FACTORS AFFECTING MANURE EXCRETION BY DAIRY COWS[1]

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

Society is becoming 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.

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 have been assayed for N and P, therefore, the number of observations are 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 about 7% higher than the current U.S. average (2003 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 were 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 in some experiments. The

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concentration of crude protein (i.e., N x 6.25) 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.

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, kg	605	64	412	810
Dry matter intake, kg/d	21.0	3.6	9.8	30.5
Milk yield, kg/d	30.5	7.9	8.0	59.0
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

The average amount of manure (feces plus urine) produced daily by cows in this data set was about 64 kg (140 lbs.) and ranged from 27 to 102 kg/d (Table 2). The vast majority (87.5%) of manure was water. The excretion of urine averaged 20.5 L/d but ranged from 8.4 to almost 46 L/d. Excretion of wet feces averaged 43.1 kg/d. 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 more than 62% urine. On average, 2.2 kg of manure was produced for every 1 kg of milk produced.

Excretion of N via feces averaged 385 g/d and excretion of P averaged 47.4 g/d (Table 2). On average, one-half of the N excreted was via urine but almost all the P excreted was via feces. Only 33% of N and 40% of the P consumed by these cows was secreted in milk or retained in the body. Although these efficiencies are low and can be increased, they are similar to the average N use efficiency (33%) of cereal grain production (Raun and Johnson, 1999). The choice of ingredients used in diets for cows and the nutrient composition of diets have a major impact on the excretion of manure and manure nutrients. The efficiency of nutrient use (N and P) can be increased and the amount of manure produced can be decreased without adversely affecting milk production.

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, kg	43.1	9.5	17.7	70.8
Fecal DM, kg	7.1	1.5	3.2	12.3
Urine, L	20.5	7.8	8.4	45.9
Manure[b], kg	63.6	13.8	27.1	102.3
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, g/kg DM	27.9	5	17	44.2
P, g/kg DM	6.8	1.2	3	10
Urine composition				
N, g/L	9.1	2.7	3.9	16
P, g/L	0.025	0.004	0.014	0.04
Manure composition				
DM[c], %	12.5	1	8.2	15.1
Urine, % of wet wt	31.7	7.8	16.5	62.4
N, g/kg wet	5.9	0.7	3.8	8.0
P, g/kg wet	0.77	0.17	0.28	1.19
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.

FACTORS AFFECTING MANURE EXCRETION

The data base described above was used to evaluate major dietary (concentrations of forage, corn silage, NDF, CP, and P) and cow factors (dry matter intake (DMI) and milk production) that influenced the 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.

Manure Excretion

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. The relationship between DMI and manure production was much stronger than the relationship between milk yield and manure production

[1] Wet Manure, kg/d = 3.0 ($\pm$ 0.06) X DMI, kg/d (Figure 1)

[2] Wet manure, kg/d = 48.0 ($\pm$ 4.3) + 0.50 ($\pm$ 0.11) X milk yield, kg/d (Figure 2)

