Manure Collection and Distribution on Wisconsin Dairy Farms

J. Mark Powell,* Daniel F. McCrory, D. B. Jackson-Smith, and H. Saam

ABSTRACT

Manure management plans require knowing the amount of manure produced, collected, and available for land-spreading. Whereas much information is available to calculate manure production, little is known about the types and amounts of manure actually collected on typical dairy farms. This study of 54 representative Wisconsin dairy farms showed significant regional, housing, and herd size differences in collection of manure from lactating cows (*Bos taurus*), dry cows, and heifers. Significantly ($P < 0.05$) less manure is collected in the hilly southwest (56% of total annual herd production) than in the undulating south central (72%) or the flat northeast (68%) regions. Collection of lactating cow manure is significantly ($P < 0.05$) lower from stanchion (66% of total annual production) than free-stall (89%) housing, and significant ($P < 0.05$) positive relationships were found between the number of lactating cows a farm keeps and the percentage manure collected. Average annual manure N (range of 116–846 kg N ha^{-1}) and P (range of 24–158 kg P ha^{-1}) loading rates in areas where manure goes uncollected was highest in unvegetated barnyards followed by vegetated and partially vegetated outside areas. Once uncollected manure was accounted for, average annual loading rates on cereal cropland ranged from 128 to 337 kg ha^{-1} of manure N, and from 45 to 139 kg ha^{-1} of manure P. Compared with adjacent cropland, the accumulation of uncollected manure has vastly increased soil test P, K, and organic matter levels in outside areas. Manure management on Wisconsin dairy farms with small to medium herds might require assistance in managing manure in outside confinement areas to reduce the risk of impairing surface and ground water quality.

In recent years, concern has grown about the potential soil buildup of manure nutrients and their loss to ground water, lakes, and streams (USEPA, 2003). These water quality issues have now been joined by heightened awareness of the potential for livestock operations to emit pollutants into the atmosphere, which can adversely affect air quality and contribute to nutrient enrichment and acidification of land and surface water resources (NRC, 2003). To respond to these concerns, federal and state agencies have increasingly focused regulations on the amount and timing of manure application to cropland, especially on large concentrated animal feeding operations (CAFOs).

Policymakers face the challenge of formulating regulations that limit environmental risk without unduly curtailing a farmer's ability to effectively manage manure under diverse biophysical and socioeconomic conditions. The current regulatory focus is on large livestock operations, under the assumption that they produce the most manure and therefore pose the greatest environmental risk. It is becoming increasingly evident, however, that farms of all sizes can generate negative environmental impacts, and that confinement areas, such as barnyards and feedlots, may pose high environmental risk (Wright, 2003; USEPA, 2004). Under new CAFO guidelines (USEPA, 2003), a dairy farm may be designated as either a medium-size CAFO (200–699 mature cows) if manure runoff, such as that from barnyards or other denuded or partially denuded areas, is directed toward surface water; or a small CAFO (<200 mature cows) if the farm is deemed to be a significant polluter of surface waters.

A recent study (Saam et al., 2005) of approximately 800 Wisconsin dairy farms showed that although most dairy farms have sufficient cropland for spreading manure, there is a large and regionally variable "manure gap" between cropland areas available for manure application and the cropland area that actually receives manure. For example, dairy farmers in the northeast spread manure on only 23% of their total operated cropland area vs. 30% in the central and 44% in the southwest regions of the state. Farmers' inability to use a greater proportion of their cropland area for manure spreading may be due to various factors, such as (i) the presence or absence of manure storage facilities; (ii) labor availability and machinery capacity for manure spreading; (iii) the amount of manure actually collected and, therefore, that needs to be spread on cropland; (iv) variations in the manure "spreading window," or days that manure can be spread given regional differences in weather and soil conditions; and (v) distances between where manure is produced and fields where manure is applied (Nowak et al.,1997). Manure spreading is also related to land ownership; as the percentage ownership of cropland operated by a farmer increases, so does percentage of operated cropland that receives manure (Saam et al., 2005).

The development of manure management plans requires knowledge about the amount of manure produced and collected on livestock farms. Various approaches are available to estimate manure nutrients excreted by dairy cattle (e.g., MWPS, 2000). No information exists, however, on actual manure collection practices on typical dairy farms, so assumptions are made about how much manure is collected and how average collection values are used. For example, in recent national assessments of the ability of croplands to assimilate manure

J.M. Powell, USDA-ARS, Dairy Forage Research Center, 1925 Linden Dr. West, Madison, WI 53706; D.F. McCrory and H. Saam, Dep. of Soil Science, Univ. of Wisconsin, 1525 Observatory Dr., Madison, WI 53706; and D.B. Jackson-Smith, Dep. of Sociology, Social Work and Anthropology, Utah State Univ., 216 H Old Main Building, Logan, UT 84322. Received 11 Dec. 2004. *Corresponding author (jmpowel2@wisc.edu).

Published in J. Environ. Qual. 34:2036–2044 (2005).
Technical Reports: Waste Management
doi:10.2134/jeq2004.0478

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

Abbreviations: AMC, apparent manure collection; AM_N, apparent manure nitrogen; AM_P, apparent manure phosphorus; CAFOs, concentrated animal feeding operations; CRP, Conservation Reserve Program; NE, SC, and SW, northeast, southcentral, and southwest regions of Wisconsin; PPB, partial phosphorus balance; STK, soil test potassium; STP, soil test phosphorus.

Table 1. Sampling framework based on partial P balance of dairy farms.†

Partial P balance (PPB)‡			No. of dairy farms	
Category	Range	Description	*n*	% of sample farms
Low	0–0.80	manure P insufficient to meet crop P requirement	278	41
Medium	0.81–1.20	manure P meets crop P requirement	258	38
High	>1.20	manure P exceeds crop P requirement	143	21

† Adapted from Saam et al. (2005).
‡ PPB = Total manure P − P removal by cropping.

nutrients (Kellogg et al., 2000; Gollehon et al., 2001), the authors assumed that 80% of the manure excreted on confined dairy operations is collected, and that 40 and 85% of manure N and P collected from milk cows and 30 and 85% of manure N and P collected from dairy heifers would be available for crop uptake. A shortcoming of these national studies was that the authors considered only an "average" confined dairy operation, excluding the probable diverse manure production and collection practices on dairy farms in the USA. A recent national study (USDA, 2004) of nutrient management on U.S. dairy farms showed that most (53%) dairy farms use stanchions as their primary type of housing for lactating cows, followed by free-stalls (31%). The use of stanchions and associated gutter cleaners and alley scrapers to remove manure from housing are used on 81% of the farms in the Midwest, and 90% of the farms in the Northeast.

