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Feedlot Manure Nutrient Loadings on South Dakota Farmland

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FEEDLOT MANURE NUTRIENT LOADINGS OF SOUTH DAKOTA FARMLAND[1]

by

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ABSTRACT

A key determinant of whether livestock manure is an asset or liability in agricultural production and to society more generally is the amount of manure produced relative to the nearby farmland area to which the manure can be economically transported for application. The objectives of the study reported in this article are to (1) estimate levels of manure nutrient (nitrogen = N and phosphorus = P) loadings on the cropland and rangeland associated with 78 feedlot farm operations in South Dakota and (2) determine factors, including size-of-feedlot and cropland hectarages, associated with cropland N and P loadings for the feedlots studied.

Findings from the study show that (1) substantial percentages of the South Dakota feedlot operators studied apply livestock manure plant-available N and P that exceed crop and grass fertility requirements and (2) greater intensity of manure nutrient loadings on cropland is strongly related to larger sizes-of-feedlot and smaller farmland areas on which manure is applied. These two main findings raise some potential "red flags" in regard to possibilities for non-point source pollution of vulnerable water resources from manure produced by fed cattle--both within South Dakota and in other major cattle producing states in the U.S.

FEEDLOT MANURE NUTRIENT LOADINGS ON SOUTH DAKOTA FARMLAND

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Introduction

Attitudes in the U.S. toward livestock manure have changed greatly over the past several decades. Until the third or fourth decade in the 20th Century, manure was considered as a significant natural resource for use in agricultural production. As a result of changes in technologies, institutions, and price relationships during the past four to five decades, however, manure has come to be viewed rather commonly as a waste product (Kaffka, 1992; National Research Council, 1993; Wadman et al., 1987). Nevertheless, in recent years, some producers are again viewing manure as a resource with positive agronomic and economic value (Honeyman, 1991; Nelson and Shapiro, 1989).

Whether livestock manure is an asset or liability in agricultural production and to society more generally depends on (1) the amount of manure produced relative to the nearby farmland area to which the manure can be economically transported for application and (2) soundness of management practices in handling, storing, and applying the manure (taking into account on-site evaluation of possible soil and water contamination risks). In this article, which is focused on the first issue, the production and disposition of livestock manure produced on 78 feedlot farming operations in South Dakota are examined. Compared to most other major cattle feeding states in the United States, South Dakota is unique in that its feedlots are relatively small, its farmland area is relatively great, and its crop production levels (and hence soil fertility nutrient needs) are relatively modest.

Problem Identification

Benefits of manure

Livestock manure contains nitrogen (N), phosphorus (P), and potassium (K) which can be used as substitutes for the N-P-K in synthetic fertilizer. These macro-nutrients in manure, when managed effectively and efficiently, result in crop yields essentially equivalent to those from similar amounts of nutrients in commercial synthetic fertilizers. In addition to the N-P-K present in both livestock manure and synthetic chemical fertilizer, livestock manure contains certain other macro-elements (e.g., calcium) and micro-elements (e.g., boron, cobalt, copper, manganese, molybdenum, zinc) which can meet important nutrient needs of crops (Chase et al., 1991; Holt and Zentner, 1985; National Research Council, 1993; Office of Technology Assessment, 1990; Roka et al., 1993; Walter et al., 1987).

Further, applying manure to farmland leads to a build-up of organic matter in soil. Accompanying organic matter build-up and associated processes are (1) improvements in soil tilth, aeration, biological diversity and activity, water infiltration, water holding capacity, and solar heat absorption capacity; (2) greater soil moisture retention and less water runoff, with an associated reduction in leaching of potential surplus nutrients into ground and surface water supplies; (3) improvements in the aggregate stability of soils which enhances soil's resistance to water and wind erosion, compaction, and crusting; and (4) improved chemical properties of soil (e.g., provision of a greater cation exchange capacity to retain nutrient cations, facilitating the availability of micronutrients, buffering soil pH against rapid changes) (Baker et al., 1990; Hornick and Parr, 1987; Koepf, 1993; Mathers and Stewart, 1984; National Research Council, 1993; Roka et al, 1993; Wallingford et al., 1975).

Possible limitations of manure

The National Research Council (1993), in its recent study "Soil and Water Quality, An Agenda for Agriculture," reports that the increasing regional concentration of livestock in the U.S. and the increasing concentration of cattle in large confinement feeding operations are giving rise to more manure being produced than can be used efficiently on nearby croplands. Baker et al. (1990), Logan (1990), Sutton (1994), and Vanderholm (1994) note the potential adverse impacts of highly concentrated livestock on soil and water quality.