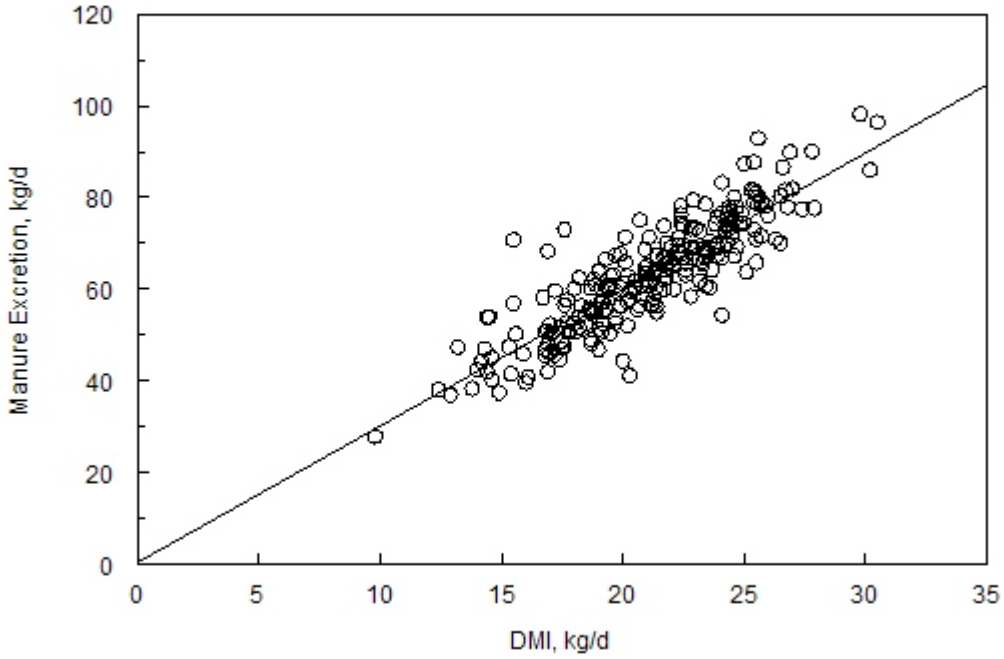

Figure 1. Relationship between dry matter intake and excretion of wet manure in lactating dairy cows.

Although manure excretion increased, on average, with increasing milk production, substantial variation is evident (Figure 2) meaning that increased milk production does not necessarily mean greatly increased manure production. Not unexpectedly, DMI was clearly the most important single factor affecting manure production, but actual manure excretion varied about ± 10 kg from predicted excretion at a specific DMI. To increase the precision of estimating manure excretion, models with DMI and additional independent variables were evaluated. To be evaluated, the factor had to have no significant ($P < 0.01$) correlation with DMI. The best fitting model was one that included DMI (kg/d) and the concentration of corn silage (CS, % of forage DM) in the diet:

[3] Wet manure, kg/d = 7.6 (± 3.7) + 3.0 (± 0.15) X DMI - 0.11 (± 0.03) X CS

Assuming no effect on DMI, cows fed a diet with no corn silage (all hay crop) would produce, on average, 11 kg/d more manure than would cows fed a diet with 100% of the forage as corn silage. At the average DMI of this database (21 kg) this is equivalent to a 16% reduction in manure excretion.

