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Article *in* Applied Engineering in Agriculture · January 2007

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Particle Size and Nutrient Distribution in Fresh Dairy Manure

D. Meyer, P. L. Ristow, M. Lie

Abstract. *Particle size was quantified in dairy manure from three different age groups; lactating cows, heifers, and calves. Manure was separated according to five different screen sizes: 2.0, 1.0, 0.5, 0.25, and 0.125 mm. The material on each screen was analyzed for Total Solids (TS), Nitrogen (N), Phosphorus (P), and Potassium (K). The majority of nutrients in the manure were found to be associated with particle sizes smaller than 0.125 mm, specifically 86% of N, 85% of P, and 99.8% of K. Furthermore, particle sizes smaller than 0.125 mm accounted for 46% of TS. Maximum expected removals with standard mechanical separators used on dairy farms would be 19% TS and 5% of N, 5% of P, and 0.07% of K excreted as fresh manure when 2.0-mm screen is used. Maximum anticipated removal when a double screen separator system is used is 31% of TS, 7% of N, 7% of P, and 0.09% of K excreted as fresh manure with both the 2.0- and 1.0-mm screens. Actual removal values under field conditions would vary depending on particle size and quantity of bedding used.*

Keywords. *Mechanical separation, Manure particle size, Appropriate technology, Separators, Waste management.*

Ford and Fleming (2002) suggested that the greatest single improvement to most mechanical separator test protocols would be the analysis of particle size distribution of raw manure. The profile of solids in the raw manure would allow for the selection of the most appropriate screen size. Four reports were identified by Ford and Fleming (2002) to have evaluated particle size distribution of separated solids. In those reports, particle size evaluations were conducted to illustrate screen efficiencies, but only three of them used actual manure. TS removal ranged from 47% to 59% for influent slurries with 3% to 8% TS (Ford and Fleming, 2002). Meyer et al. (2004) reported particle size distributions of separated solids and found influent particles in flushwater from a freestall dairy were from manure (feces and urine), bedding, and feed. The flushwater was not recycled from the dairy lagoon. Total solids retained on sieves of 2-, 1-, 0.5-, 0.25-, and 0.125-mm screens were 10.38%, 12.26%, 13.80%, 14.27%, and 18.28%, respectively, with 30.90% of influent solids passing through the 0.125-mm screen. None of the particle size studies reported the nutrient distribution for various particle sizes for either influent, effluent, or separated solids. Particle size and nutrient fractionation information are critical to identifying effective treatment technologies (Ford and Fleming, 2002; Masse et al., 2004). The minimum size of particle requiring removal will vary if N, P, K, or specific salts are of interest. The aim of this study was to quantify particle size and nutrient characteristics of manure from various classes of dairy animals.

Submitted for review in February 2006 as manuscript number BE 6329; approved for publication by the Biological Engineering Division of ASABE in October 2006.

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Material and Methods

Lactating dairy cows, replacement heifers, and post-weaned calves were enrolled in metabolism studies where feces and urine were collected. The four lactating cows had variable production rates at 40, 40, 45, and 25 kg day^{-1} (88, 88, 100, and 55 lb day^{-1}, respectively). Briefly, animals were brought into the metabolism room, urinary catheters were inserted, and animals were allowed to acclimate to their environment for 24 h. Animals were maintained in individual stanchions and fed ad libitum. The diets fed to all animals represent typical diets found on California dairy operations (table 1). Lactating animals received a total mixed ration consisting of coarsely chopped alfalfa, whole cottonseed, and concentrate mix (no ensiled feed used). Replacement heifers received alfalfa hay and calves were fed an alfalfa-corn processed pellet.

All animals were monitored regularly throughout the day. Feed and water intake were measured daily. Lactating animals were milked with a portable milking machine twice daily. Feces were collected when deposited. Urine was collected through indwelling urinary catheters. Parameters were measured for five consecutive days. Feed, feces, and urine were weighed, mixed, and sampled daily. Two sets of urine samples were taken. The first was acidified and the

Table 1. Daily feed intake.

Animal Class	Dry Matter (Kg day^{-1})	N (% DM Intake)	P (% DM Intake)	K (% DM Intake)
Lactating	24.57	2.83	0.43	1.31
Lactating	20.60	2.78	0.45	1.30
Lactating	19.42	2.73	0.42	1.25
Lactating	23.04	2.35	0.31	2.16
Heifer	7.81	3.71	0.28	1.62
Heifer	6.67	3.70	0.27	1.56
Calf	2.85	2.77	0.41	1.45
Calf	3.81	2.55	0.44	1.40
Calf	2.57	2.55	0.44	1.40

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second was not acidified. Acidified urine samples were used to measure urea-N and total kjeldahl-N. Samples were stored at -20°C for future analyses. Un-acidified samples were used for subsequent ammonia studies (James et al., 1999). Two sets of fecal samples were taken daily. The first was used for chemical determination. The second was stored fresh in sealed containers at -20°C for future analyses.