Whereas estimates of manure N and P excretion are first-steps in developing manure management plans, manure collection information is needed to not only estimate cropland requirements for effective manure recycling, but also, and perhaps more importantly, to identify potential "hot-spots" on a farm where uncollected manure may result in soil nutrient buildup and environmental damage. The objectives of this study were to determine the type and amount of manure N and P excreted, collected, and uncollected on typical Wisconsin dairy farms; to estimate collected manure N and P loading rates on cropland; to estimate uncollected manure N and P loading rates in outside livestock access areas, and the impact these loading rates have on soil chemical properties; and to elicit farmer feedback on management of the outside areas they use for their dairy cattle.

METHODS AND MATERIALS

Farm Selection

Dairy farms were selected using a three-step procedure. First, a subset of 270 dairy farms was selected from a representative pool of 804 respondents to the 1999 Wisconsin Dairy Farm Survey (Buttel et al., 1999). The subset of farms included (i) respondents who reported complete data on livestock inventories and cropping patterns; and (ii) those located in the 12 principal dairy counties of Wisconsin. These counties fall within three distinct biophysical regions: (i) the hilly, southwest (SW) region; (ii) the undulating southcentral (SC) region; and (iii) the relatively flat northeast (NE) region. The SW region is characterized by well-drained silt loam soils, the NE has less permeable clay loam and loam soils, and the SC region has physical characteristics somewhat intermediate to those of the SW and NE (Hole, 1976). Second, farms within each region were stratified into one of three partial P balance categories (PPB; Table 1). Third, farms were randomly selected within each region from each of the three PPB categories. These farms were contacted by phone and asked to participate in the study. Phone calls were made until 18 farms (6 within each PPB stratum) from each region agreed to participate in the study. This stratified random sampling provided a total of 54 farms distributed across the major soil types, watersheds of impaired waterbodies, and dairy counties of Wisconsin (Fig. 1). These participating farms had herd size and cropping pattern characteristics (Table 2) similar to the general dairy farm population in these regions (Jackson-Smith et al., 2000).

The Survey

Initial farm visits and data collection were conducted from mid-September through mid-December 2002. A survey instrument was designed to compile an overall picture of each farming operation including herd size, cropping patterns, livestock facilities, management practices, and motivations and goals related to feed, fertilizer, and manure management. Before conducting the first series of on-farm visits, previsits were conducted on three farms of varying herd sizes and management techniques to further refine the survey instrument.

Manure Collection

During the interview, farmers were asked the number of hours their animals spent outside daily. Outside areas were

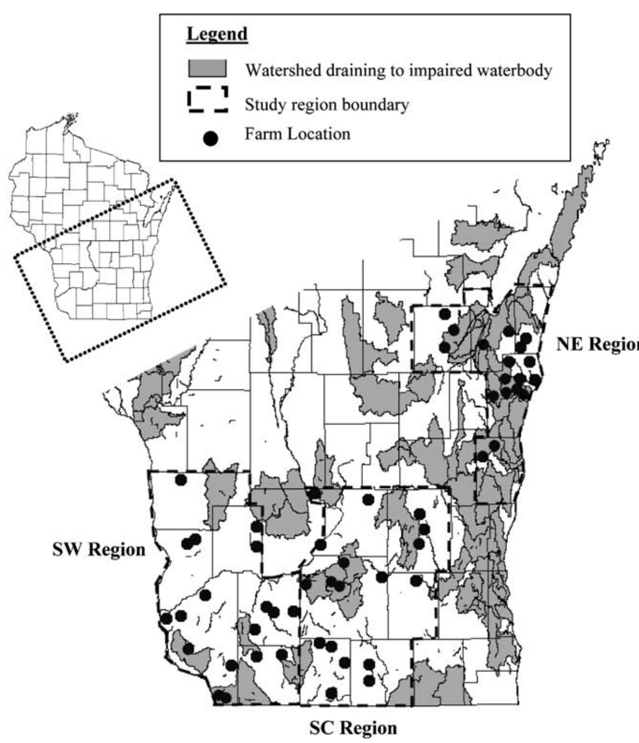

Fig. 1. Regional, county, and watershed location of study dairy farms in Wisconsin.

Table 2. Regional dairy herd and cropping characteristics of 54 dairy farms in Wisconsin.

	Regions			
	SW	SC	NE	All
Production components	n = 18 farms	n = 18 farms	n = 18 farms	n = 54 farms
	% of n farms			
Herd size				
1–49 cows	31	26	16	25
50–99 cows	56	53	68	59
100–199 cows	0	10	5	6
200+ cows	13	11	11	10
	no. of animals farm^{-1}			
Animal type				
Lactating cows	49 (11–270)†	53 (23–480)	52 (32–387)	52 (11–480)
Dry cows	9 (2–50)	10 (0–75)	8 (3–46)	9 (0–75)
Young heifers	14 (0–30)	20 (5–173)	15 (5–145)	15 (0–173)
Mature heifers	20 (0–55)	28 (5–247)	35 (0–245)	28 (0–247)
	ha farm^{-1}			
Land use				
Total operated cropland	65 (15–257)†	90 (38–442)	82 (30–339)	80 (15–442)
Corn grain	14 (0–69)	30 (0–138)	12 (0–54)	15 (0–138)
Corn silage	5 (0–108)	11 (0–130)	15 (6–132)	11 (0–132)
Soybean	0 (0–26)	0 (0–300)	0 (0–53)	0 (0–300)
Alfalfa	22 (4–99)	25 (8–112)	26 (13–109)	25 (4–112)
Small grain	0 (0–13)	0 (0–16)	0 (0–61)	0 (0–61)
Pasture	17 (0–52)	4 (0–75)	1 (0–6)	4 (0–75)
Conservation Research Program, fallow	0 (0–23)	0 (0–14)	0 (0–53)	0 (0–53)
Vegetated outside areas‡	7.7 (2.0–43.6)	6.3 (1.3–11.1)	1.9 (1.4–11.0)	6.5 (1.3–43.6)
Partially vegetated areas§	1.1 (0.5–1.7)	2.8 (0.7–5.5)	2.4 (0.8–2.9)	2.0 (0.5–5.5)
Unvegetated barnyards	0	1.0 (0.4–4.2)	0.7 (0.4–3.4)	0.7 (0.4–4.2)

