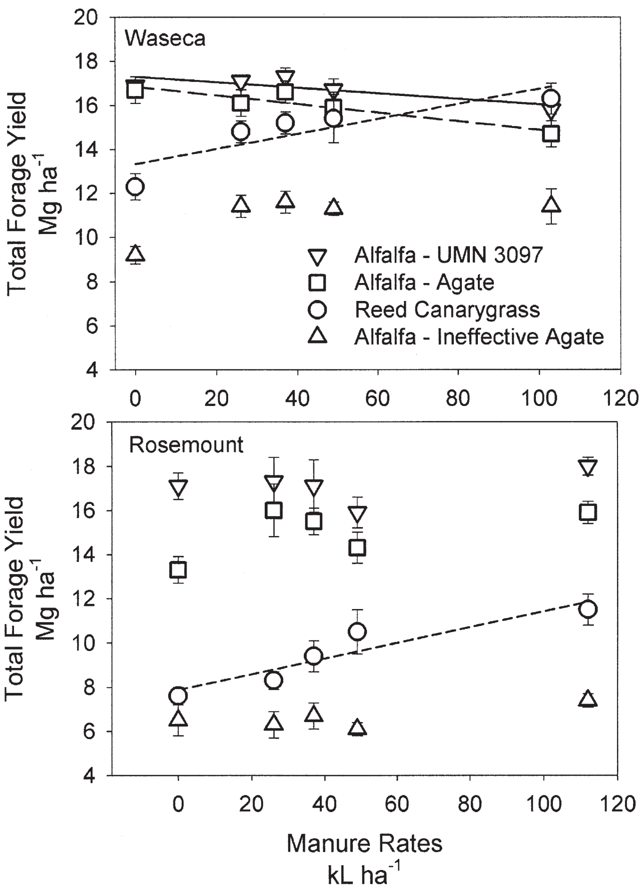

Fig. 3. Total yield response to midsummer swine manure slurry applications for each entry in the rate experiment for two years at Rosemount and Waseca, MN. Total yield for reed canarygrass increased with increasing manure rates at Rosemount ($y = 7.98 + 0.04x$, $P \geq 0.01$) and Waseca ($y = 13.3 + 0.03x$, $P \geq 0.01$). Total yield for UMN 3097 ($y = 17.3 - 0.01x$, $P \geq 0.03$) and Agate ($y = 16.8 - 0.02x$, $P \geq 0.02$) declined with increasing manure rates only at Waseca.

the manure slurries, but that a single annual application of manure at typical N application rates even during the growing season did not meet the N supply needed to keep it productive.

Reed Canarygrass

Reed canarygrass increased in third harvest yield in response to increasing manure application rate in both years at Rosemount (Fig. 1). In both years, reed canarygrass yielded the same as Ineffective Agate and less than the two N_2–fixing alfalfas at the first four manure rate treatments. At the highest application rate, reed canarygrass yielded the same as the other three entries in 1998 and the same as the N_2–fixing alfalfas in 1999. For both years at Waseca, reed canarygrass demonstrated a quadratic response in third harvest yields to increasing manure rate, reaching maximum yield at the intermediate manure application rates and then declining at the highest application rate. We suggest that reed canarygrass yields increased with increasing manure N until plant growth was limited by the quantity of organic matter solids that coated the plants. In the control 0 plots in 1999, reed canarygrass was intermediate in yield between Ineffective Agate and the two N_2–fixing alfalfas, but out-yielded the other three entries for all other manure rate treatments, suggesting that it was less damaged by traffic or manure solids. Reed canarygrass fall stand scores were comparable to the two N_2–fixing alfalfas at both locations in both years and did not change as manure rates increased (Fig. 2). Total forage yield for reed canarygrass at both locations increased as manure rate increased (Fig. 3). Total forage yield was less at Rosemount, probably because of the lower N content of the manure slurries at that location.