Both TS and VS analyses were conducted for feces and urine. Samples were handled according to Method 2540G with one alteration to use 180°C (356°F) as the highly mineralized samples were hygroscopic and required prolonged drying at 100°C (212°F) (APHA, 1992). Briefly, beakers were placed in a 180°C (356°F) drying oven for 4 h and then maintained at 100°C (212°F) prior to being placed in desiccators and reweighed. Total solids were calculated by the difference in the dry beaker weight with the sample and the dry weight of the empty beaker. Beakers were then ashed at 540°C (1000°F) for 4 h. Fixed solids were calculated by the difference between the ashed beaker weight and the dry weight of the beaker. Beakers were washed thoroughly, rinsed three times with de-ionized water, and dried in a 100°C (212°F) oven. Beakers were re-weighed after cooling in a desiccator prior to reuse. Nutrient analyses were done on fresh feces and urine samples. Total Kjeldahl nitrogen (TKN) (AOAC, 1990), P (Technicron autoanalyzer method N-4C; Kraml, 1966), K (atomic absorption spectrophotometry model #3030B; Perkin-Elmer, Norwalk, Conn.), urine urea N (Technicon autoanalyzer method N-1 C; Marsh et al., 1957), and pH were determined.

Route of nutrient excretion (urinary or fecal) was determined by multiplying the daily excretion of feces and urine by respective nutrient concentration divided by the sum of daily nutrient excretions. Four thawed fecal samples from each animal totaling approximately 15 to 20 g of dry matter were pre-weighed and introduced into a micro wet vacuum sieve used to separate particle sizes (Allen et al., 1984). A 10-cm (4-in.) Plexiglas column was divided into segments. Each segment was fitted with plastic screens (2-, 1-, 0.5-, 0.25-, and 0.125-mm openings). A reservoir box at the bottom of the column stored rinseate. Additionally, water was sprayed from the top of the column to rinse the sidewall of the column. Ten 1-min rinse cycles were used to slowly push samples up from each screen (water coming from the bottom of the column). The column drained 5 cm between rinse cycles into the reservoir box. After the final drain each screen was inverted and rinsed into a beaker. Beaker contents were rinsed into pre-weighed crucibles. Crucibles were dried and re-weighed to determine TS. The weight of TS less than 0.125 mm was calculated as the difference in the TS of the sample and the sum of the TS collected on all screens and includes all errors associated with measurements. The TS were scraped off crucibles, collected into glassine envelopes, and saved for nutrient analyses. Samples were pooled by sieve size and animal to amass sufficient sample size for nutrient analyses. Samples were taken to the Division of Agriculture and Natural Resources Analytical laboratory for nutrient analyses (N, P, K) for each particle size. Urine nutrients were included in calculations as 100% of the urine solids passed through the 0.125-mm sieve.

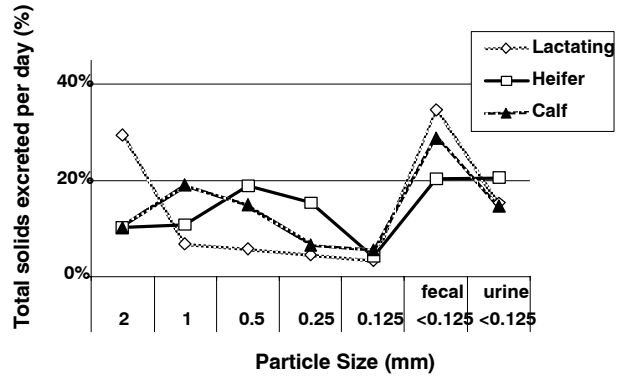

Figure 1. Total Solids distribution by dairy animal type.

Results and Discussion

Total Solids Distribution

Total solids (TS) distributions varied among three classes of dairy animal manure: lactating cow, heifer, and calf (fig. 1, table 2). Regardless of animal class, the largest amount of TS were found to be smaller than 0. 125 mm and the least amount of TS were found to be <0.25 and >0.125 mm, all other rankings of the size categories differed among the three animal classes. Variation in TS distribution across animal types was due to differences in feedstuff particle size and digestibility. Calves had the smallest particle size and most digestible feed while heifers had the largest particle size and least digestible feed.