† Median (minimum − maximum).
‡ Outside areas used specifically for activities such as exercise and holding dairy cattle (not contributing significantly to forage intake).
§ Feed bunks areas within vegetated areas.

defined as areas used by farmers to exercise, hold, or rest their livestock, and where manure was not collected. Farmers delineated three types of outside areas where they keep dairy cattle for various periods of time on a seasonal basis: vegetated, partially vegetated (feed bunk areas), and unvegetated (barnyards). Farmers distinguished vegetated and partially vegetated outside areas as separate from pastures in that they were viewed as cattle holding and/or feeding areas and not significant sources of forage.

Time spent outside was delineated by animal type (lactating cows, dry cows, young heifers [<7mo], and mature heifers [>7 mo]), season (spring, summer, fall, and winter), and location (vegetated, partially vegetated, and unvegetated areas). Farmers were then asked to define the approximate date each season starts and ends. This information was used to calculate apparent manure collection (AMC) fractions as shown in Eq. [1].

$$\text{AMC} = 1 - \Sigma\, D_pY_p + D_sY_s + D_fY_f + D_wY_w \quad [1]$$

The term AMC represents the apparent manure collection fraction for an animal type (lactating cows, dry cows, young and mature heifers); D represents time spent daily in outside areas (fractional days), as reported by farmers during spring (p), summer (s), fall (f), and winter (w); and Y represents a season's length (fractional year) as reported by farmers.

Annual manure N and P excretions by the herd on each dairy farm were calculated by summing the products of the number of each animal type by respective annual manure N and P excretions as shown in Eq. [2] and [3].

$$\text{AMN} = \Sigma\, [(\text{LC})(\text{LC}_n)] + [(\text{DC})(\text{DC}_n)] + [(\text{YH})(\text{YH}_n)] + [(\text{MH})(\text{MH}_n)] \quad [2]$$

$$\text{AMP} = \Sigma\, [(\text{LC})(\text{LC}_p)] + [(\text{DC})(\text{DC}_p)] + [(\text{YH})(\text{YH}_p)] + [(\text{MH})(\text{MH}_p)] \quad [3]$$

The terms AMN and AMP represent annual amounts of manure N and P, respectively, excreted by the dairy herd; LC, DC, YH, and MH are numbers of lactating cows, dry cows, young heifers, and mature heifers, respectively; and LC_n, LC_p; DC_n, DC_p; YH_n, YH_p; and MH_n, MH_p are annual manure N and P excretions (kg) of 136 and 30.3 for a 635-kg LC, 83 and 14.6 for a 635-kg DC, 13 and 1.5 for a 113-kg YH, and 38 and 5.1 for a 340-kg MF (MWPS, 2000).

The amount of manure N and P collected from each herd was determined by summing the products of AMC fractions times AMN and AMP. The difference between annual herd manure N and P excretion and collection was assumed deposited in outside areas.

Manure Nitrogen and Phosphorus Application to Cropland

The manure N and P collected by each operation were allocated to the land areas used for corn (*Zea mays* L.), small grain, and hay production. In some cases, several adjustments were made. Eight farms reported manure export; seven estimated export of <25%, and one estimated export of between 50 to 75% of annual herd manure production. For these farms, annual gross manure N and P collections were reduced by the upper percentages (25 and 75%) of the annual herd manure production that were estimated to have been exported. Two farms reported importing sludge. No estimates were made of the amounts of sludge imported and land-spread. For all farms, collected manure N was reduced by 30%, the typical N loss during manure handling and storage (MWPS, 2001). No losses of collected manure P were assumed. Finally, the amount of corn land potentially available for manure spreading on each farm was determined using Eq. [4].

$$\text{Corn land area available for manure application} = \text{Corn} - (0.33 \times \text{Alf}) \quad [4]$$

Corn in Eq. [4] includes corn grain and silage land (ha), and Alf equaled alfalfa (*Medicago sativa* L.) land (ha). This adjustment was done to account for N available from preceding alfalfa. The N accumulated under a good alfalfa stand can often provide the N needed for a corn crop following it in rotation (Bundy et al., 1994). In Wisconsin, alfalfa is usually grown for 3 yr followed by corn.

During the interview, farmers were asked about management of outside areas. Outside areas on some farms (based on accessibility) were visited and measured using a hand-held global positioning system. Soil samples were taken to the 0- to 25-cm depth with a stainless steel auger at approximately 10-m intervals along a randomly placed transect that traversed the outside area center, established visually. An average of 10 soil samples per outside area were analyzed for pH (water), organic matter (loss on ignition), and Bray-1–extractable (plant-available) P and K according to procedures at the Soil and Plant Analyses Lab, University of Wisconsin-Madison (Soil, Plant Analysis Laboratory Services, 2004).

Statistics

The farms that participated in this study represented the diversity of the Wisconsin dairy industry. Farms, therefore, encompassed a very wide range of herd size, composition, and cropping systems (Table 2); manure land application rates (Tables 5 and 6); and soil test values (Table 7). Because of this diversity and the relatively small sample size, data medians and minimum and maximum values have been reported, unless stated otherwise. The median provides a better estimate of central tendency than the mean for data sets that are skewed due to small sample size, but for which a normal population distribution might be legitimately assumed. Where relevant, significant ($P < 0.05$) differences among data least square means were delineated using the pdiff method of the general linear model (SAS Institute, 1990).

