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Quality of Livestock Manure in North Dakota

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ABSTRACT

Manure samples and management data were collected from 43 North Dakota cooperators and three North Dakota State University facilities. Most of the samples were collected as the manure was being pumped for land application. The samples were analyzed to determine the solids concentration, fertilizer nutrients, and other chemical components. The results were compared to published data and found to vary by as much as 100% for some nutrients. The variation appeared to relate to the housing-handling system and management programs. Manure characteristics, except potash, were not found to be closely related to rations fed to the animals.

INTRODUCTION

Manure is a complex material containing valuable nutrients and potential pollutants. Little information is available about the value or quality of manure from modern North Dakota livestock operations. Estimates are available based on nationwide averages (Midwest Plan Service, 1985); however, comparative data reflecting North Dakota livestock production systems, feedstuffs, and management is needed. A livestock producer's manure management plan may emphasize efficient utilization or disposal without pollution. In either case an accurate estimate of the quality of the manure permits setting appropriate application rates.

Evaluation of the manure quality and development of a management plan can result in an economic benefit (Hest, 1986). Manure is normally utilized as a fertilizer for crop production. Knowledge of the plant nutrient concentrations in the manure is necessary to determine appropriate application rates and to prevent environmental pollution.

REVIEW OF LITERATURE

There is a long history of study on manure. In his "Treatise on Manures," Griffiths (1889) reports on studies by earlier researchers. Griffiths gave some data on manure from cows, horses, pigs, and sheep. A farmyard manure was reported to be 72.5% water and 13.94% organic matter. The following percentages were listed: nitrogen 0.38%; ammonia 0.46%; potash 0.32%; phosphoric acid 0.31%. Griffiths also used a mass balance approach in discussing the fate of nitrogen fed to animals. He reported that in other experiments, when 14.15 kg of nitrogen was consumed by cows, 22.0% was assimilated in flesh and milk, 52.8% was recovered in the manure and 25.3% was lost. Russell (1946) gave the composition of dairy manure as 19.4% total solids and 15.2% organic matter. The organic matter contained: 2.8% nitrogen, 1.25% P_2O_5 and 2.9% K_2O. "Manure draining from cow sheds..." was reported to contain 18.2 lbs of nitrogen per 1000 gallons; the P_2O_5 and K_2O contents were 1.7 and 40.1 lb/1000 gal.

In recent years manure values have been published by the American Society of Agricultural Engineers, Soil Conservation Service, Midwest Plan Service, and other individual researchers (Martin and Matthews, 1983; ASAE, 1985). While the values published may be useful in estimating the nutrients in manure, there is a great deal of variation. The cause and effects of variation have not been well defined. Several attempts have been made to better define manure characteristics as they relate to crop utilization and potential environmental impacts (Barth, 1985; Chescheir and Westerman, 1984; Converse and Holmes, 1985; Payne, 1984; Safley et. al, 1985; Schulte et. al, 1985; Steenhuis, 1979; Welty, 1985; and Westerman et. al, 1985).

Manure quality varies with feedstuff, age and kind of animal. Growing animals or those producing milk excrete about 70 to 80 percent of the nitrogen consumed. Mature animals not gaining in weight or producing milk excrete nearly all the nitrogen, phosphorous and potassium in their ration (Morrison, 1957).

Manure is collected and stored different ways after being produced and before being hauled to cropland. Modern livestock systems minimize bedding use to save labor and costs; with less bedding absorbing the liquids the manure has a more liquid characteristic. Typical handling systems used with modern drylot, confinement livestock production systems include: barn (gutter) cleaner to stack or liquid storage tank; tractor or mechanical scraper to small storage tank or pump chamber and then to long term storage; slotted floor over a large storage tank or a gutter that is flushed or scraped to long term storage; and bedded manure pack (Midwest Plan Service, 1985). Although little study has actually been done it is supposed that these various handling/storage techniques affect manure quality (Figure 1 and 2). Generally the less manure is exposed to air (e.g. stepped-on, scraped, stirred, pumped) the longer it should retain its original nutrients (Figure 3).

Schulte et. al (1985) reported 66% nitrogen loss from swine manure during collection by use of

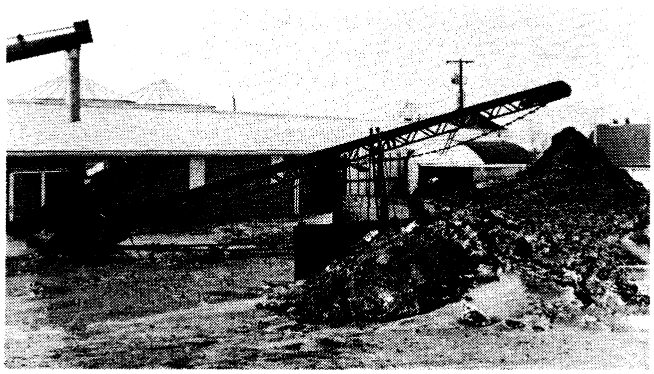


Figure 1. Semi-solid manure (20-25% TS) is sometimes stacked and spread later. Seepage, files, freezing and odors are problems. About one-fourth of the nitrogen may be lost during handling and storage.

Figure 2. A high investment in facilities and equipment is needed for storing, agitation, pumping, hauling and spreading liquid manure (up to 15% TS). About one-third of the nutrients are lost in handling and storage. Fenced, earthen storage is often used to contain several months manure production from large dairy, swine and poultry operations.