Table 5. Cultivar experiment analysis of variance for forage yield from harvest after manure was applied (third harvest) and stand score for two years, two locations, three manure rates, and six alfalfa cultivars.

		Mean squares	
Source	**df**	**Third harvest forage yield**	**Fall stand score**
Year (Y)	**1**	**54.10*****	**283.56*****
Location (L)	**1**	**36.17*****	**14.08****
Y × L	**1**	**31.63*****	**1.81**
Rep within L	**10**	**1.79**	**0.55**
Error a	**10**	**0.70**	**0.80**
Manure rate (M)	**2**	**4.09*****	**2.92**
Y × M	**2**	**0.25**	**0.41**
L × M	**2**	**13.46*****	**3.84***
Y × L × M	**2**	**0.17**	**1.02**
Error b	**40**	**0.16**	**1.12**
Cultivar (C)	**5**	**0.16**	**3.13*****
Y × C	**5**	**0.21**	**0.19**
L × C	**5**	**0.05**	**0.13**
M × C	**10**	**0.09**	**0.38**
Y × L × C	**5**	**0.06**	**0.10**
Y × M × C	**10**	**0.18**	**0.34**
L × M × C	**10**	**0.19**	**0.36**
Y × L × M × C	**10**	**0.05**	**0.42**
Error c	**297**	**0.11**	**0.30**

*** Significant at the 0.05 level of probability.**
**** Significant at the 0.01 level of probability.**
***** Significant at the 0.001 levels of probability.**

Cultivar Experiment

No differences in third harvest or total yield were found among the cultivars for any of the manure application treatments in any environment (Tables 4 and 5). However, as a group the cultivars yielded differently in response to the manure treatments between locations, and in some cases between years. In 1998, third harvest yields were similar between the two locations, whereas in 1999 third harvest yields were greater at Waseca than at Rosemount (data not shown). Third harvest yields (Mg ha^{-1}) were larger at both the low (mean = 2.4; SE = 0.1) and high (mean = 2.5; SE = 0.1) manure rates than without manure (mean = 2.1; SE = 0.1) at Rosemount, whereas the control (mean = 3.1; SE = 0.1) and low manure rate (mean = 3.2; SE = 0.1) yielded more forage than the high manure rate treatment (mean = 2.4; SE = 0.1) at Waseca. Fall stand scores were similar for all manure treatments at Rosemount (mean = 80; SE = 1), but at Waseca, fall stand scores were highest in the control (mean = 86; SE = 1), intermediate in the low manure rate (mean = 83; SE = 1), and lowest at the high manure application treatment (mean = 80; SE = 1). As in the rate experiment, we infer that these location by manure treatment interactions for

Table 6. Cultivar experiment mean of entries over locations for stand score taken at the end of each growing season.

Cultivar	Stand Fall 1998	Stand Fall 1999
	Score†	
Magnagraze	93	76
5312	91	73
Rushmore	89	72
Wintergreen	90	74
Winterstar	88	71
WL 325 HQ	91	75
$LSD_{0.05}$	3	4

† Scored 1 to 100; 0 = no plants; 50 = 50% of ground covered by alfalfa plants; 100 = 100% of ground covered by alfalfa plants.

third harvest yield and fall stand score were caused by the greater organic solids content of the manures at Waseca compared to Rosemount. Total forage yield was greater in the manure-treated plots (high mean = 17.2; SE = 0.2 and low mean = 17.0; SE = 0.3) than the control (mean = 15.9; SE = 0.2) at Rosemount, but no differences in total forage yield were found among the manure treatments at Waseca (mean = 19.3; SE = 0.1). These results suggest that forage yield may improve or at least not be compromised by applying manure slurry in midsummer within a few days after cutting to commercially available alfalfa cultivars. Caution should be taken to avoid conditions that would cause wheel traffic damage.

Difference for stand score were found among entries in the fall of both 1998 and 1999 (Table 5). Magnagraze had consistently greater fall stand score than Winterstar, but neither was different from the rest of the cultivars (Table 6). The minimal difference in fall stand score between these two cultivars did not translate to differences in third harvest or total forage yield.