RESULTS AND DISCUSSION

Farm Characteristics

As already determined in larger-scale studies of the Wisconsin dairy industry (Jackson-Smith et al., 2000), most (60%) dairy farms in this study were of moderate size, milking between 50 and 100 cows, with a median herd size of 52 lactating cows (Table 2). The highest percentage (21%) of farms having greater than 100 cows were found in the SC part of the state, followed by the NE (16%) and the SW (13%). The most polarized size distribution of dairy farms occurred in the SW.

Total operated cropland ranged from 15 to 442 ha farm^{-1} with a median of 80 ha farm^{-1} (Table 2). Although all farms ($n = 54$) grew alfalfa, most (91%) grew corn silage and corn grain (87%). Soybean [*Glycine max* (L.) Merr.] was cultivated on 21% of all farms (mostly in the SC part of the state) and small grains were cultivated on 18% of all surveyed farms (mostly in the NE). Approximately one-half of the total cropland area on these Wisconsin dairy farms was devoted to the forages alfalfa and corn silage. However, there were distinct regional differences in the relative amount of land devoted to each forage type. Farmers in the SC and NE regions devoted 30 to 36% of their forage land to corn silage, but farmers in the SW devoted only 18%. Likewise, there were regional differences in the relative proportion of corn land harvested as silage. In the NE, 56% of the total corn land was harvested as silage, followed by SC (26%) and SW (26%). Regional differences in corn silage production could have been due to topography and greater risk of erosion, especially in the SW. The risk of soil loss due to water erosion from the relatively flat landscapes of the NE is not as severe as in the more undulating regions of the SC, and especially the hilly SW region of Wisconsin. Approximately one-fourth of the farmland area in the SW was devoted to pasture, fallow, or land in the conservation reserve program (CRP).

Vegetated, partially vegetated, and unvegetated outside areas occurred in each region, except for unvegetated barnyards absent among participants in the SW region. Although vegetated areas were the largest outside areas used by farmers in the SW and SC region, partially vegetated areas were the largest outside areas used by livestock in the NE, perhaps indicating a greater use of outside feed bunks in the NE than in other regions of Wisconsin.

Manure Production and Collection

On all studied farms, annual manure N excretions ranged from approximately 2.0 to 83.0 Mg farm^{-1} and manure P excretions from 0.4 to 17.1 Mg farm^{-1} (data not shown), depending primarily on livestock inventories. Highest total manure N and P production occurred in the SC and NE regions, where dairy herds were larger than in the SW region (Table 2). Manure nutrients excreted by lactating and dry cows in our sample accounted for roughly 85% of total N and 90% of total P excreted by the whole dairy herd, and this did not differ much by region. The manure excretion values used in this study (MWPS, 2000) may be slightly lower than newly developed and soon to be published values (J. Harrison, personal communication, 2005).

The study revealed great variation in manure collection rates on dairy farms, depending on herd size and composition, housing type, and the time dairy cattle spend in outside areas. Of all farms ($n = 54$), only 24% reported total collection of the manure excreted by lactating cows, 15% collected all manure from dry cows, 65% collected all manure from young heifers, and 18% collected all manure from mature heifers. There were, however, distinct regional differences in the type and relative amount of manure collected. Highest manure collection from lactating cows occurred in the NE and SC, and lowest in the SW region (Table 3). Many farms, especially in the SW, kept dry cows and heifers outside year-round, and no manure was collected from these outside areas. Because manure collection was positively related to herd size (Fig. 2), the proportion of cows under various manure collection regimes did not match the share of farms. For example, although only 24% of farms in this study collected all lactating cow manure, these farms represented approximately one-half of all lactating cows in the sample. The majority of lactating cows in the SC and NE were kept in a total collection situation, while the majority of dry cows and mature heifers in all three regions were raised in a partial collection situation.

On average, 65% of the total manure produced on Wisconsin dairy farms was apparently collected (Ta-

Table 3. Regional farm and animal type differences in manure collection on Wisconsin dairy farms.

			Percentage of manure collected, by category					
	Sample size		Total collection		Partial collection		No collection	
Animal type	Farms	Animals	Farms	Animals	Farms	Animals	Farms	Animals
	n		%					
SW region								
Lactating cows	18	1215	11.1	39.8	88.9	60.2	0.0	0.0
Dry cows	18	257	11.1	23.7	66.7	51.8	22.2	24.5
Young heifers	16	269	43.8	43.9	31.3	29.4	25.0	26.8
Mature heifers	17	411	17.6	21.2	47.1	32.6	35.3	46.2
SC region								
Lactating cows	18	1653	33.3	56.0	66.7	44.0	0.0	0.0
Dry cows	18	334	27.8	36.8	66.7	62.3	5.6	0.9
Young heifers	18	583	66.7	77.9	22.2	17.8	11.1	4.3
Mature heifers	18	1043	33.3	50.0	50.0	34.7	16.7	15.3
NE region								
Lactating cows	18	1508	27.8	55.5	72.2	44.5	0.0	0.0
Dry cows	18	217	5.6	2.8	83.3	89.4	11.1	7.8
Young heifers	18	455	88.9	87.9	11.1	12.1	0.0	0.0
Mature heifers	17	911	5.9	7.7	76.5	82.0	17.6	10.3
All regions								
Lactating cows	54	4376	24.1	51.3	75.9	48.7	0.0	0.0
Dry cows	54	808	14.8	23.5	72.2	66.2	13.0	10.3
Young heifers	52	1166	67.3	83.4	21.2	8.3	11.5	8.3
Mature heifers	52	1965	19.2	34.5	57.7	63.3	23.1	2.2

ble 4), which differs considerably from the average 80% collection assumed in the national study (Kellogg et al., 2000). There were significant ($P < 0.05$) regional, housing type, and herd class differences in manure collection (Table 4). Manure collection in the SW (56% of total herd manure) was significantly ($P < 0.05$) lower than in the SC (72%) region of Wisconsin. Of all study farms in each region ($n = 18$ farms region^{-1}), there were 10 farms (55%) in the SW, 6 (33%) farms in the SC, and 7 (39%) farms in the NE region that collected <60% of their herd's annual manure N and P production.