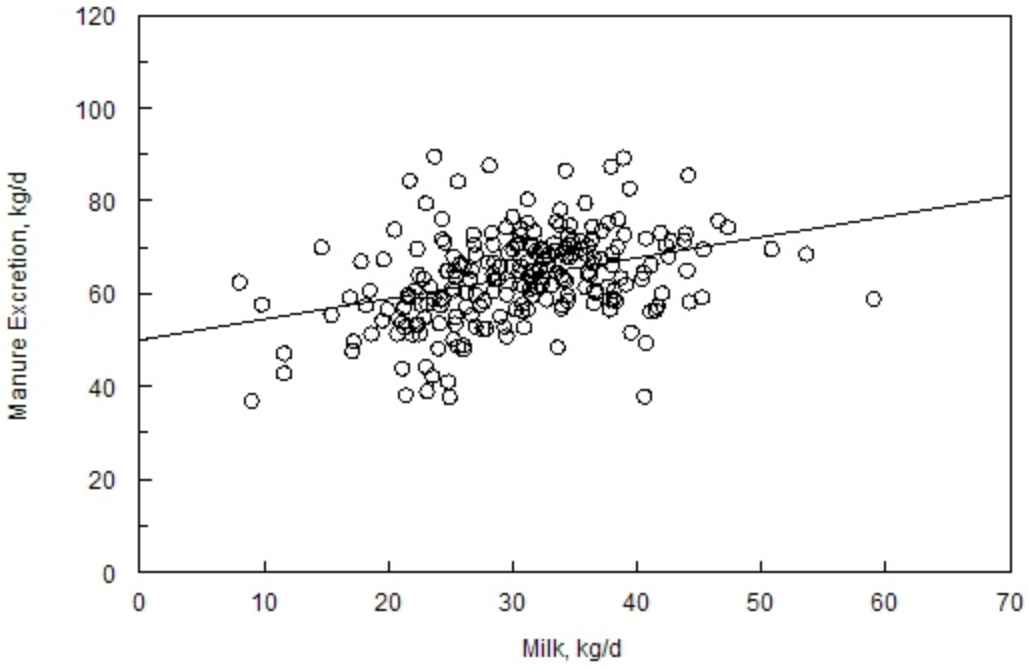

Figure 2. Relationship between milk yield and excretion of wet manure in lactating dairy cows.

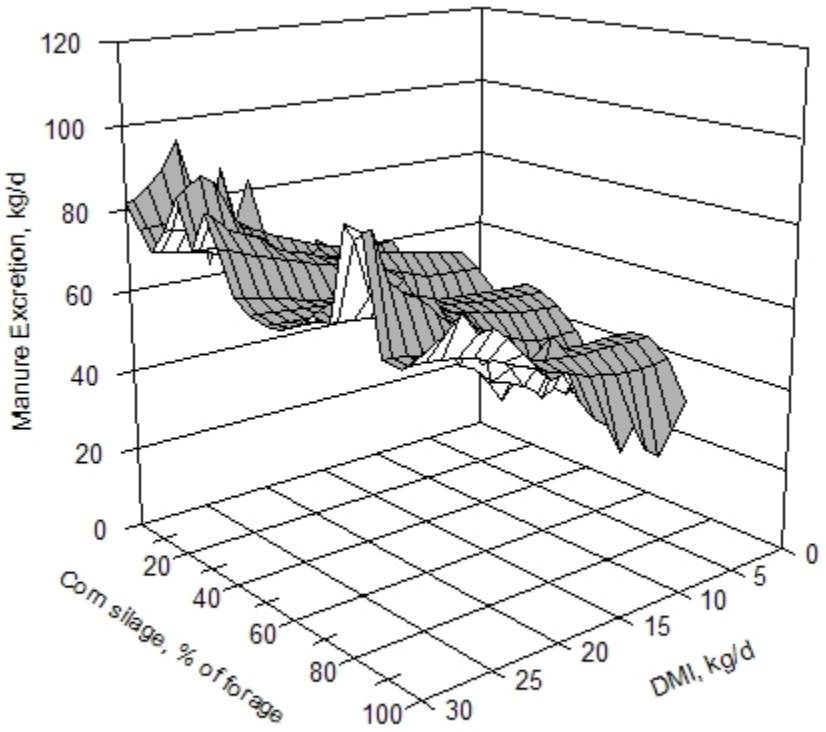

Figure 3. Relationship between DMI, corn silage in the diet, and excretion of wet manure by lactating dairy cows.

Excretion of Fecal DM

To better understand the relationships between manure production and dietary and cows factors, manure was partitioned into feces and urine. Excretion of fecal water was not related to any variable except DMI, therefore, 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 concentration of dietary NDF was associated with a 0.03 kg/d 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 0.0067 kg/d decrease in excretion of fecal DM. The concentration of dietary NDF and the proportion of forage that was 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 (kg/d) was strongly related to urine excretion but the percentage of forage as corn silage (CS) also was strongly related with urine excretion:

[4] Urine, L/d = 12.3 (± 3.1) + 0.72 (± 0.13) X DMI - 0.11(± 0.02) X CS (Figure 4)

Based on equation [4], the effect corn silage has on 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 11 L/d less urine than cows fed diets with hay crops providing all the forage. The cause of this is most likely caused by the increased concentration of potassium in hay crops compared with corn silage.

