Factors Affecting Manure Excretion by Dairy Cows

W. P. Weiss and N. R. St-Pierre

Department of Animal Sciences
Ohio Agricultural Research and Development Center
The Ohio State University

Manure is an inevitable byproduct of the production of meat and milk destined for human consumption. Excessive excretion of manure and manure nutrients represents inefficiencies that increase feed costs, increase the environmental impact of dairy farming, and increase costs associated with moving and storing manure. Profitability often can be enhanced when feeding and management practices are used that reduce manure production per unit of milk produced. Furthermore, good environmental stewardship will maintain the generally positive public image of dairy farming.

Society is increasingly concerned about the environmental impact of manure and manure nutrients. In response, the federal government and many states have developed environmental rules regulating certain dairy farms (EPA, 2003). Although regulations vary, the amount of P and N excreted via manure are of major regulatory importance. The selection of proper feed ingredients and diet formulation can affect the mass of manure produced and the amount of specific nutrients (e.g., N and P) that are excreted.

Average Manure Production

Over the past several years, our laboratory has conducted numerous experiments measuring fecal and urinary output by lactating dairy cows fed a variety of diets. The current database contains data from 14 different experiments with cows (232 observations) fed 55 different diets. Not all samples were assayed for N and P; therefore, the number of observations is 202 for N data and 161 for P data. In all experiments, cows were housed in metabolism stalls for 4 to 6 days, fed for ad libitum consumption, and all feces and urine produced was collected, weighed, and sampled. All animals were Holstein cows in their second or greater lactation and varied greatly in milk production, body weight, and days in milk (Table 1). The average milk production in this data set is very close to the current U.S. average (2005 USDA statistics). The objectives of the individual experiments included the evaluation of different types of forages, fat supplements, byproduct feeds, and mineral supplementation. A diverse array of feedstuffs was used, but corn silage and alfalfa silage were the predominant forages fed (alfalfa hay and orchardgrass silage were also included in some experiments). Dry ground corn was the predominant starch source and soybean meal was the predominant source of supplemental crude protein. Several byproducts including soyhulls, dried distillers grains, wheat middlings, and animal protein meals were fed. The concentration of crude protein and P varied among diets (Table 1), but in most cases P was fed to only slightly exceed the NRC (1989; 2001) recommendations in place when the experiment was conducted.

The average amount of manure (feces plus urine) produced daily by cows in this data set was about 140 lbs and ranged from 59 to 224 lbs/day (Table 2). The vast majority (87.5%) of manure was water. The excretion of urine averaged 45.1 lbs/day (5.4 gal) and ranged from 18.5 to 101 lbs/day (2.2 to 12.2 gal/day). Excretion of wet feces averaged 94.8 lbs/day. The excretion of urine was more variable than excretion of feces (CV = 38% vs. 22%). On average, slightly less than one-third of manure was urine, but this proportion was highly

variable ranging from 16.5 to 62% urine. Excretion of N and P via manure averaged 385 and 47 g/d, respectively (Table 2). On average, 50% of the N excreted was via urine but almost all the P excreted was via feces.

Over the past 2 years we have been conducting a very large experiment to evaluate the relationships we observed with our original data set and to expand our information regarding factors that influence manure excretion and excretion of N (108 observations). Those data have not been fully analyzed yet, but some preliminary findings are included in this paper. For the new data set, DM intake averaged 53.0 lbs/day and milk production averaged 84 lbs/day.

Factors Affecting Manure Excretion

The original data base was used to evaluate major dietary (concentrations of forage, corn silage, NDF, CP, and P) and cow factors (dry matter intake and milk production) that influenced excretion of manure and manure nutrients. Mixed model regression with experiment included as a random factor (St. Pierre, 2001) was used for all statistical analyses.

The only two independent variables (when included in single factor models) that were significantly ($P < 0.05$) related with wet manure production were dry matter intake (DMI) and milk production (Figures 1 and 2). The relationship between DMI and manure production was much stronger than the relationship between milk yield and manure production

Although manure excretion increased, on average, with increasing milk production, substantial variation is evident (Figure 2) meaning that increased milk production does not necessarily increase manure production. Not unexpectedly, DMI was clearly the most important single factor affecting manure production, but actual manure excretion varied about ± 22 lbs from predicted excretion at a specific DMI. With our new dataset that included cows with higher average milk yield and higher average DMI than the original data set, the relationship between DMI and manure production was very similar (Manure, lbs/day = 3.3 × DMI, lbs/day).