The collection of lactating cow manure (which accounts for 75–80% of total herd manure N and P) was related to housing type and herd size (Table 4). Farms that were using free-stall housing collect significantly ($P < 0.05$) more (89%) lactating cow manure than farms using stanchions (66%). All 13 dairy farms that reported total manure collection used free-stall housing. Seven

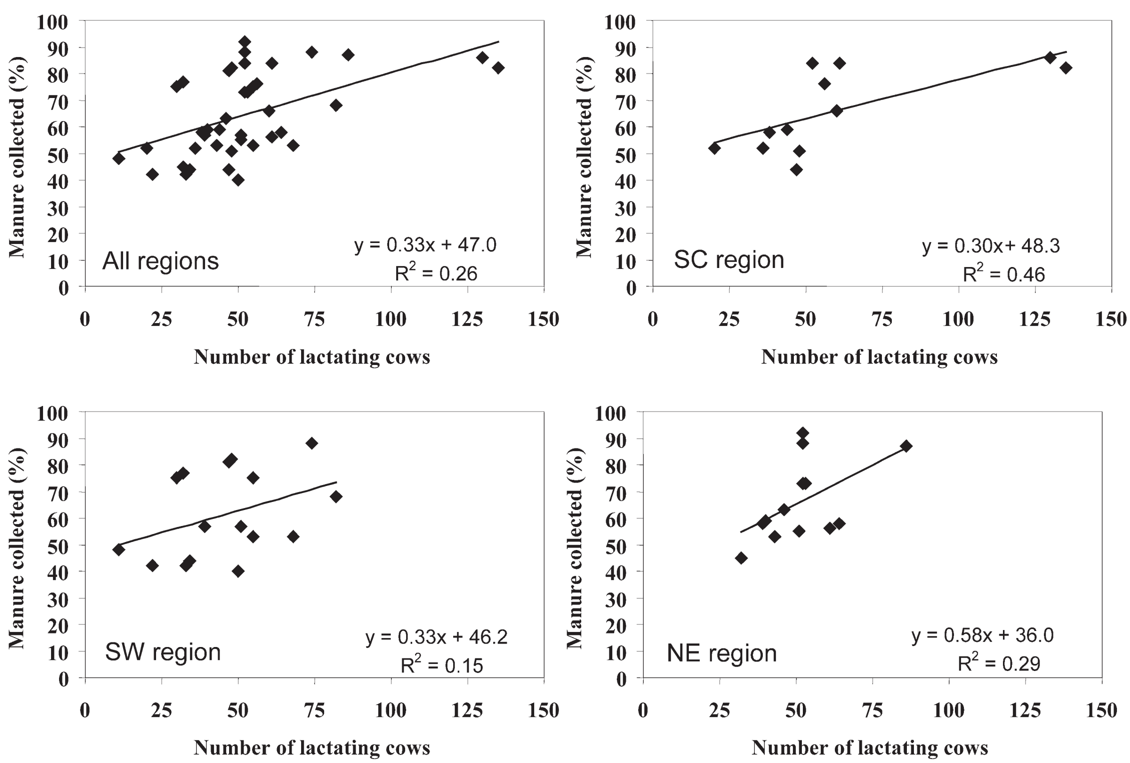

Fig. 2. Relationships between lactating cow herd size and apparent manure collection in three regions of Wisconsin.

Table 4. Regional, housing type, and herd class differences in manure collection on Wisconsin dairy farms.

Category	Subcategory	Mean (SD)
		% Total manure N and P collected
Region	SW (18)†	56 (22.9) b‡
	SC (18)	72 (21.8) a
	NE (18)	68 (21.5) ab
		% Total lactating cow manure N and P collected
Housing type	freestall (13)	89 (16.5) a
	stanchion (34)	66 (18.9) b
Herd class	<50 cows (20)	57 (12.6) c
	50–99 (24)	76 (18.2) b
	100–199 (6)	95 (5.1) a
	200+ (4)	100 (0) a

† Farm numbers in parentheses.
‡ Within a subcategory, means followed by different letters are significantly ($P < 0.05$) different.

farms in this survey reported using a combination of free-stall and stanchions. Herd expansion and use of free-stall housing and accompanying automated manure collection and storage systems appear to be key factors in a farm's ability to collect a higher percentage of total manure.

This study revealed no relationships between the numbers of dry cows, young, or mature heifers a farm kept, and the relative amount of manure collected from these animal types. For lactating cows, the amount of manure collected depended on number of lactating cows a farm kept. There were farms of all sizes, from 50 to 480 cows, that manage to collect all manure; however, farms with the smallest herds (<50 cows) collected the lowest percentage (57%) of manure (Table 4). For farms (76%) that partially collected lactating cow manure, there were significant ($P < 0.001$) positive relationships between herd size and manure collection (Fig. 2). The relationship was strongest ($R^2 = 0.46$) in the SC region. Similar relationships between herd size and manure collection were found nationally (USDA, 2004), where manure collection on small (<100 cows) and medium (100–499 cows) size dairy farms was found to be less than on large (>500 cows) farms.

Manure Application to Cereals and Grassland

The uniform application of collected and adjusted manure N and P on two-thirds of corn land and small grains would result in a wide range of estimated manure N and P application rates (Table 5). Farms that collect all lactating cow manure had much higher average manure N (243 kg ha^{-1}) and P (87 kg ha^{-1}) application rates to cereals than farms that only partially collected lactating cow manure (154 and 45 kg ha^{-1} manure N and P, respectively). Highest manure N and P application rates for farms that collected all or partially collected manure would occur in the SW, followed by the NE and SC regions.

Some farmers in each region harvested grass and made hay from vegetated outside areas (Table 2). On farms that collected all manure, the application of manure to grassland areas would not reduce the estimated manure N and P application rates to cereals. On farms

Table 5. Calculated annual manure N and P applications to cereals and grasslands on dairy farms that collect total or partial manure.