The highest percentage of TS was found in the <0.125-mm category with 50% (±3.7), 41% (±6.9), and 44% (±1.4) for lactating, heifers, and calves, respectively (table 2). The second highest concentration of TS was different for all three manure classes with an average of 30% (±2.9) of TS associated with particles sizes greater than 2.0 mm for lactating cows, 19% (±1.1) of TS in heifer manure associated with particle sizes less than 1.0 mm and greater than 0.5 mm, and 19% (±0.8) of calf manure TS were associated with particles less than 2.0 mm and greater than 1.0 mm. The least amount of TS was represented by particles ranging from 0.249 to 0.125 mm with 3% (±1.4), 4% (±0.9) and, 6% (±1.0) for lactating cows, heifers and calves, respectively. The very high recovery of solids from lactating animals is believed to be a function of the high roughage, large particle size diet fed. Total solids distribution patterns are supported by both Wright (2005) and Powers et al. (1995). Wright (2005) reported data from one fecal pat from one cow and found 67% of totals fecal solids to be greater than 125 microns. Our data

Table 2. Particle size distribution of daily total solids excreted (%) by animal class.

Particle Size (microns)	Source	Lactating (s.d.) n = 4 (%)	Heifer (s.d.) n = 2 (%)	Calf (s.d.) n = 3 (%)
2000	Feces	30 (2.9)	10 (1.9)	10 (2.5)
1000	Feces	7 (1.6)	11 (0.6)	19 (0.8)
500	Feces	6 (1.1)	19 (1.1)	15 (0.8)
250	Feces	5 (0.6)	15 (9.7)	7 (1.9)
125	Feces	3 (1.4)	4 (0.9)	6 (1.0)
<125	Feces	35 (3.6)	20 (6.0)	29 (0.3)
<125	Urine	15 (2.1)	20 (0.9)	15 (1.2)

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show an average of 65% of fecal solids greater than greater than 125 microns. Powers et al. (1995) found cows fed a 14% crude protein (CP) diet had manure (feces + urine) total solids distributed as such; 22% of TS greater than 2.0 mm, 7.2% of TS between 1.99 and 1.0 mm, 8.2% on a 0.5-mm screen, and 60.2% smaller than 0.5 mm.

Nutrient Sources in Dairy Manure

Nutrients (N, P, K) were not distributed equally between feces and urine (fig. 2). Averaging the total pool of samples (fig. 2) found 41% N of fecal origin and 59% from urine with a standard deviation of ±11. We found 96% of P was associated with the fecal fraction while only 4% was from urine (s.d. ±8). Thirteen percent of the K was found in the feces with 87% associated with the urine (s.d.= ±9). These results corroborate with nutrient distribution research done over the past century by Duley (1919), Salter and Schollenberger (1939), Graves (1986), and Powell et al. (1999), which all cite similar distributions. Duley (1919), and Salter and Schollenberger (1939) appear in the literature as the gold standard to which subsequent distribution research is compared. They found 48% of N, 97% of P, and 30% of K were found in cattle feces and 52% of N, 3% of P, and 70% of K was found in the urine.

Nutrient distribution differed by animal class (fig. 3a, b, c). Nitrogen distribution was very similar between lactating cows and calves but N distribution in heifer manure components was 25% of N recovered in feces and 75% in urine. The high percentage of N recovered in heifer urine was due to a diet of alfalfa hay with N levels exceeding standard feeding recommendations for this age group. The partitioning of N in heifers is supported by Marini and Van Amburgh (2005) who found a replacement dairy heifer fed a high N diet had 29% N in the feces and 71% in the urine. Ten percent more P was present in calf urine than in lactating cow and heifer urine. The high percentage of total P in lactating cow feces is supported by similar findings by Knowlton et al. (2002). Calf feces also had more K than lactating cow and heifer feces, 24% as compared to 8% and 6%, respectively.

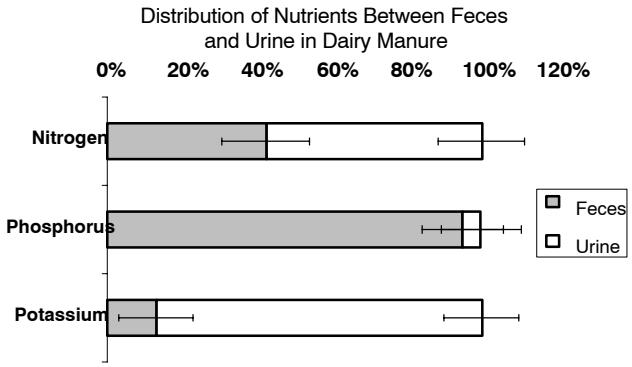

Figure 2. Nutrient distribution between feces and urine of dairy animals.