To increase the precision of estimating manure excretion, models with DMI and other independent variables were evaluated. To be evaluated, the factor had to have no significant ($P < 0.05$) correlation with DMI. The best fitting model was one that included DMI (lbs/day) and the concentration of corn silage (CS, % of forage DM) in the diet:

[1] Wet manure, lbs/day =
$16.7 + 3.0 \times DMI - 0.25 \times CS$

Assuming no effect on DMI, cows fed a diet with no corn silage (all hay crop) would produce, on average, 25 lbs/day more manure than would cows fed a diet with 100% of the forage as corn silage. At the average DMI of this database (46 lbs) this is equivalent to a 16% reduction in manure excretion. This relationship was confirmed with our new data set. Cows fed diets with 75% of the forage as corn silage (the remaining forage was alfalfa silage) produced 14% less manure than cows fed with 25% of the forage as corn silage (165 vs. 191 lbs/day).

Excretion of Fecal DM

To better understand the relationships between manure production and dietary and cow factors, manure was partitioned into feces and urine. Excretion of fecal water was not related to any variable except DMI; therefore, only excretion of fecal DM will be discussed. As expected, DMI accounted for most of the explainable variation in excretion of fecal DM. In all equations the coefficient associated with DMI was 0.35, meaning that the average DM digestibility of these diets was 65% (i.e., 100 - 35). The concentration of dietary NDF and the percent of forage as corn silage also were significantly related with excretion of fecal DM, but the effects were quantitatively small. A one percentage unit increase in the con-

centration of dietary NDF was associated with a 0.07 lb/day increase in excretion of fecal DM. A one percentage unit increase in the concentration of corn silage (as a % of forage DM) was associated with a 0.015 lb/day decrease in excretion of fecal DM. The concentration of dietary NDF and the proportion of corn silage were negatively correlated; therefore, the effects of one cannot be statistically separated from the other. Most likely, NDF concentration was primarily responsible because average NDF digestibility is less than average DM digestibility.

Excretion of Urine

As with excretion of fecal DM and manure, DMI (lbs/day) was strongly related to urine excretion but the percentage of forage as corn silage (CS) also was strongly related with urine excretion:

[2] Urine, lbs/day =
27.1 + 0.72 × DMI - 0.24 × CS

Based on equation [2], the effect corn silage has on total manure excretion is caused almost entirely by its effect on urine excretion. Replacing hay crop forage with corn silage reduced excretion of urine. On average, cows fed diets in which all the forage was corn silage would be expected to produce about 24 lbs/day less urine than cows fed diets with hay crops providing all the forage. In our new data set, cows fed diets with 25% of the forage as corn silage produced, on average, 22 lbs more urine/day than cows fed diets with 75% of the forage as corn silage. The reason decreasing corn silage (and increasing hay crop) increased urine output was most likely the increased concentration of potassium in hay crops compared with corn silage.

Excretion of N and P via Manure

Because of the importance of P in nutrient management plans and environmental regulations, P excretion was extensively examined using the data base described above (Weiss and Wyatt, 2004). The only variables related to excretion of P via manure were P intake and milk production, but the equation based solely on P intake was almost as accurate as the equations using P intake and milk production:

[3] Manure P, g/day =
-2.5 + 0.64 × P intake, g/day

Excretion of N in manure increased as N (or CP) intake increased and decreased as milk production increased (Equation 4).

[4] Manure N, g/day =
51 + 0.63 × N intake, g/day - 0.43 × Milk, lbs/day

Based on this equation, if increased N intake results in increased milk production, the marginal efficiency of N utilization can increase. For example, if a cow consumes 46 lbs of DM of a diet with 17% CP (2.72% N) and produces 66 lbs of milk, N intake equals 571 g and expected excretion of N equals 382 g/day (67% of N intake is excreted in manure). If intake increases to 48 lbs (17% CP) and production increases to 73 lbs, N intake is 598 g and expected N excretion is 397 g (66% of N intake is excreted in manure). The only other factor tested that affected excretion of N in manure was the concentration of corn silage (% of forage DM). Including that term reduced residual variation only slightly and the resulting model was not appreciably more precise or accurate (data not shown). The coefficient was 0.28, which means that changing from a diet with all the forage as hay crop to one with all corn silage would be expected to reduce manure N excretion by 28 g/day (7% of average N excretion in this data set). Corn silage reduced fecal N excretion but slightly increased urinary excretion of N (data not shown).