		Potential manure application rates			
		N	P	N	P
		Land type			
Regions	Farms	Cereal		Cereal + grass	
	n	kg ha^{-1}			
		Total manure collection			
SW	2	337† (243–431)	139 (101–177)	337 (243–431)	139 (101–177)
SC	6	150 (51–307)	62 (15–121)	148 (51–279)	61 (15–110)
NE	5	287 (225–582)	87 (71–171)	287 (225–582)	87 (71–171)
All	13	243 (51–582)	87 (15–177)	239 (51–582)	87 (15–177)
		Partial manure collection			
SW	16	226 (45–3435)	67 (13–1077)	159 (17–567)	49 (5–217)
SC	12	128 (40–446)	39 (12–126)	113 (40–446)	35 (12–126)
NE	13	152 (63–1033)	45 (18–309)	152 (40–1033)	45 (12–309)
All	41	154 (40–3435)	45 (12–1077)	140 (17–1033)	41 (5–309)

† Median (minimum − maximum).

(n = 16, or 89%) in the SW that partially collected manure, manure application on grasslands would significantly ($P < 0.05$) reduce manure N and P application rates on cereals. The main reason for this was that more farms in the SW had greater vegetated outside areas than in other regions (Table 2), a portion of which was used for hay production. One "outlier" farm in the SW devoted a very small land area (1 ha) to cereals and a large area (15 ha) to grass for hay.

In Wisconsin, dairy farmers continue to follow manure N-based land application recommendations whereby sufficient manure is applied to meet crop N requirements. Current fertilizer N recommendations range from 135 to 200 kg N ha^{-1} for soils of medium to high yield potential (Kelling et al., 1998). Average apparent manure N application rates to cereals (154 kg ha^{-1}) or cereal + grass (140 kg ha^{-1}) for all farms fell within this fertilizer N recommendation range. Although applied manure N would be less available than fertilizer N (Muñoz et al., 2004), these potential manure N application rates would be insufficient to meet crop N demands and additional (fertilizer-) N would be required. Apparent manure P applications to cereals (Table 5) were two to three times greater than average P uptake of 28 to 30 kg ha^{-1} by corn grain or silage across a wide range of Wisconsin dairy farms (Powell et al., 2002). Apparent manure P application rates came closest to corn P requirements on farms that partially collect manure.

Manure Deposition in Outside Areas

Very wide ranges of annual manure N (19–10 099 kg ha^{-1}) and manure P (4–2019 kg ha^{-1}) deposition rates in outside areas were calculated (Table 6). Lowest average manure N (116–218 kg ha^{-1}) and P (24–40 kg ha^{-1}) deposition appeared to have occurred in vegetated and partially vegetated areas in the SC and SW, where average size of these outside areas per farm was much larger than in the NE region (Table 2). Highest average manure N (846–942 kg ha^{-1}) and P (158–164 kg ha^{-1}) deposition occurred in the partially vegetated and unvegetated barnyards of the NE. High manure N (528 kg ha^{-1}) and P (109 kg ha^{-1}) deposition also occurred in

Table 6. Annual manure N and P loading rates on vegetated, partially vegetated, and unvegetated barnyards on dairy farms in the southwest (SW), southcentral (SC), and northeast (NE) regions of Wisconsin.

	Vegetated and partially vegetated areas			Unvegetated barnyards		
		Manure loading			Manure loading	
Regions	Areas	N	P	Areas	N	P
	n	kg ha^{-1}		n	kg ha^{-1}	
SW	15	116† (19–312)	24 (4–63)	0	0	0
SC	9	218 (44–1999)	40 (6–329)	5	528 (145–10 999)	109 (31–2019)
NE	10	942 (279–1344)	164 (54–277)	7	846 (552–5 330)	158 (103–1103)

† Median (minimum − maximum).

unvegetated barnyards of the SC region of Wisconsin. An even greater concentration of manure N and P within these outside areas was likely. Our calculations were based on an even distribution of manure in outside areas. However, livestock do not graze or congregate in uniform patterns (Hobbs, 1999). This often results in very uneven distribution patterns of manure deposition and subsequent impacts on soil chemical properties (Mathews et al., 1996).

Soil samples were taken from many of the outside areas on the study farms. The results suggest that soil test P (STP) and K (STK) levels in outside areas were in great excess of what would be considered optimum for any field crop grown in Wisconsin (Table 7). For example, average STP and STK levels in any of the three outside area types are 20 to 30 times greater than what would be considered optimum for corn production. Soil pH and STP, STK, and organic matter levels in outside areas were also severalfold greater than levels in soil test reports provided by farmers for their adjacent fields (Table 7).

Elevated soil pH and STK levels in outside areas were likely due to the continuous deposition of urine. Dairy cow urine has a pH of approximately 8.2 (Gans and Mercer, 1977), and urine is the principal pathway of K excretion by dairy cows (NRC, 2001). Elevated STP and soil organic matter levels in outside areas were likely due to continuous fecal deposition. Most P excreted by dairy cows is in the form of feces (NRC, 2001).

The extremely high levels of STP in partially vegetated and unvegetated outside areas would seemingly put these areas at particular risk to lose P in runoff, particularly from sloping areas close to surface water. Although much of the current environmental concern relates to abating manure runoff into surface water from barnyards and other denuded areas (USEPA, 2004; Wright, 2003), the repeated deposition of uncollected manure in outside areas elevate the risk of ground water contamination, especially if these areas are tile-drained or if the soils are highly permeable.

On the study farms, manure N and P application rates to cereals were calculated to be close to agronomic recommendations (Table 5). Given that farmers are only able to apply manure to a fraction of their cropland annually (Saam et al., 2005) due to labor, equipment, weather, and other constraints, then the dual goal of reducing manure overloads in outside areas while maintaining agronomic levels of manure application to cropland could require the collection of manure from outside areas and exporting it off-farm.

Farmer Reasons for Use of Outside Areas

Farmers offered several reasons why lactating cows were provided access to outside areas. Many reasons were associated with often-unfavorable temperature and humidity conditions in stanchions.