With concentrated livestock production, environmental concerns can arise in connection with (1) waste runoff or leaching from feedlots (hereafter referred to as "point source pollution") and (2) nutrients leaching into soil and water from manure in excess of the nutrients required by crops (hereafter referred to as "non-point source pollution"). Other things the same, possibilities for pollution are greater if cattle are fed in large feedlots. [One factor that may not be the same is quality of livestock waste management. Twenty thousand cattle in one well designed and managed feedlot may give rise to fewer pollution problems than those same 20,000 cattle in 50 poorly designed and managed feedlots with 400 cattle each.] Point source pollution may increase because of large amounts of feedlot waste available as potential runoff into surface water or leaching to groundwater in the immediate vicinity of large feedlots. Non-point source pollution may increase because economic disincentives for transporting manure long distances from its point of origin may result in excessively heavy manure applications on farmland close to large feedlots (Freeze and Sommerfeldt, 1985; Roka et al., 1993).

Point source pollution is represented by runoff from feedlots to surface water and leaching to groundwater. Such runoff may contain high concentrations of nutrients (e.g., phosphorus), salts, pathogens, and oxygen-demanding organic material. When feedlot runoff enters streams or lakes, the excess organic material and nutrients can cause eutrophication, algae blooms, and oxygen depletion which can lead to fish kills (Logan, 1990; National Research Council, 1989 and 1993; Paine, 1973). In South Dakota, 98% of lakes smaller than 2,023 ha (5,000 acres) do not meet fishable and swimmable standards. The lakes are severely impacted by nutrient inputs from agricultural activity (S.D. Dept. of Environment and Natural Resources, 1990).

When nutrients in animal manure applied to farmland exceed nutrient requirements of crops, excess nutrients (nitrate-N most commonly) often leach through the soil and may reach groundwater supplies. Groundwater exceeding 10 ppm nitrate-N is unsuitable for drinking purposes. The 1989 South Dakota Centennial Environmental Protection Act requires sampling of all new domestic wells in the state. Of the 747 wells sampled, 237 (32%) failed to meet the 10 ppm nitrate-N safe drinking water criterion (S.D. Association of Conservation Districts, 1991).

Plant growth can be retarded by excessive manure applications to farmland because of the following possible chain of events: build-up of salts (e.g., sodium chloride) in soil, breakdown of soil structure, and reduced soil aeration and water infiltration. Ammonia may build up which can damage emerging seedlings. When manure or plant residues are added to land, oxygen levels can drop and carbon dioxide levels can increase rather drastically, thereby inhibiting plant growth. Because of heavy equipment often involved in manure distribution, problems of soil compaction can be accentuated by heavy manuring of fields (Kaffka, 1992; Mathers and Stewart, 1984; Midwest Plan Service, 1985; National Research Council, 1993).

Geographic concentration of fed cattle

In two respects, the concentration of fed cattle in the United States has changed greatly during the past two decades. Regionally, the geographic focus of cattle feeding has shifted from the Midwest and Southwest to the Central and Southern Plains (Albin and Thompson, 1990; Krause, 1991). Accompanying this regional shift has been a rather dramatic increase in the proportion of cattle fed in "very large" feedlots (Barkema and Drabenstott, 1990; Krause, 1991).

Today, 13 states account for 85% of the cattle and calves on feed nationally (U.S. Dept. of Agriculture, 1989). In 1993, the U.S.'s four major cattle feeding states--Texas, Nebraska, Kansas, and Colorado, all in the Central and Southern Plains--accounted for 63% [(16,580/22,316) * .85] of the nation's total fed cattle marketed (Table 1). The degree of within-state fed cattle concentration in these states is high. For example, in these four states, between 113 and 212 cattle and calves are on feed per 1,000 ha of cropland. Average numbers of fed cattle marketed per feedlot in these states range from 798 to 8,266. Average marketings per feedlot are even greater in Arizona, Washington, and California.

Far at the other end of the geographic concentration continuum are South Dakota and the three Midwest-heartland states of Iowa, Minnesota, and Illinois. For example, in none of these four states, are (1) more than an average of 59 cattle and calves on feed per 1,000 ha of cropland and (2) average marketings per feedlot more than 121. The nation's big-four cattle producing states have from 3.3 to 5.6 times as many cattle and calves on feed per 1,000 ha as the 38 in South Dakota and from 6.6 to 68.3 times as many average cattle marketings per feedlot per year as the 121 in South Dakota.

Manure nutrient loading evaluation criteria

Identifying benchmarks against which livestock manure nutrient loadings can be evaluated is problem-prone. Maximum "environmentally safe" nutrient loadings on farmland depend--among many factors--on site-specific soil N and P levels, soil properties and condition, aquifer depths, distance from surface water, crop nutrient requirements, conservation practices, and weather at the time of manure application.

Table 1. Concentration of fed cattle production, 13 major U.S. cattle producing states.