Brown Midrib Corn Silage and Manure Excretion

Corn silage made from brown midrib (bmr) hybrids usually has higher in vitro NDF digestibility and lower lignin concentrations than silage made from conventional hybrids. In vivo digest-

ibility of nutrients has not been affected consistently by hybrid. The effect of bmr silage on excretion of nutrients and manure has not been examined until very recently (Weiss and Wyatt, 2006). Prior to our experiment, data from two studies (Tine et al., 2001; Greenfield et al., 2001) suggested that manure N may be decreased when cows were fed bmr silage. Excretion of manure N was not statistically analyzed in either paper, but numerically, manure N as a percent of N intake was lower for cows fed bmr silage than for cows fed the control silage (72.7 vs. 70.3% for Tine et al. and 73.5 vs. 67.7% for Greenfield et al.).

To determine effects of bmr silage on manure excretion and N metabolism we (Weiss and Wyatt, 2006) conducted a digestion study comparing bmr (Mycogen F697 bmr) silage with a conventional hybrid (Mycogen 7511 FQ). The conventional hybrid was not the isogenic hybrid used in previous studies and has above average in vitro NDF digestibility. Diets were 55% corn silage (either bmr or conventional) and 45% concentrate and contained either 14 or 17.5% CP. Cows fed the bmr silage tended ($P < 0.09$) to excrete less manure (154 vs. 160 lbs/day) than cows fed the conventional hybrid. As expected, increasing dietary CP concentration greatly ($P < 0.01$) increased excretion of N via manure (374 vs. 465 g/day for the 14 and 17.5% CP diets, respectively). At a specific N intake, cows fed bmr silage excreted 14 g/day less N ($P < 0.08$) than cows fed the conventional hybrid. Hybrid affected manure N excretion but the response was quite modest (reduced manure N by 3.6%).

(In)Efficiency of the Dairy Industry

With all the recent interest and increasing regulations, one would think that excretion of manure and manure nutrients by dairy cows is worse now than in the past. Based on USDA statistics, 20 years ago (1985) we had 11 million dairy cows in the US producing 143 billion pounds of milk/year. Based on our equation (Figure 2), in 1985 the US dairy herd produced about 690,000 tons of manure each day. In 2005, we had 9 million dairy cows producing 177 billion pounds of milk/year. Again based on Figure 2, manure production was about 621,000 tons per day. In the last 20 years, the US dairy industry has reduced manure production by about 10% and increased milk production about 23%. Clearly we should continue to develop and use new methods that reduce the environmental impact of the dairy industry, but we also should be proud of the progress already made. From our data set, "manure inefficiency" averaged 2.2 lbs of manure/pound of milk produced. But because cows produce manure even when they produce no milk (averaged 100 lbs/day from our data), manure inefficiency will decrease as milk production increases. Cows producing 40 lbs of milk will average 3.1 lbs of manure per pound of milk, but for cows producing 80 lbs of milk, the ratio drops to 1.9 lbs of manure/pound of milk.

On average, only 33% of the N and 40% of the P consumed by these cows was secreted in milk or retained in the body. Although these efficiencies appear low and can be increased, they are similar to the average N use efficiency (33%) of cereal grain production (Raun and Johnson, 1999). Efficiency of P use (g of P in milk/g of P consumed) is increased by: 1) not overfeeding (feed to just meet NRC requirements for absorbed P), 2) using highly available sources of P (e.g., monosodium phosphate vs. dical), and 3) obtaining high production (high yielding cows have higher P efficiency than low yielding cows). New technologies are being evaluated and developed that may improve P efficiency further. Efficiency of N use is increased by: 1) not over feeding protein, 2) using feeds with high protein digestibility (e.g., not using heat-damaged forages), 3) providing the proper balance of rumen degradable and undegradable protein, and 4) having high producing cows.

We must continue to strive to improve efficiency of N use (i.e., milk N output divided by N intake), but obtaining maximum efficiency may not be desirable or economically sustainable. In the US, cows are most commonly fed and managed as groups. Because of variation in nutrient require-

ments among cows and variation in nutrient supply (i.e., variation in feed composition), a diet balanced to meet the protein requirements of an average cow in a group will, on average, result in reduced milk production for that group although it will usually increase N efficiency. St-Pierre and Thraen (1999) using a simulation technique concluded that if all cows in the US were fed for maximum N efficiency, rather than maximum income over feed costs (and concomitantly lower N efficiency), it would cost the industry approximately $4/lb of reduced N excretion. Perhaps it would make more economic sense to put greater emphasis on proper crop fertilization practices and crop selection than on maximizing N efficiency of the cow.