For example, one farmer stated, "Letting my cows

Table 7. Soil chemical properties in outside areas and crop fields.

	Outside area type							
Soil property	Vegetated		Mixed		Unvegetated		Crop fields†	
	n	median (min. − max.)	n	median (min. − max.)	n	median (min. − max.)	n	median (min. − max.)
				SW region				
pH	6	7.7 (6.3–9.1)	2	7.6 (6.1–9.2)	NA‡	NA	33	7.1 (6.9–7.4)
Bray-1 P, mg kg^{-1}	6	388 (52–457)	2	355 (133–448)	NA	NA	31	41 (18–79)
Bray-1 K, mg kg^{-1}	6	1376 (93–4051)	2	1099 (193–3057)	NA	NA	33	87 (69–221)
Organic matter, %	6	7.0 (3.0–18.1)	2	4.8 (2.4–11.5)	NA	NA	33	2.8 (2.1–3.5)
				SC region				
pH	NM§	NM	5	8.1 (6.3–9.3)	4	7.7 (6.6–9.0)	8	6.9 (6.6–7.3)
Bray-1 P, mg kg^{-1}	NM	NM	5	399 (65–449)	4	391 (236–429)	8	48 (21–145)
Bray-1 K, mg kg^{-1}	NM	NM	5	2119 (104–7186)	4	1783 (398–6554)	8	147 (95–470)
Organic matter, %	NM	NM	5	9.4 (2.1–23.2)	4	7.1 (2.6–20.1)	8	3.9 (2.8–4.2)
				NE region				
pH	NM	NM	4	7.6 (7.1–8.6)	4	8.4 (7.4–9.3)	46	7.1 (6.0–7.8)
Bray-1 P, mg kg^{-1}	NM	NM	4	196 (31–498)	4	415 (127–492)	48	38 (9–178)
Bray-1 K, mg kg^{-1}	NM	NM	4	722 (141–4573)	4	2119 (257–4996)	47	136 (64–340)
Organic matter, %	NM	NM	4	4.2 (1.9–8.8)	4	9.5 (3.0–18.8)	48	2.5 (1.7–4.1)

† Crop fields are on same farms as outside areas.
‡ NA, not applicable.
§ NM, not measured.

out on solid ground, in the sunshine, keeps them drier and cooler. I think it keeps them more comfortable."

Another farmer offered, "I let my cows outside because of general health reasons. I feel it's better for their legs and they have less hock problems. It keeps my vet bills low."

Other farmers said that they were better able to keep track of breeding activity when animals were outside.

Farmer Management of Outside Areas

There appeared to be considerable manure buildup in many outside areas (Table 6); some farmers managed these areas by either removing manure and/or rotating these areas with crops or forage. For example, 2 of 18 farms in the NE removed manure from outside areas and 7 farms reported they rotated outside areas with crops and/or forage. No farms in the SC and only one farm in the SW reported manure collection from outside areas. Few farms in the SW (three) and the SC (two) regions reported that they rotated outside areas.

While follow-up visits will be used to better understand farmer management of outside areas, several farmers have reported benefits of rotating cows between different outside areas, and in and out of crop production.

In the words of one farmer, "I have four different areas I use for exercise lots. I keep one covered with grass and let the cows out there when it rains. The main thing is to keep them dry and clean. I started rotating these areas ten years ago and have seen my somatic cell count drop dramatically. It's good for my cows' udder health."

Another farmer stated, "I have a couple different areas close to the barn where I let the cows out. The one I'm using now has been there for a year. Every two years or so I plow it up and plant it to corn or seed it down."

Also, there were comments related to manure management, for example, "The cows put the manure outside. I don't have to haul it. I just plow it (exercise area) up every few years, reseed it, and move the cows to a new area."

CONCLUSIONS

Many Wisconsin dairy farms do not collect all their livestock manure. Lowest manure collection occurs on farms that allow their livestock regular access to outside areas, generally farms with small and medium herd sizes, or farms that use stanchion rather than free-stall housing. Manure collection on farms in the hilly SW region is significantly ($P < 0.05$) lower than in other regions of Wisconsin. Outside areas, especially unvegetated barnyards, have much higher manure loading rates than cropland, which (once we accounted for apparent manure collection rates) appear to have nutrient loading rates close to agronomic recommendations. The noncollection of manure has vastly increased soil test nutrient levels in outside areas, thereby increasing the risk of impairing surface and ground water quality. Conversely, lower rates of manure collection are associated with lower risk of over applying manure to crop fields.

This study showed that management of uncollected manure in outside areas might require particular attention. The current regulatory focus is on manure spreading on cropland, particularly on farms having large herd sizes. Farm size is the current regulatory indicator of pollution potential because it is commonly thought that large farms due to high concentration of livestock and manure pose the greatest threat to environmental damage. Economics, however, allows many large farms to hire labor and management, and incorporate technologies that improve manure collection, storage, and land spreading. Smaller farms often rely solely on family labor and do not have additional resources to invest in the housing, manure collection, storage, and land spreading options that improve manure management. For example, the appropriateness of manure storage depends on costs and farmer ability to spread costs over many animal units. Most small-scale dairy operations will not be able to afford—nor should they be encouraged to adopt—long-term manure storage because this technology requires maintenance and may put an unmanageable burden on seasonal labor. The current practice of frequent removal and land spreading of manure fits the fluctuating labor supply of small-scale dairy operators. These farm types might need low-cost alternatives to current practices, such as improved ways to protect manure during short-term stacking, ways to improve the management of their barnyards (Wright, 2003), and so forth. The input of farmers managing these operation types should be pursued to more clearly define the challenges and opportunities they face in improving manure management, especially manure deposited in outside areas.

ACKNOWLEDGMENTS

This article is dedicated to the late Dr. Les Lanyon. Appreciation is extended to Kevin Shelley for his review of the manuscript draft. Partial funding for this research was received from USDA-CSREES Initiative for Future Agricultural and Food Systems, grant 00-52103-9658; and NRI Agricultural Systems Program, grant 01-35108-10698.