Nutrient Particle Size

The majority of nutrients in fresh dairy manure were associated with particle sizes smaller than 0.125 mm (fig. 4, table 3). Results show that 86% of N, 85% of P, and 99.8%

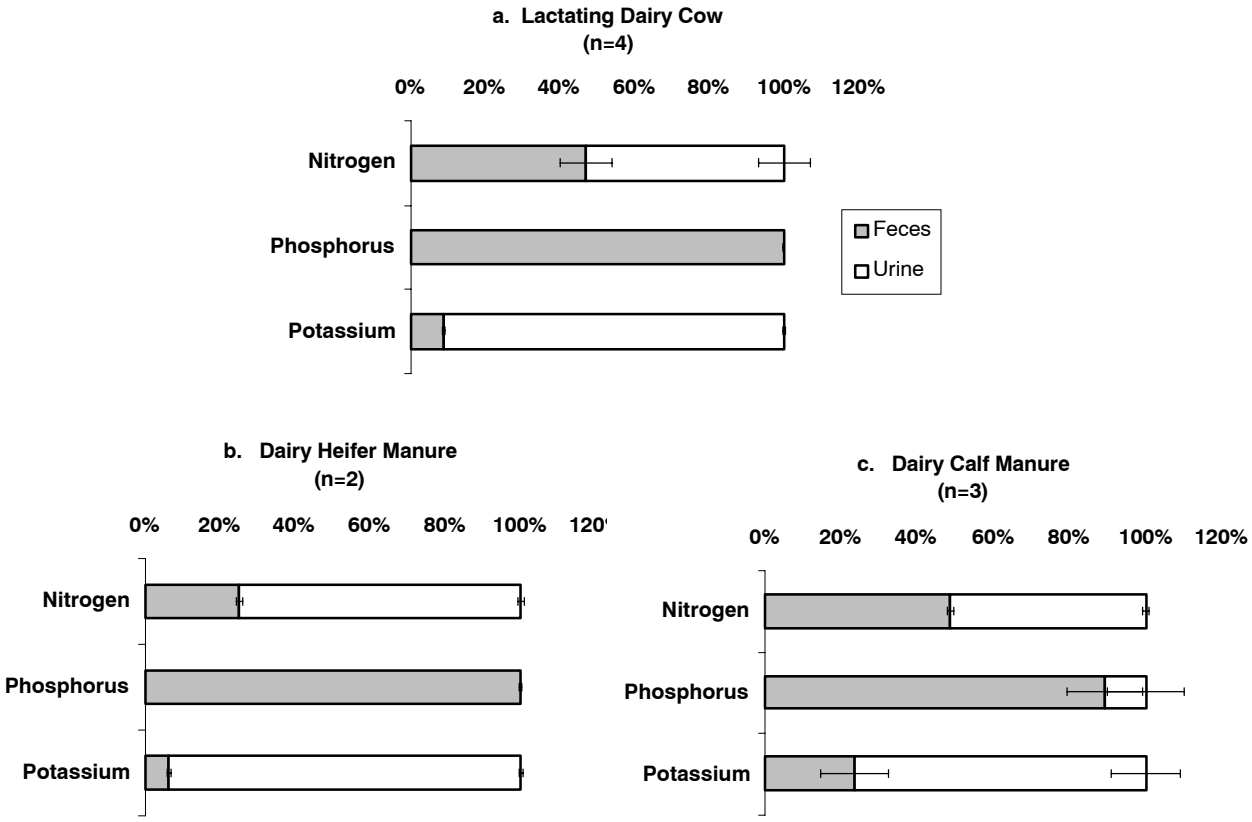

Figure 3. Nutrient distribution between feces and urine by animal class.