Region and state	Number of fed cattle marketed 1991 ('000 head)	Cattle and calves on feed* per 1,000 ha of cropland, 1988	Average number of fed cattle marketed per feedlot, 1993
Central and Southern Plains			
Texas	5,290	156	8,266
Nebraska	4,790	212	798
Kansas	4,160	113	1,733
Colorado	2,340	211	7,932
Oklahoma	835	55	3,884
Southwest			
California	585	99	15,000
Arizona	378	596	34,364
Northwest			
Idaho	625	71	4,464
Washington	453	60	15,100
South Dakota	485	38	121
Midwest-heartland states			
Iowa	1,445	59	94
Minnesota	485	35	61
Illinois	445	37	62
Thirteen state total	22,316	102	504

Source: Columns 1 and 3 based on data from Livestock Marketing Information Center (1994); Column 2 based on data from U.S. Dept. of Agriculture (1989) and U.S. Dept. of Commerce (1989).

*Of the 11,527 thousand head of cattle and calves on feed in the U.S. on January 1, 1988, 9,769 thousand (85%) were on feed in the nation's 13 major cattle feeding states (U.S. Dept. of Agriculture, 1989).

Nevertheless, because of increased concentration of fed cattle and increased public concerns over possible environmental pollution associated with geographically dense populations of cattle, regulatory authorities in several states now stipulate maximum recommended levels of manure N for land application. Information on guidelines governing these maximum manure N levels in two nearby major cattle feeding states, plus those for South Dakota, represent the benchmarks against which the manure nutrient levels estimated in this study are evaluated.

To minimize potential for nitrate leaching to groundwater in Iowa, the N application from all sources--including animal wastes, legumes, and commercial fertilizers--should not exceed the annual N requirement of the crop being grown (Iowa Dept. of Natural Resources, 1994). The average N application rate over an extended period should not exceed 280 kg/ha (250 lb/acre) of available N per year.

At present, Kansas has a recommended guideline of a maximum one-time application of 280 kg/ha (250 lb/acre) of plant-available N from livestock manure on cropland. However, the Kansas Bureau of Water is in the process of seeking approval for a manure land application permit system with a maximum allowable amount of 112 kg/ha (100 lb/acre) of plant-available N year-after-year. Applicants who desire to apply larger amounts must present plans showing that, under their circumstances, soil/water quality would not be impaired by their proposed higher nutrient loading. Producers are strongly encouraged to conduct annual soil nutrient tests and periodic tests of the nutrient content of their manure and to tailor their manure applications accordingly (personal communication, Division of Environment, Kansas Bureau of Water, Topeka, May 1996).

In South Dakota, agricultural waste plans, covering waste storage and utilization, must be developed for new feedlots with a capacity for more than 1,000 head and for any existing feedlot which has been shown to be the source of water pollution (Johnson and Ullery, 1993). The waste utilization plan requires annual soil tests with subsequent manure applications not to exceed crop N requirements. Depending on distance of feedlots to surface water and soil erosion potential, crop P requirements may also need to be covered in waste utilization plans.

Since corn and wheat are the main crops grown in the vicinity of South Dakota's feedlots, local benchmark N and P levels--against which manure N and P loadings were evaluated in this study--are in respect to recommended N and P levels for corn and wheat on cropland and grass on rangeland. Recommended fertilization levels for these crops are based on equations in Gerwing and Gelderman (1996). Illustrative equations for corn for grain are as follows:

* Recommended N: 1.2 * yield goal (YG in bu) - soil test nitrogen at 0.61 meter (2 feet) depth (STN in lb/acre); and

* "Bray-1 P recommendation:" [(0.770 - 035 * STP) * YG] * 0.44.

These levels were evaluated relative to (1) yield goals equal to historical county averages for corn and wheat (Ranek and Noyes, 1995) and (2) average cropland soil test residual N and P levels (unpublished data, South Dakota State University Soil Testing Laboratory, April 1996) in the respective counties in which the 78 feedlots studied are located. The following illustrative recommended per-hectare (per-acre) N and P levels are with respect to state-wide per-hectare (per-acre) 5-year average yields of 5.08 mt (81 bu) for corn and 2.08 mt (31 bu) for wheat (Ranek and Noyes, 1995) and state-wide cropland average STN and STP values of 44.8 kg/ha (40 lb/acre) and 16 ppm, respectively (personal communication, South Dakota State University Soil Testing Laboratory, April 1996):

* 64 kg (57 lb) N and 6 kg (5 lb) P for corn; and
* 43 kg (38 lb) N and 3 kg (3 lb) P for wheat.

Since systematically-collected South Dakota county-level data on average rangeland yields and average rangeland soil test residual N and P data are not available, the evaluation of N and P loadings on rangeland in this study was limited to the state-level. Based on an assumed average grass yield of 1.32 mt (1.2 tons) (judgment of South Dakota Resource and Conservation Service personnel) and assumed zero residual N and P for rangeland (personal communication, South Dakota State University Soil Testing Laboratory, April 1996), the benchmark per-hectare (per-acre) N and P levels for rangeland grass were determined to be as follows: 34 kg (30 lb) N and 6 kg (5 lb) P.