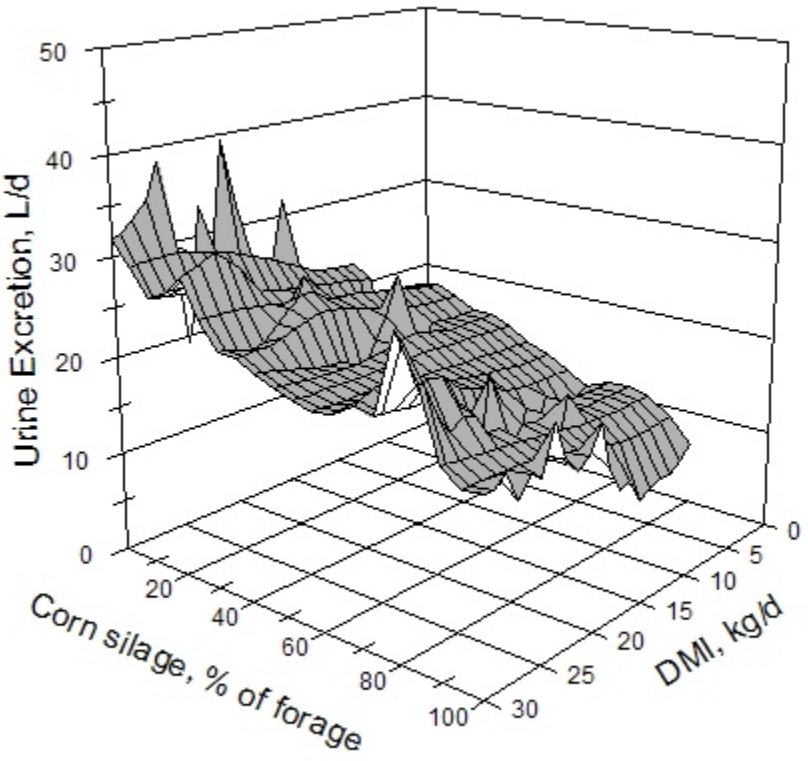

Figure 4. Relationship between urine excretion by lactating dairy cows, intake, and type of forage in the diet.

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 was 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:

[5] Manure P, g/d = -2.5 (± 4.1) + 0.64 X P intake, g/d

Excretion of N in manure was largely a function of N (or CP) intake (Figure 5). On average, as a 1 kg increase in CP intake was associated with a 0.6 kg increase in CP excretion, however, increased milk production at a constant DMI reduced N excretion:

[6] Manure N, g/d = 51 (± 19) + 0.63 (± 0.03) X N intake, g/d) - 0.94 (0.40) X Milk, kg/d

Based on this equation, if increased N intake results in increased milk production, the marginal efficiency of N utilization will increase. For example, if a cow consumes 21 kg of DM of a diet with 17% CP (2.72% N) and produces 30 kg of milk, N intake equals 571 g and expected excretion of N equals 382 g/d (67% of N intake is excreted in manure). If intake increases to 22 kg (17% CP) and production increases to 33 kg, N intake is 598 g and expected N excretion is 397 g (66% of N intake is excreted in manure). The only other factors tested that affected excretion of N in manure was the concentration of corn silage in the diet (% 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/d (7% of average N excretion in this data set). The effect corn silage had on manure excretion was via a reduction in fecal N excretion, increased corn silage was associated with increased excretion of N via urine (data not shown).

Brown Midrib Corn Silage and N Excretion

Corn silage made from brown midrib (bmr) hybrids usually have higher in vitro NDF digestibility and have lower lignin concentrations than silage made from conventional hybrids. Organic matter truly digested in the rumen and flow of microbial N from the rumen was increased when cows were fed bmr silage compared with silage from an isogenic hybrid, but total tract apparent digestibility of nutrients were largely unaffected by hybrid (Oba and Allen, 2000). In that experiment cows were fed for ad libitum consumption and DMI was higher for cows fed bmr silage. In another experiment in which DMI of cows fed bmr silage was restricted to that of cows fed the isogenic silage, total tract digestibility of most nutrients was higher with the bmr silage (Tine et al., 2001). The exception was CP which had a lower digestibility for bmr silage. In that study, excretion of N via urine was reduced (269 vs. 319 g/d) when bmr silage was fed, but excretion of fecal N was not affected by hybrid. Excretion of N in manure was numerically lower for cows fed bmr silage (480 vs. 522 g/d) but this variable was not analyzed statistically.