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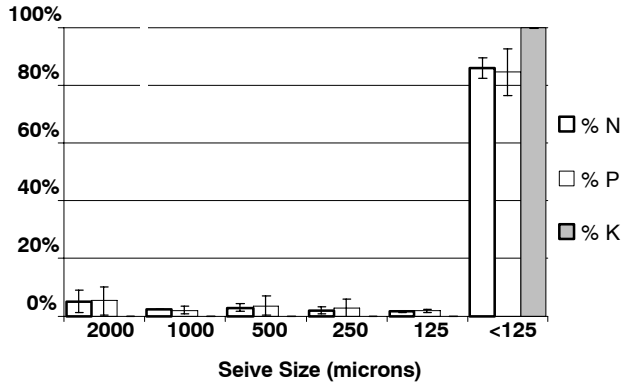

Figure 4. Distribution of N, P, and K in dairy manure (feces + urine).

of K passed through a 0.125-mm screen. Particle sizes greater than 2.0 mm held the next largest fraction of nutrients representing 5%, 5%, and 0.06% of N, P, and K, respectively. Powers et al. (1995) found that 90% of N and 95% of P were associated with particle sizes smaller than 0.5 mm.

The size of particle removed during a mechanical separation process is a function of screen size, influent solids (quantity and type), type of separator, and flow rate over the separator. Mechanical solids separation screens typically found on dairies in California are stationary incline screens with 1.5-mm screen openings. The smaller screen openings associated with the second phase of a two-phase separator system are 0.812 mm (0.032 in.). Total solids of influent on California dairies generally range from 0.5% to 2% with peak values as high as 5%. While field implementation of separators use much larger volumes than lab experiments, results from previous lab and field studies show that results are similar in the field and in the lab (Powers, 1995). Where commercial separators were evaluated, static separators with screen sizes of 1.52 mm (0.06 in.) were found to remove 13% to 19% of TS. A tilted plane screen having a 1-mm screen size coupled with a screw press consisting of a central screw conveyor housed in a cylindrical screen with a 1-mm screen size was found to remove 13.12% to 29.94% of TS, 4% to 7.6% of TN, and 7.9% to 15.5% of TP (Moller et at., 2002).

Vibrating wet sieve shakers with a screen size of 2.45 mm were found to remove 11% to 23% of TS (Holmberg et al., 1983; Auvermann and Sweeten, 1992). Applying these results to farm scale separation with 1.5-mm screens, we would estimate capturing a maximum of 19% of TS, 5% of N, 5% of P, and 0.07% of K based on the 2.0-mm screen data. Two-phase separator systems using both 2.0- and 1.0-mm screens would be estimated to capture a maximum of 31% of TS, 7% of N, 7% of P, and 0.09% of K. Actual removal values under field conditions will vary depending on TS in the influent and the quantity of bedding used.

Conclusion

The results of this study supports previous finding by Powers et al. (1995). The data suggest particle size and nutrient distribution of fresh dairy manure is not conducive to significant removal of TS or nutrients by mechanical separation systems. The fibrous solids removed can improve the management of liquid wastes, especially when used in irrigation systems; however, recovered solids have low fertilizer value as the vast majority of nutrients remain in the liquid fraction.

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Table 3. Distribution of N, P, and K by particle size and animal class.

Screen Opening (mm)	N[a]			P			K		
	L % (s.d.)	H % (s.d.)	C % (s.d.)	L % (s.d.)	H % (s.d.)	C % (s.d.)	L % (s.d.)	H % (s.d.)	C % (s.d.)
2.0	8.96 (3.2)	1.52 (0.16)	2.54 (0.73)	8.91 (5.5)	3.38 (0.57)	1.91 (1.2)	0.12 (0.06)	0.02 (0.00)	0.02 (0.00)
1.0	1.45 (0.57)	1.63 (0.18)	4.16 (0.37)	0.84 (0.54)	3.14 (0.24)	3.22 (0.64)	0.02 (0.01)	0.02 (0.00)	0.04 (0.01)
0.5	1.62 (0.66)	4.18 (0.41)	3.74 (0.36)	1.07 (0.72)	9.82 (0.82)	3.15 (0.73)	0.02 (0.01)	0.05 (0.01)	0.03 (0.01)
0.25	1.69 (0.39)	3.00 (2.1)	2.00 (0.58)	1.41 (0.83)	6.61 (4.7)	1.49 (0.26)	0.02 (0.01)	0.04 (0.03)	0.02 (0.01)
0.125	1.40 (0.54)	1.09 (0.23)	2.06 (0.36)	1.38 (0.38)	2.76 (0.63)	1.61 (0.32)	0.02 (0.01)	0.01 (0.00)	0.02 (0.01)
<0.125	84.88 (4.8)	88.58 (1.6)	85.5 (0.67)	86.73 (7.9)	74.3 (3.7)	88.63 (2.2)	99.81 (0.08)	99.86 (0.02)	99.87 (0.03)

[a] L = lactating cow, H = heifer, C = calf.

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