Study objectives

Within the perspective that (1) livestock manure can be either an asset or liability in agricultural production and to society and (2) South Dakota is unique in its feedlots being relatively small, its farmland area being relatively great, and its crop production levels (and hence soil fertility nutrient needs) being relatively modest, the objectives of the study reported in this article were to:

1. Estimate levels of manure nutrient (N and P) loadings on the cropland and rangeland associated with 78 feedlot farm operations; and

2. Determine factors, including size-of-feedlot and cropland hectarages, associated with cropland manure nutrient (N and P) loadings for the feedlots studied.

Methods and Materials

Cattle feedlots studied

Responses by 78 South Dakota cattle feeders to questionnaires mailed during winter 1991-92 represent a main data source in this study (Taylor and Feuz, 1994). In this study, the following information was used: feedlot design capacities and quarterly utilization rates; hectares of cropland and rangeland operated; nature and size of commercial livestock enterprises other than fed cattle; total days fed cattle on feed; days fed cattle graze rangeland and crop residues; percentage of total dry matter feed intake from grain; form of manure applied to farmland; and percent of cropland receiving manure applications.

The mean design capacity of the feedlots operated by the 78 feedlot managers studied is 890 head, which is 10-15 times the state-wide average [based on an average of 121 fed cattle marketed per feedlot in 1993 (Table 1) and a judgment that an average of 1.5-2.0 batches of cattle are fed in each feedlot per year]. An average feedlot manager in the study operates 597 ha of cropland, which is 1.9 times the state-average for all farmers in the state of 318 ha (U.S. Dept. of Commerce, 1994).

In addition to fed cattle, 51 (65%) of the 78 feedlot operators have other livestock and poultry enterprises. Of these 51 operators, 26 have one other livestock enterprise, 14-two other enterprises, 9-three other enterprises, and 2-four other enterprises. The most common other livestock enterprise involves beef cows. Forty-five (58%) of the 78 cattle feeders maintain beef cow herds ranging in size from 11 to 550 head and averaging 135 cows each. Other livestock enterprises maintained by the feedlot operators are as follows:

* Slaughter hogs: 15 operators (19%) selling an average of 750 head/yr each;

* Brood sows: 11 operators (14%) with an average of 75 sows each;

* Dairy cows: 9 operators (12%) with an average of 90 cows each;

* Stocker cattle: 8 operators (10%) selling an average of 120 stockers/yr each;

* Sheep: 3 operators (4%) with an average of 210 ewes each;

* Slaughter lambs: 3 operators (4%) selling an average of 135 lambs/yr each;

* Broilers: 2 operators (3%) selling an average of 4,250 broilers/yr each; and

* Layers: 2 operators (3%) with an average of 270 hens each.

In estimating the amount of manure produced on the 78 feedlot operations, attention was given to the manure produced by both fed cattle and the animals represented in these other livestock enterprises.

Estimated manure production

Since the vast majority of the surveyed feedlot operators apply manure to their farmland in a solid raw form, we assumed all spread manure to be solid raw. Estimating amounts of livestock manure N and P produced, available for use by crops on cropland and grass on rangeland, involved taking into joint account the following:

1. Amounts of solid manure ("spreader dry matter") available for application to farmland, from different categories and weights of livestock, during periods of time within a year that animals are present in farmers' herds/flocks;

2. Proportions of total manure available for application to farmland from various species of livestock assumed to be scraped, collected, and spread on cropland versus dropped on rangeland;

3. N and P nutrient content of manure produced by various species of livestock; and

4. Percentages of total N and P present in manure assumed to be available for plant use.

Estimated values for these parameters were based on various findings reported in the literature as follows.

Amounts of manure available for application to farmland. Estimated rates of livestock manure voided were obtained from Conservation Technology Information Center (1992), Ensminger (1987), Killorn (1985), Midwest Plan Service (1985), Nelson and Shapiro (1989), Sutton et al. (1985), Van Dyne and Gilbertson (1978), and Watts (1991). Amounts of manure produced by different types of beef cattle and sheep were reported to be directly proportional to body-weight within each species-type. For hogs and poultry, on the other hand, reported rates of manure production differed for breeding versus finishing animals. Rates of manure production for different categories of hogs and poultry were based directly on per-day amounts reported in the literature review, rather than calculated relative to species' baseline body-weights.

Based on Ensminger (1987), Killorn (1985), Midwest Plan Service (1985), Nelson and Shapiro (1989), Sutton et al. (1985), and Watts (1991), the dry matter content of manure produced by various species at the time of application to farmland was estimated to be as follows: 55% poultry, 30% beef cattle and sheep, and 18% hogs and dairy cattle. Assumed manure storage and handling losses were based on Van Dyne and Gilbertson (1978) who indicate such losses to result in 89% of the manure initially voided being available for application to farmland.