Short-term Manure Solids Effect

We combined data from both experiments to examine the putative short-term effect of swine manure slurry solids on forage productivity (Fig. 4). Third harvest yields were expressed on a relative basis within each entry, site, and year. We then removed the presumed effect of manure N supply by omitting those relative yield means that were both lower than the maximum yield and occurred at manure rates smaller than that required for maximum yield.

We conclude from this analysis that rates of swine manure slurry in excess of about 3300 kg ha^{-1} resulted in loss of late summer yields. We observed no differences among normal, N_2–fixing alfalfas, between N_2–fixing and non-N_2–fixing alfalfas, or between reed canarygrass and alfalfa. This suggests that, other conditions being the same (soil water availability, slurry salinity, etc.), manures containing less than about 3300 kg ha^{-1} organic matter applied 3 to 4 d after cutting in July should not affect yield or fall stand scores of N_2–fixing alfalfa. We cannot be certain that organic solids were the reason for this decline in yield during the regrowth following application, but assuming alfalfa stubble had a leaf (and stem) area index of 1, that manure solids had a density of 1 g cm^{-3}, and that manure solids were uniformly distributed on all surface areas, the high rate at Waseca was equivalent to a coating on soil and stubble 1.2 mm thick.

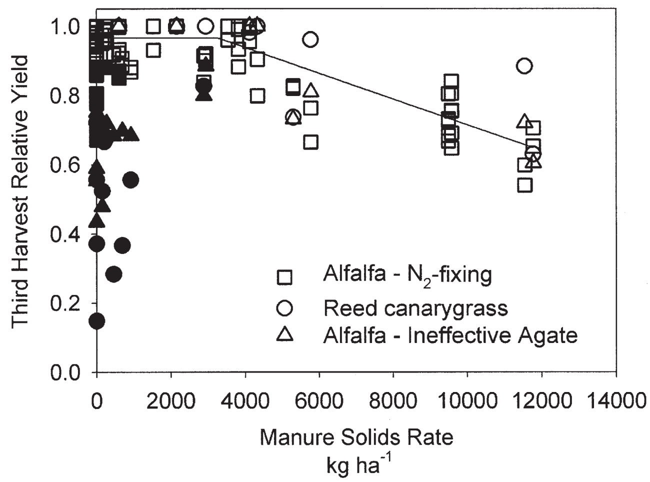

Fig. 4. Third harvest yield response to manure solids rate in midsummer swine manure slurry application to N_2–fixing alfalfas, non-N_2–fixing Ineffective Agate alfalfa, and reed canarygrass. Yields are expressed on a relative basis within each entry-site-year combination in both the rate and cultivar experiments. Ignoring plots that had not attained maximum yield because of insufficient manure-N supply (solid symbols), there was no effect of solids on relative yield ($y = 0.97$) until application rate exceeded about 3300 kg solids ha^{-1}, after which relative yield declined linearly ($y = 1.09 - 0.000037x$ for $x > 3300$ kg ha^{-1}, $R^2 = 0.73$, $n = 112$).

Manure solids can coat vegetation and result in what is colloquially known as “smothering” (Smith et al., 1995), but also can seal soil pores (Barrington et al., 1987), limiting gas exchange with the atmosphere, and reduce the partial pressure of O_2 in the soil due to high biological oxygen demand (Burford, 1976). Alfalfa has poor tolerance to low O_2 supply in the root zone (Barta, 1980), so the latter effect may have played a role in plant response. This is less likely for reed canarygrass, because it has greater tolerance to low O_2 supply in the root zone (McKenzie, 1951). A greater role for the grass was coating of the herbage, which likely reduces leaf gas exchange (thereby affecting photosynthesis, respiration, and transpiration) and raises leaf temperature, resulting in both scorch and smothering (Wightman et al., 1997).