To explore the effect of bmr silage on N metabolism we recently 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. In situ NDF digestibility (48 h) was 59 and 50% for the bmr and conventional silage, respectively. Diets were 55% corn silage (either bmr or conventional) and 45% concentrate and contained either 14 or 17.5% CP. No interactions between hybrid and protein treatments were observed in the variables and only hybrid effects will be discussed in this paper. Cows fed the bmr silage tended ($P < 0.10$) to excrete less manure (69.8 vs. 72.9 kg/d) than cows fed the conventional hybrid. Hybrid (bmr vs. conventional) did not affect ($P > 0.10$) N intake (630 vs. 624 g/d), N digestibility (64.8 vs. 63.5%), urinary excretion of N (184 vs. 191 g/d) or fecal excretion of N (221 vs. 228 g/d), but excretion of N in manure tended ($P < 0.10$) to be lower for cows fed bmr (404 vs. 419 g/d) and N utilization for productive purposes (N excreted in milk and retained) was higher ($P < 0.05$) for cows fed bmr silage (225 vs. 208 g/d). These data in combination with the data from Tine et al. (2001) suggests that feeding bmr silage can reduce N excretion via manure.

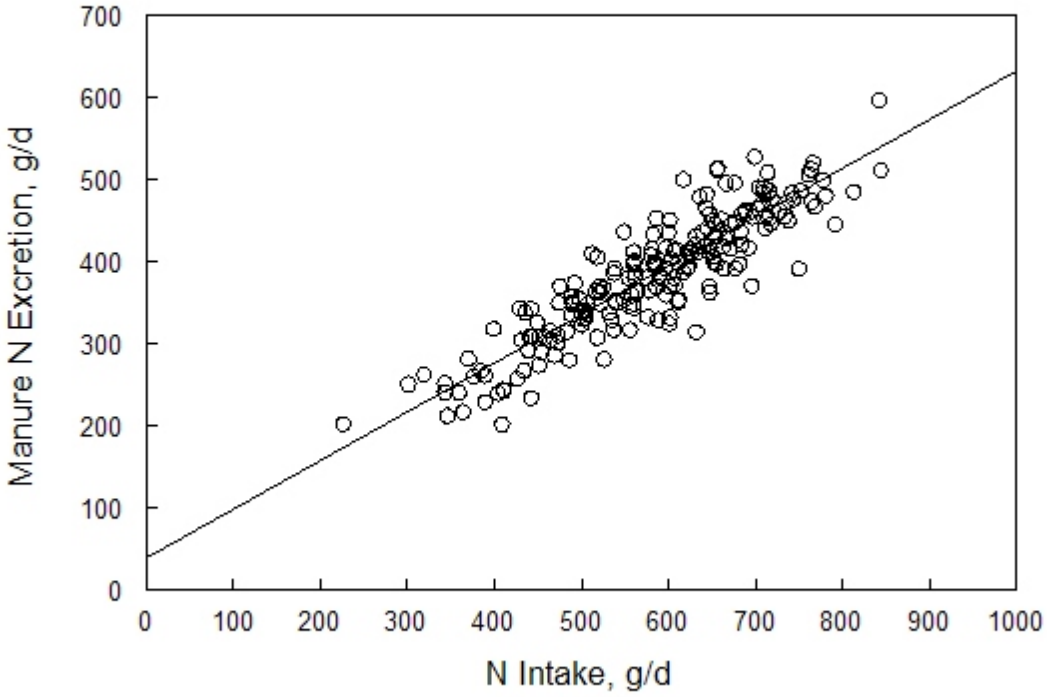

Figure 5. Relationship between N intake and excretion of N in manure (feces + urine) by lactating dairy cows.

CONCLUSIONS

The average lactating dairy cows produces about 64 kg 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 11 L/d 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.

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