Thus, in this study, amounts of "manure produced at the time of application to farmland" should be interpreted as estimated amounts of manure voided--adjusted down for (1) moisture losses by 45% for poultry, 70% for beef and sheep, and 82% for hogs and dairy and (2) storage and handling losses by an additional 11%. Amounts of "spreader dry matter" manure resulting from these considerations assumed to be produced and available for land application by various species and types of livestock and poultry found on the farms studied are shown in Table 2. [While manure dropping on grazing land is not literally in "spreader dry matter" form, an accurate portrayal of its N and P content is not violated through its being treated analytically as if it were in this form.]

Table 2. Estimated amounts of "spreader dry matter" manure available for land application from various species and types of livestock and poultry.

	Livestock management assumptions		Available manure	
Category of livestock	Body-weight (kg)	Days in herd/flock	Kg/day	Metric tons for days in herd/flock
Beef cattle				
Service bulls	775	365	42.9	15.66
Brood cows	500	365	27.8	10.15
Replacement heifers	310	442	17.1	7.56
Finishing cattle	355	270[a]	19.6	5.29
Stockers	280	200	15.5	3.10
Backgrounded cattle	235	91	13.1	1.19
Dairy cows	595	365	42.4	15.48
Hogs				
Brood sows	160	365	5.0	1.83
Market hogs	62	150	5.0	0.75
Sheep				
Ewes	82	365	2.9	1.06
Market lambs	32	140	1.1	0.15
Poultry				
Layers	3.2	365	0.14	0.051
Broilers	3.2	45	0.18	0.008

[a]The 270 days is for illustration only.

Proportions of manure spread on cropland versus dropped on grazing land. It was assumed that manure dropped in dry lot would be scraped, collected, and spread only on cropland. For fed cattle, total estimated manure produced was allocated to cropland versus rangeland according to ratios of days fed cattle were reported by individual feedlot operators to be in dry lot versus grazing on rangeland and crop residues. For other categories of livestock and poultry, the following percentages of total manure available for application to farmland were assumed to (1) be spread on cropland versus (2) dropped on rangeland (percentage decisions made taking into account Office of Technology Assessment, 1990):

* Beef brood cows, service bulls, and stockers: 20%-80%;
* Dairy cows: 50%-50%; and
* Brood sows, market hogs, market lambs, and poultry: 100%-0.

Thus, for example, of a mature beef cow's annual manure production of 10.15 mt, 2.03 mt (20%) were assumed to be spread on cropland and 8.12 mt (80%) to be dropped on rangeland.

N and P nutrient content of livestock manure. Data on estimated percentages of nitrogen (N) and phosphorus (P) in the manure produced by various species of livestock were obtained from Baker and Raun (1989), Cooke (1982), Ensminger (1987), Gerwing and Gelderman (1996), Killorn (1985), McGary (1989), Midwest Plan Service (1985), Nelson and Shapiro (1989), Schmitt (1988), Sutton et al. (1985), and Watts (1991). In references in which phosphorus was reported as P_2O_5, rather than P, the P_2O_5 percentage was multiplied by 0.44 (Midwest Plan Service, 1985). Based on consideration of these references, we assumed the N and P percentages of ("spreader-weight," not oven-dried weight) manure produced by various livestock species shown in Table 3.

Table 3. Assumed nitrogen (N) and phosphorus (P) content in "spreader dry matter" manure from various livestock species.

Livestock species	Percent of manure applied to farmland: Nitrogen (N)	Phosphorus (P)
Poultry	1.736	0.696
Sheep	0.992	0.197
Beef cattle	0.724	0.227
Dairy cattle	0.485	0.098
Hogs	0.422	0.142

Percentages of plant-available N and P present in manure. Of the total manure N and P estimated to be produced and applied annually to farmland, 75% of N and 100% of P was assumed to be available over time for plant use. This assumption was based on Lorimor et al. (1995) and research undertaken by Pennsylvania State University reported by McGary (1989).

Estimated amounts of manure N and P (i.e., manure N and P fertilizer credits) available for use by crops and grasses on each feedlot operator's farmland were determined by:

* Multiplying the N and P percentages in Table 3 by the respective cross products of (a) per-head amounts of manure for the various species and types of livestock available for application to farmland in Table 2 and (b) the numbers of each species and type of livestock maintained on the respective feedlot operations; and

* Taking into account the availability to plants of 75% of the total manure N and 100% of manure P applied to farmland.