In our experiments, the effect of extra wheel traffic at the high manure rate occurred at both sites, but yield declines associated with the highest manure rate occurred only at Waseca. We conclude that extra wheel traffic was not a significant independent factor related to short-term yield decline. Regardless of the mechanisms involved, this research highlights the need to restrict rates of broadcast manure slurry on the basis of solids content, as well as nutrient content.

SUMMARY

Physical and chemical characteristics of manure slurries are variable and can affect the response of perennial forages to midsummer manure applications. Our results emphasize the importance of manure testing to reduce adverse effects of midsummer applications on established forages. Manure application protocols should be developed to minimize plant damage caused by wheel traffic from the application equipment. Manure slurry application rates involving less than 3300 kg ha^{-1} organic solids and increasing amounts of N applied within 4 d after cutting in July increased reed canarygrass yields, had little effect on yield of normal N_2–fixing alfalfas, and had no effect on plant stand of either forage species. Ineffective Agate alfalfa increased in third harvest forage yield and plant stand as manure rates increased in some locations and years, but a single annual application even during the growing season did not meet the N supply needed to keep this non-N_2–fixing alfalfa viable and productive.

REFERENCES

Barnes, D.K., G.H. Heichel, C.P. Vance, and R.N. Peadon. 1990. Registration of 'Ineffective Agate' and 'Ineffective Saranac' non-N2-fixing alfalfa germplasms. Crop Sci. 30:752–753.

Barrington, S.F., P.J. Jutras, and R.S. Broughton. 1987. The sealing of soil by manure. 1. Preliminary investigations. Can. Agric. Eng. 29:99–103.

Barta, A.L. 1980. Regrowth and alcohol dehydrogenase activity in waterlogged alfalfa and birdsfoot trefoil. Agron. J. 72:1017–1020.

Blumenthal, J.M., and M.P. Russelle. 1996. Subsoil nitrate uptake and symbiotic dinitrogen fixation by alfalfa. Agron. J. 88:909–915.

Blumenthal, J.M., M.P. Russelle, and J.F.S. Lamb. 1999. Subsoil nitrate and bromide uptake by contrasting alfalfa germplasms. Agron. J. 91:269–275.

Burford, J.R. 1976. Effect of application of cow slurry to grassland on composition of soil atmosphere. J. Sci. Food Agric. 27:115–126.

Daliparthy, J., S.J. Herbert, L.J. Moffitt, and P.L.M. Veneman. 1995. Herbage production, weed occurrence, and economic risk from dairy manure applications for alfalfa. J. Prod. Agric. 8:495–501.

Eghball, B., and J.F. Power. 1994. Beef cattle feedlot manure management. J. Soil Water Conserv. 49:113–122.

Kelling, K.A., and M.A. Schmitt. 2003. Applying manure to alfalfa: Pros, cons and recommendations for three application strategies. N. Central Reg. Res. Rep. 346. College Agric. Life Sci., Univ. of Wisconsin, Madison.

Lamb, J.F.S., D.K. Barnes, M.P. Russelle, C.P. Vance, G.H. Heichel, and K.I. Henjum. 1995. Ineffectively and effectively nodulated alfalfas demonstrate biological nitrogen fixation continues with high nitrogen fertilization. Crop Sci. 35:153–157.

Lanyon, L.E., and W.K. Griffith. 1988. Nutrition and fertilizer use. p. 333–372. *In* A.A. Hansen, D.K. Barnes, and R.R. Hill, Jr. (ed.) Alfalfa and alfalfa improvement. Agron. Monogr. 29. ASA, CSSA, SSSA, Madison, WI.

Lloveras, J., M. Arán, P. Villar, A. Ballesta, A. Arcaya, X. Vilanova, I. Delgado, and F. Muñoz. 2004. Effect of swine slurry on alfalfa production and on tissue and soil nutrient concentration. Agron. J. 96:986–991.

Lory, J.A. 1993. Management of manure-nitrogen and fertilizer-nitrogen in alfalfa-corn rotations. Ph.D. diss. Univ. of Minnesota, St. Paul, MN.