REFERENCES

Bundy, L.G., K.A. Kelling, E.E. Schulte, S. Combs, R.P. Wolkowski, and S.J. Sturgul. 1994. Nutrient management practices for Wisconsin corn production and water quality protection. Publ. A3557. Univ. of Wisconsin Coop. Ext., Madison, WI.

Buttel, F.H., D. Jackson-Smith, and S. Moon. 1999. A profile of Wisconsin's dairy industry, 1999. Program on Agricultural Technology Studies, Univ. of Wisconsin, Madison, WI.

Gans, J.H., and P.F. Mercer. 1977. The kidneys. p. 463–492. *In* M.J. Swenson (ed.) Dukes' physiology of domestic animals. Comstock Publ. Assoc., Cornell Univ. Press, Ithaca, NY.

Gollehon, N., M. Caswell, M. Ribaudo, R. Kellogg, C. Lander, and D. Letson. 2001. Confined animal production and manure nutrients. Agric. Inf. Bull. 771. USDA-ERS, Washington, DC.

Hobbs, N.T. 1999. Responses of large herbivores to spatial heterogeneity in ecosystems. p. 97–129. *In* H.-J.G. Jung and G.C. Fahey, Jr. (ed.) Nutritional ecology of herbivores. Proc. 5th Int. Symp. on the Nutrition of Herbivores, San Antonio, TX. 11–17 Apr. 1999. Am. Soc. Anim. Sci., Savoy, IL.

Hole, F.D. 1976. Soils of Wisconsin [Online]. Available at http://

digital.library.wisc.edu/1711.dl/EcoNatRes.Hole01 (accessed 3 May 2005; verified 27 June 2005). Univ. of Wisconsin Press, Madison, WI.

Jackson-Smith, D.B., S. Moon, M. Ostrom, and B. Barham. 2000. Farming in Wisconsin at the end of the century: Results of the 1999 Wisconsin farm poll. PATS Research Summary 4. Program on Agricultural Technology Studies, Univ. of Wisconsin, Madison, WI.

Kelling, K.A., L.R. Bundy, S.M. Combs, and J.B. Peters. 1998. Soil test recommendations for field, vegetable and fruit crops. Rep. A2809. Univ. of Wisconsin Coop. Ext., Madison, WI.

Kellogg, R.L., C.H. Lander, D.C. Moffitt, and N. Gollehon. 2000. Manure nutrients relative to the capacity of cropland and pastureland to assimilate nutrients: Spatial and temporal trends for the United States. GSA National Publ. Center, Fort Worth, TX.

Mathews, B.W., L.E. Sollenberger, and J.P. Tristschler, II. 1996. Grazing systems and spatial distribution of nutrients in pastures: Soil considerations. p. 213–230. *In* R.E. Joost and C.A. Roberts (ed.) Nutrient cycling in forage systems. Proc. of a Symp., Columbia, MO. 7–8 Mar. 1996. Potash and Phosphate Inst. and the Foundation for Agronomic Res., Manhattan, KS.

Mid-West Plan Service. 2000. Manure characteristics. Publ. MWPS-19, Manure management systems series. Section 1. MidWest Plan Service, Iowa Univ. Press, Ames, IA.

Mid-West Plan Service. 2001. MidWest Plan Service. Manure storages. Publ. MWPS-18, Manure management system series. Section 2. MidWest Plan Service, Iowa State Univ., Ames, IA.

Muñoz, G.R., K.A. Kelling, J.M. Powell, and P.E. Speth. 2004. Comparison of estimates of first-year dairy manure N availability or recovery using ^{15}N and other techniques. J. Environ. Qual. 33: 729–737.

National Research Council. 2001. Nutrient requirements of dairy cattle. 7th ed. National Research Council, Nat. Acad. of Sci., Washington, DC.

National Research Council. 2003. Air emission from animal feeding operations: Current knowledge, future needs. National Research Council, Nat. Acad. of Sci., Washington, DC.

Nowak, P., R. Shepard, and F. Madison. 1997. Farmers and manure management: A critical analysis. p. 1–32. *In* J.L. Hatfield and B.A. Stewart (ed.) Waste utilization: Effective use of manure as a soil resource. Ann Arbor Press, Chelsea, MI.

Powell, J.M., D. Jackson-Smith, and L.D. Satter. 2002. Phosphorus feeding and manure recycling on Wisconsin dairy farms. Nutr. Cycling Agroecosyst. 62:277–286.

Powell, J.M., Z. Wu, and L.D. Satter. 2002. Dairy diet effects on phosphorus cycles of cropland. J. Soil Water Conserv. 56:22–26.

Saam, H., J.M. Powell, D.B. Jackson-Smith, W.L. Bland, and J.L. Posner. 2005. Use of animal density to estimate manure nutrient recycling ability of Wisconsin Dairy Farms. Agric. Syst. 84:343–357.

SAS Institute. 1990. SAS/Stat user's guide. Version 6. SAS Inst., Cary, NC.

Soil, Plant Analysis Laboratory Services. 2004. Procedures for soil testing, plant analysis and feed & forage analysis. *In* J. Peters (ed.) [Online]. Available at http://uwlab.soils.wisc.edu/procedures.htm (accessed 15 Oct. 2004; verified 27 June 2005). Univ. of Wisconsin, Madison, WI.

USDA. 2004. Nutrient management and the U.S. dairy industry in 2002. Publ. N426.0804. USDA-APHIS-VS-CEAH, National Animal Health Monitoring System, Fort Collins, CO.

USEPA. 2003. Producers' compliance guide for CAFOs. USEPA Rep. 821-R-03-010. USEPA National Service Center for Environmental Publ., Cincinnati, OH.

USEPA. 2004. Managing manure nutrients at concentrated animal feeding operations. USEPA Rep. 821-B-04-006. USEPA Office of Water (43037), 1200 Pennsylvania Avenue, NW, Washington, DC.

Wright, P. 2003. CAFO requirements for barnyards. Fact Sheet 11. Livestock and poultry environmental stewardship curriculum. MidWest Plan Service, Iowa State Univ., Ames, IA.