Thus, assumptions for the following items were common for all 78 feedlot operators: (1) "dry matter" manure production rates per 100 lb of liveweight for beef cattle and sheep, and per day for various types of hogs and poultry; (2) proportions of manure assumed to be spread on cropland versus dropped on rangeland (except for fed cattle); (3) manure N and P nutrient content; and (4) percentages of total manure N and P applied assumed to be available to crops and grasses produced. Case farmers were also assumed to follow sound management practices in handling, storing, applying, and incorporating manure in their farming operations. Further, manure was assumed to be applied uniformly over all cropland receiving spread manure applications and to drop uniformly over all rangeland in the respective farming operations. While these assumptions are acknowledged to be somewhat unrealistic, research resources were inadequate to permit gathering and use of farmer-specific information on these variables. Results of the study must, therefore, be considered as indicative rather than definitive.

Factors associated with cropland manure nutrient loadings

The following seven factors were hypothesized to affect the amounts of nitrogen (N) and phosphorus (P) from livestock manure that producers spread on their cropland:

* Feedlot design capacity: a direct relationship with cropland area was hypothesized, since amounts of manure produced can be expected to be greater for feedlots with larger feeding capacities;

* Cropland hectarage: an inverse relationship, since--other things the same--manure can be expected to be spread more thinly if areas receiving the manure are large;

* Percent of cropland hectares receiving spread manure applications: an inverse relationship for the same reason as above;

* Percent of total dry matter intake from grain, during each of three successive stages of feeding: inverse relationships, since proportions of non-digested feed can be expected to be less for cattle receiving diets with high grain-to-roughage ratios; and

* Number of beef cows on farm, since the total amount of manure produced on a feedlot operation can be expected to be positively related to the number of beef cows on the farm.

Possible relationships between these seven independent variables and the dependent variables of nitrogen and phosphorus applications per acre were examined through multiple regression analysis (SAS Institute, Inc., 1988). The unit of analysis was a feedlot farming operation.

Results

Total manure produced and applied

An estimated average of 4,870 mt of manure is produced annually by the livestock associated with each feedlot studied. Of this manure, 77% (3,765 mt) is spread on cropland and 23% (1,105 tons) on rangeland. Finishing cattle account for 92% of total manure produced. On average for the 78 feedlots, beef cow and hog enterprises each account for 3%, dairy for 2%, and sheep and poultry for 0.1% of total manure produced.

Estimated annual applications of livestock manure on cropland range among feedlots from 0.4 to 31.5 mt/ha (0.4-28.1 tons/acre) and average 6.8 mt/ha (6.1 tons/acre). Nineteen percent of feedlot operators spread on their cropland more than 11.2 mt/ha (10.0 tons/acre) and 4% spread more than 22.4 mt/ha (20.0 tons/acre).

Cropland loading rates

The estimated annual nitrogen (N) loading on cropland from livestock manure ranges among feedlot operations from 5 to 426 kg/ha (5 to 380 lb/acre) and averages 82 kg/ha (73 lb/acre) (Table 4). Manure for 5% of producers provides 280 kg/ha or more of N, for 24% of producers more than 112 kg/ha of N, for 42% of producers more than 64 kg/ha of N, and for 59% of producers more than 43 kg/ha of N. At the other extreme, manure for 9% of producers provides less than 10 kg/ha of N.

The estimated annual phosphorus (P) loading to cropland from livestock manure ranges among feedlot operations from 2 to 178 kg/ha (2 to 159 lb/acre) and averages 34 kg/ha (31 lb/acre). Manure for 38% of producers provides 30 kg/ha or more of P, for 74% of producers more than 10 kg/ha of P, for 86% of producers more than 6 kg/ha of P, and for 95% of producers more than 3 kg/ha of P.

Table 4. Levels of plant-available N and P from livestock manure spread on cropland, 78 feedlots.

N		P	
Range (kg/ha)	5 - 426	Range (kg/ha)	2 - 178
Mean (kg/ha)	82.1	Mean (kg/ha)	34.2
Frequency distribution		Frequency distribution	
kg/ha	Percent	kg/ha	Percent
280 or more	5.1	70 or more	11.5
112 - 279	19.2	50 - 69	11.5
64 - 111	17.9	30 - 49	15.4
43 - 63	16.7	20 - 39	15.4
30 - 42	11.6	10 - 19	20.5
20 - 29	6.4	6.0 - 9.9	11.5
10 - 19	14.1	3.0 - 5.9	9.0
< 10	9.0	< 3.0	5.2

Rangeland loading rates

The estimated annual nitrogen (N) loading to rangeland from livestock manure ranges among feedlot operations from 0 to 98 kg/ha (0 to 87 lb/acre) and averages 37 kg/ha (33 lb/acre) (Table 5). Manure for 37% of producers provides 34 kg/ha or more of N, and for 60% of producers more than 15 kg/ha. At the other extreme, 32% of producers have no livestock that graze (and hence drop manure) on rangeland.