Lory, J.A., R. Kallenbach, and C. Roberts. 2000. Managing manure on alfalfa hay. MU Guide G 4555. Univ. of Missouri-Columbia Ext. Serv., Columbia.

Mathers, A.C., B.A. Stewart, and B. Blair. 1975. Nitrate-Nitrogen removal from soil profiles by alfalfa. J. Environ. Qual. 4:403–405.

McKenzie, R.E. 1951. The ability of forage plants to survive early spring flooding. Sci. Agric. (Ottawa) 31:358–367.

Niehaus, M.H. 1971. Effect of N fertilizer on yield, crude protein content, and *in vitro* dry-matter digestibility in *Phalaris arundinacea* L. Agron. J. 63:793–794.

Raun, W.R., G.V. Johnson, S.B. Phillips, W.E. Thomason, J.L. Dennis, and D.A. Cossey. 1999. Alfalfa yield response to nitrogen applied after each cutting. Soil Sci. Soc. Am. J. 63:1237–1243.

Rehm, G., M. Schmitt, J. Lamb, and R. Eliason. 2001. Fertilizer recommendations for agronomic crops in Minnesota. Univ. of Minnesota Ext. Serv. BU-06240-S. Available online at www.soils.umn.edu/extension/extension_publications.php (accessed 3 Sept. 2004; verified 29 June 2005). Univ. of Minnesota, St. Paul.

Russelle, M. 1997. Survey results of forage nutrient management on Minnesota dairy farms. p. 30–38. *In* 23rd Forage Prod. and Use Symp., Appleton, WI. 26–27 Jan. 1999. Wisc. Forage Counc., Appleton, WI.

Russelle, M.P. 2005. Biological dinitrogen fixation in agriculture. *In* J.S. Schepers and W.R. Raun (ed.) Nitrogen in agricultural soils. 2nd ed. ASA, CSSA, and SSSA, Madison, WI. (in press).

Russelle, M.P., J.F.S. Lamb, B.R. Montgomery, D.W. Elsenheimer, B.S. Miller, and C.P. Vance. 2001. Alfalfa rapidly remediates excess inorganic nitrogen at a fertilizer spill site. J. Environ. Qual. 30:30–36.

SAS Institute. 2001. The SAS system for Windows. Release 8.02. SAS Institute Inc. Cary, NC.

Schmitt, M.A., M.P. Russelle, G.W. Randall, C.C. Sheaffer, L.J. Greub, and P.D. Clayton. 1999. Effect of rate, timing, and placement of liquid dairy manure on reed canarygrass yield. J. Prod. Agric. 12:239–243.

Schmitt, M.A., C.C. Sheaffer, and G.W. Randall. 1993. Preplant manure and commercial P and K fertilizer effects on alfalfa production. J. Prod. Agric. 6:385–389.

Schmitt, M.A., C.C. Sheaffer, and G.W. Randall. 1994. Manure and fertilizer effects on alfalfa plant nitrogen and soil nitrogen. J. Prod. Agric. 7:104–109.

Smith, K.A., D.R. Jackson, R.J. Unwin, G. Bailey, and I. Hodgson. 1995. Negative effects of winter-applied and spring-applied cattle slurry on the yield of herbage at simulated early grazing and first-cut silage. Grass Forage Sci. 50:124–131.

Vetsch, J.A., G.W. Randall, and M.P. Russelle. 1999. Reed canarygrass yield, crude protein, and nitrate N response to fertilizer N. J. Prod. Agric. 12:465–471.

Viands, D.R., C.P. Vance, G.H. Heichel, and D.K. Barnes. 1979. An ineffective nitrogen fixation trait in alfalfa. Crop Sci. 19:905–908.

Wightman, P.S., M.F. Franklin, and D. Younie. 1997. The effect of sward height on response of mini-swards of perennial ryegrass/white clover to slurry application. Grass Forage Sci. 52:42–51.