Conclusions

The average lactating dairy cow produces about 140 lbs of manure/day of which approximately 85% is water. Replacing hay crop forage with corn silage significantly reduced the volume of urine excreted resulting in less total manure production. Cows fed diets with all the forage provided by corn silage would be expected to produce about 25 lbs/day less urine than cows fed diets with hay crops providing all the forage. Excretion of P and N via manure was mostly affected by intake of P and N respectively. Excretion of P via manure was not affected by forage type, but diets with high concentrations of corn silage relative to hay crop forages excreted less N in manure. Cows fed bmr silage also tended to excrete less N in manure than did cows fed conventional corn silages.

Acknowledgments

The new experiment discussed in this paper was supported by National Research Initiative Competitive Grant no. 2005-35206-15263 from the USDA Cooperative State Research, Education, and Extension Service.

References

EPA. 2003. National pollutant discharge elimination system permit regulation and effluent limitation guidelines and standards for concentrated animal feeding operations (CAFOs): Final Rule. Federal Register 68 (No. 29) 7175-7274 (Feb. 12).

Greenfield, T. L., R. L. Baldwin, R. A. Erdman, and K. R. McLeod. 2001. Ruminal fermentation and intestinal flow of nutrients by lactating cows consuming brown midrib corn silages. J. Dairy Sci. 84:2469-2477.

NRC. 1989. Nutrient Requirements for Dairy Cattle. 6th rev. ed. Natl. Acad. Sci, Washington DC.

NRC. 2001. Nutrient Requirements of Dairy Cattle. 7th rev. ed. Natl. Acad. Press, Washington DC.

Raun, W. R. and G. V. Johnson. 1999. Improving nitrogen use efficiency for cereal production. Agron. J. 91:357-363.

St-Pierre, N. R. 2001. Invited review: Integrating quantitative findings from multiple studies using mixed model methodology. J. Dairy Sci. 84:741-755.

St-Pierre, N. R. and C. S. Thraen. 1999. Animal grouping strategies, sources of variation, and economic factors affecting nutrient balance on dairy farms. J Anim Sci. 77 (Suppl. 2):72-83.

Tine, M. A., K. R. McLeod, R. A. Erdman, and R. L. Baldwin VI. 2001. Effects of brown midrib corn silage on the energy balance of dairy cattle. J. Dairy Sci. 84:885-895.

Weiss, W. P. and D. J. Wyatt. 2004. Macromineral digestion by lactating dairy cows: Estimating phosphorus excretion via manure. J. Dairy Sci. 87:2158-2166.

Weiss, W. P. and D. J. Wyatt. 2006. Effect of corn silage hybrid and metabolizable protein supply on nitrogen metabolism of lactating dairy cows. J. Dairy Sci. 89:1644-1653.

Table 1. Simple statistics describing the Holstein cows and diets used in the total collection digestion trials. Data are from 14 experiments with 55 dietary treatments (n = 232).

	Mean	SD	Minimum	Maximum
Cow characteristics				
Days in milk	183	57	67	272
Body weight, lbs	1331	141	906	1780
Dry matter intake, lbs/d	46.2	7.9	21.6	67.1
Milk yield, lbs/d	67.1	17.4	17.6	129.8
Diet characteristics				
Forage, % of DM	56	9	40	80
Corn silage, % of forage DM	64	35	0	100
NDF, % of DM	33.4	5.1	24.7	45.8
Crude protein, % of DM	16.8	1.6	10.5	20.9
P, % of DM	0.38	0.03	0.31	0.50

Table 2. Production and characteristics of manure from lactating Holstein cows. Data are from 14 experiments with 55 dietary treatments[a].