The estimated annual phosphorus (P) loading to rangeland from livestock manure ranges among feedlot operations from 0 to 40 kg/ha (0 to 36 lb/acre) and averages 11 kg/ha (10 lb/acre). Manure for 25% of producers provides 20 kg/ha or more of P, for 51% of producers more than 10 kg/ha of P, and for 60% of producers more than 6 kg/ha of P.

Table 5. Levels of plant-available N and P from livestock manure dropped on rangeland, 78 feedlots.

N		P	
Range (kg/ha)	0 - 98	Range (kg/ha)	0 - 40
Mean (kg/ha)	37.2	Mean (kg/ha)	11.3
Frequency distribution		Frequency distribution	
kg/ha	Percent	kg/ha	Percent
55 or more	14.3	25 or more	12.7
45.0 - 54.9	12.7	20.0 - 24.9	12.7
34.0 - 44.9	9.5	15.0 - 19.9	6.4
25.0 - 33.9	12.7	10.0 - 14.9	19.0
15.0 - 24.9	11.1	6.0 - 9.9	9.5
0 - 14.9	7.9	0 - 5.9	7.9
0	31.8	0	31.8

Factors associated with cropland manure nutrient loadings

Results of the multiple regression analyses are displayed in Table 6. Both regressions are statistically significant (P < 0.01). Sixty-six percent of the variation in the regressions for both N and P application rates is explained by the independent variables in the regressions.

Table 6. Factors associated with N and P application rates for livestock manure spread on cropland, 78 feedlots.

	Regression	
	N (lb/acre)	P (lb/acre)
Regression parameters		
F-ratio of regression	22.1^{***}	22.3^{***}
Adjusted R^2	65.7	65.9
Regression coefficients		
Intercept	177.149^{***}	54.807^{***}
Feedlot design capacity (head)	0.084^{***}	0.026^{***}
Acres cropland/farm	$- 0.041^{***}$	$- 0.013^{***}$
Percent cropland receiving spread manure applications	$- 1.549^{***}$	$- 0.487^{***}$
Percent total dry matter intake from grain during:		
Backgrounding (225 - 339 kg)	0.442	0.146
Early finishing (340 - 429 kg)	1.347^{**}	0.413^{**}
Late finishing (> 430 kg)	$- 1.121^{**}$	$- 0.338^{**}$
Number beef cows on farm	0.103^{*}	0.032^{*}

***, **, and * denote statistical significance levels of p < 0.01, p < 0.05, and p < 0.10, respectively.

The estimated parameters for six of the seven variables included in the regressions differ significantly from zero. [The one exception is percent of total dry matter intake from grain during the backgrounding feeding period. This outcome may arise because the range of values among producers for this variable is relatively small.] They are as follows:

* Feedlot design capacity (P < 0.01), which is directly related to manure nutrient application intensity--as originally hypothesized--with 0.94 kg/ha (0.84 lb/acre) more manure N and 0.29 kg/ha (0.26 lb/acre) more manure P for every additional 10 head of design capacity;

* Cropland acres ($P < 0.01$), which is inversely related to manure nutrient application intensity--as originally hypothesized--with 0.46 kg/ha (0.41 lb/acre) less manure N and 0.15 kg/ha (0.13 lb/acre) less manure P for every additional 10 acres of cropland;

* Percent of cropland receiving spread manure applications ($P < 0.01$), which is inversely related to manure nutrient application intensity--as originally hypothesized--with 1.7 kg/ha (1.5 lb/acre) less manure N and 0.55 kg/ha (0.49 lb/acre) less manure P for every additional 1% of cropland receiving spread manure applications;

* Percent of total dry matter intake from grain during the early finishing period ($P < 0.05$), which is directly related to manure nutrient application intensity--contrary to the original hypothesis--with 1.5 kg/ha (1.3 lb/acre) more manure N and 0.46 kg/ha (0.41 lb/acre) more manure P for every additional 1% of total dry matter intake from grain;

* Percent of total dry matter intake from grain during the late finishing period ($P < 0.05$), which is inversely related to manure nutrient application intensity--as originally hypothesized--with 1.3 kg/ha (1.1 lb/acre) less manure N and 0.38 kg/ha (0.34 lb/acre) less manure P for every additional 1% of total dry matter intake from grain; and

* Number of beef cows on the farm-ranch ($P < 0.10$), which is directly related to manure nutrient application intensity--as originally hypothesized--with 1.2 kg/ha (1.0 lb/acre) more manure N and 0.36 kg/ha (0.32 lb/acre) more manure P for every additional 10 beef cows in the herd.

Discussion

Only four (5%) of the 78 South Dakota feedlot operators studied apply more manure N to cropland than the maximum manure N guideline of 280 kg/ha/yr currently applicable in Iowa and Kansas. However, 24% apply more manure N than that represented in the 112 kg/ha/yr guideline currently being considered for implementation in Kansas. Since crop productivity (and hence soil fertility needs) tends to be higher in Iowa and Kansas than in South Dakota, these out-of-state benchmark levels are not fully applicable for assessing the status of manure N loadings in South Dakota.