	Mean	SD	Minimum	Maximum
Daily excretion				
Wet feces, lbs.	94.8	20.9	38.9	155.8
Fecal DM, lbs.	15.6	3.3	7.0	27.0
Urine, lbs.	45.1	17.2	18.5	101.0
Manure[b], lbs.	139.9	30.4	59.6	225.1
N, g	385	85	179	613
P, g	47.4	13	18.7	86.7
Fecal composition				
DM, %	16.5	1.5	11.9	20.9
N, % of DM g/kg DM	2.79	0.5	1.7	4.42
P, % of DM g/kg DM	0.68	0.12	0.3	1.0
Urine composition				
N, % of wet	0.91	0.27	0.39	1.6
P, % of wet	0.0025	0.0004	0.0014	0.004
Manure composition				
DM[c], %	12.5	1	8.2	15.1
Urine, % of wet wt	31.7	7.8	16.5	62.4
N, % of wet	0.59	0.07	0.38	0.80
P, % of wet	0.077	0.017	0.028	0.12
N, % from urine	47.5	7.9	27.2	63.9
P, % from urine	1.1	0.5	0.4	4.4

[a] Number of observations = 232 except n = 202 for N data and n = 161 for P data.
[b] Manure = feces + urine.
[c] Manure DM was calculated using measured fecal DM percentage and assuming urine contained 4% DM.

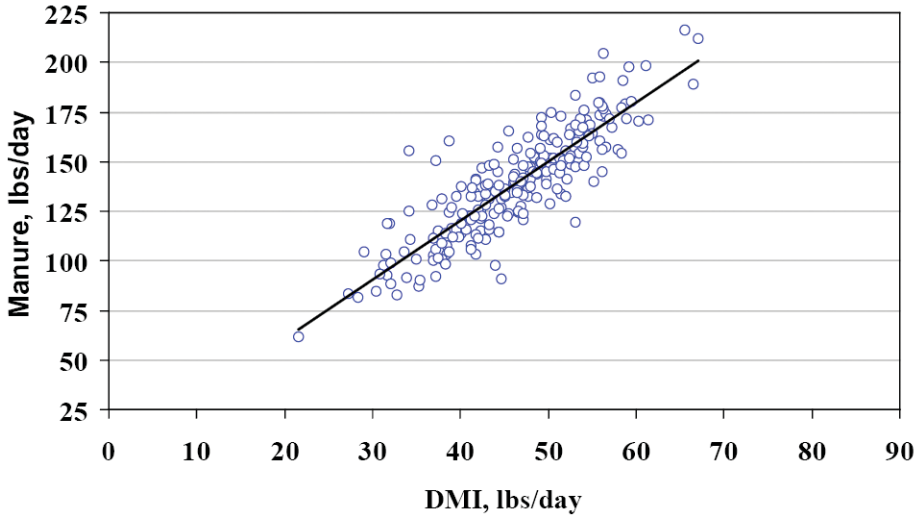

Figure 1. Relationship between dry matter intake and excretion of wet manure by lactating dairy cows. Wet Manure, lbs/day = 3.0 × DMI, lbs/day.

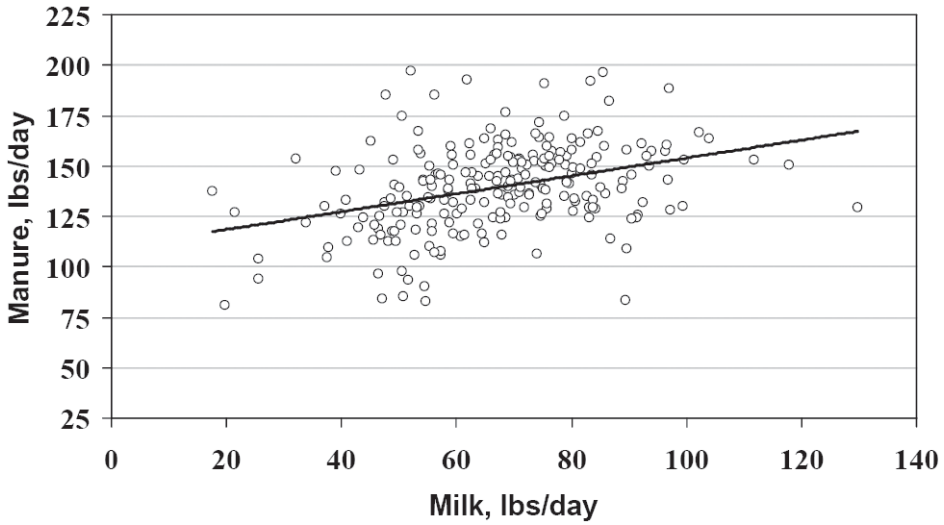

Figure 2. Relationship between milk yield and excretion of wet manure by lactating dairy cows. Wet manure, lbs/day = 100 + 0.6 × milk yield, lbs/day.