Relative to manure N benchmarks based on South Dakota's generally lower crop yields, the outcome is more environmentally sobering. Forty-two percent of the feedlot operators studied exceed the illustrative average state-wide benchmark level of 64 kg/ha for corn, and 59% exceed the 43 kg/ha benchmark level for wheat.

Because many location-specific factors--including localized crop yields, weather patterns, and soil residual nitrate levels--importantly determine crop utilization of manure N, evaluating the status of manure N at a more micro-level is sounder conceptually. Relative to respective county benchmark levels for corn and wheat, manure N loadings are greater for 41% and 51%, respectively, of the South Dakota feedlot operators studied (Table 7). For manure P, respective county benchmark levels for corn are exceeded by 71% of feedlot operators and for wheat by 52% of producers. For rangeland grass production, the average state-wide benchmark level for manure N is exceeded by 37% of feedlot operators and for manure P by 60% of producers.

Table 7. Instances in which N and P plant-need benchmark levels are exceeded, 78 feedlots.

Type of farmland, plant nutrient, and crop	Percentage of instances exceeded with evaluation criterion at level of: State	Individual counties
Cropland		
Nitrogen		
Corn grain	42	41
Wheat	59	51
Phosphorus		
Corn grain	86	71
Wheat	95	52
Rangeland grass		
Nitrogen	37	n/a
Phosphorus	60	n/a

Thus, these results show substantial percentages of the feedlot operators studied to apply livestock manure plant-available N and P that exceed crop and grass fertility requirements. Nutrient surpluses are greater for P than for N. The latter finding is consistent with Klausner (1989) and National Research Council (1993) who indicate that levels of manure just adequate to meet crop N needs often result in excessive amounts of P.

Multiple regression analyses show six factors to be significantly associated with N and P application rates for livestock manure spread on cropland. Factors directly related to application rates are size-of-feedlot, size-of-beef cow herds, and (unexpectedly) percent of total dry matter intake from grain during early finishing. Factors inversely related to application rates are cropland hectarages per farm, percent cropland receiving spread manure applications, and percent of total dry matter intake from grain during late finishing.

Of these results, the two with the greatest practical implications are the following. Other things the same, 0.94 kg/ha more manure N and 0.29 kg/ha more manure P are associated with every additional 10 head of feedlot design capacity, and 0.46 kg/ha less manure N and 0.15 kg/ha less manure P are associated with every additional 10 ha of cropland operated.

Summary and Conclusion

In summary, this study shows that (1) substantial percentages of the South Dakota feedlot operators studied apply livestock manure plant-available N and P that exceed crop and grass fertility requirements and (2) greater intensity of manure nutrient loadings on cropland is strongly related to larger sizes-of-feedlot and smaller farmland areas on which manure is applied. These two main findings raise some potential "red flags" in regard to possibilities for non-point source pollution of vulnerable water resources from manure produced by fed cattle.

However, the "red flags" are not crystal clear. While major effort was extended to carefully gather and interpret data reported in the literature and secure additional primary data for use in the study, some of the resulting data used in the study are acknowledged to be "rather soft." Further, the findings are not representative of the total population of feedlots in South Dakota, since the feedlots studied are 10-15 times the average size of feedlots in the state.

Within this context, environmental "red flags" are with respect to both South Dakota and the nation's nine major cattle producing states with average feedlot sizes larger than the average in South Dakota [of the nation's 13 major cattle producing states, average feedlot sizes for the three Midwest-heartland states are smaller than that in South Dakota]. In regard to South Dakota, the study findings show a risk of possible non-point source pollution problems arising with feedlots which have high ratios of fed cattle to cropland hectarages located in areas with vulnerable surface and ground water. The potential problems are somewhat greater for excess P than excess N.

In regard to most of the other nine major cattle producing states, it is acknowledged that crop production levels are higher and, therefore, crop nutrient needs are also generally higher than in South Dakota. Assume crop nutrient needs in these other states are as much as 5-6 times as great as those in South Dakota. Recognize also that their feedlots average 7-284 times larger than the average in South Dakota. The two main findings from this study noted above, while not formally subject to generalization, imply the possible existence of rather major challenges in these other states in handling disposition of livestock manure produced in feedlots having rather commonly tens of thousands of fed cattle.

To firm up the data base for more refined future examination of the issues raised in this study, we would suggest particular value in empirical research designed to (1) estimate amounts and nutrient content of manure produced in feedlots representing various conditions; (2) determine relationships among (a) manure production from feedlots of different sizes, (b) cropland areas required for environmentally safe distribution of that manure, and (c) distances that manure can economically be transported; (3) determine the vulnerability of particular sites to surface water and/or ground water contamination; and (4) examine technical and economic possibilities of alternative systems for handling livestock waste.

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