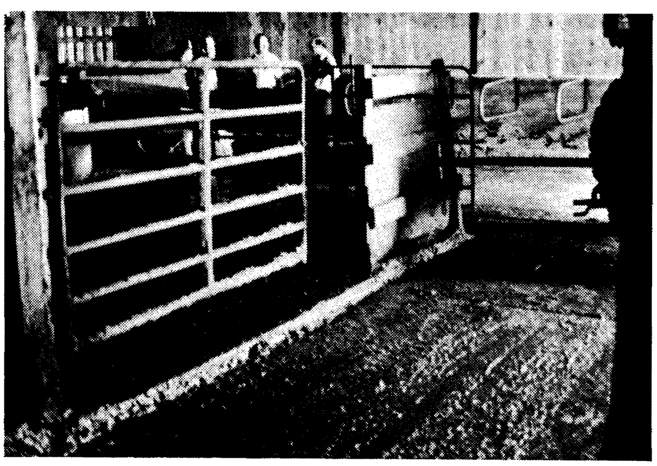


Figure 3. Scraping is a typical method of moving manure to storage. This is a daily chore and exposes large, wet surfaces that add to ventilation and odor problems.

underslat scrapers. This was based on the theoretical nitrogen concentration. Nitrogen losses from dairy manure were reported by Welty et. al (1985) as during collection, 26 to 28%, and while stored in concrete tanks, 5 to 15%. They found ammonium increased by 2.4 to 3.0 percentage points while the organic nitrogen or total Kjeldahl nitrogen (TKN) decreased a similar amount. Westerman et. al (1985) estimated ammonia losses during field spreading (Table 1). Timely incorporation can save nutrients (Figure 4). Goodrich reported that at the University of Minnesota Experiment Station - Waseca twice as much ammonia was lost from surface-spread liquid manure compared to injected manure (Farm & Ranch Guide, 1987). The result is a need for more purchased fertilizer.

Wind and temperature significantly effect ammonia volatilization losses, according to Steenhuis et. al (1976). Generally for temperatures above freezing, 50 to 90% of the ammonia was lost within two days of land application. At −20°C losses were less than 30% in 10 days (Steenhuis et al., 1976).

The rate of ammonia losses is affected by the rate of conversion of urea to ammonia, which is temperature dependent. Steenhuis et. al (1979) found when dairy manure with bedding was applied to bare (no snow) alfalfa in mid-January 90% of the urea and 75% of the water soluble organic nitrogen was lost with snow melt runoff. Urea and soluble organic nitrogen account for about 50% of the nitrogen in fresh manure.

Table 1. Estimated Ammonia Loss from Manure Exposed on Soil Surface. (Westerman, et al. 1985)

Days after spreading	Accumulated $NH_4 - N$ loss, % Fresh manure	Liquid (4-11% TS)
1	25	25
2	40	40
3	55	50
7	80	60

Figure 4. Plowing down immediately following broadcasting or knifing-in liquid manure minimizes odor problems and nutrient loss when field spreading. Application rate is limited, however, and power requirement is increased. Godwin, et al (1985) reported winged applicator tines reduced draft 50 percent and improved application efficiency compared to narrow tines.

Planning efficient manure management systems demands a knowledge of manure value. These values may be determined by laboratory analyses or by estimation from previous study results. Under most operating conditions it is difficult to get representative test analyses in a timely manner. Simple tests might alleviate this problem. Chescheir and Westerman (1984) reported on the use of a simple hydrometer to determine solids concentration and a "nitrogen meter" to determine available nitrogen concentrations. They indicated these tools were relatively successful, and although their accuracy is limited, they could be readily used, on-site, during the unloading of a manure storage facility. Payne (1984) reported that electrical conductivity, which is easily measured, is a good method for estimating nutrient concentrations in lagoon effluents.

As more knowledge is gained on transformations that occur in manure during handling, storage, and disposal, the manure value can be predicted more accurately. The specific handling conditions and how these affect the manure will have to be known. This is one need for further research. Farmers know there is benefit to spreading manure on cropland. A recent article in the Dakota Farmer (Hest, 1986) suggests that proper manure management can result in a significant economic benefit. A major factor is knowing how much to spread per acre.

PURPOSE AND OBJECTIVES

The purpose of the study reported was to identify quality of manure in North Dakota so that the best use could be made of this resource. The first objective was to compare the characteristics of as many manure samples from North Dakota farms as possible with currently published data. The second objective was to determine the effects of storage types, handling systems and management on the manure quality.

The study was intended to derive as much information as possible from a limited effort. Time and funding was not available to do an in-depth study of several questions which could provide information for the best utilization of livestock manures. Some of the questions that were only addressed superficially, or ignored, were: definitive response to ration variations, total manure production, crop response, and the effects of such innovative techniques as addition of ammonia to the manure.

METHODOLOGY

This study was conducted from 1984 through 1986.

A commercial liquid manure pumper-hauler agreed to assist with collecting samples as he went from place to place. This was useful in getting more samples from a wider area of the state. Most of the samples were "liquid" manure from drylot or indoor confinement production systems. A sample (approximately one quart) was taken by the operator as the storage, holding several months of manure production, was emptied and hauled to cropland (Fig. 5). Normally a sample was collected when the storage was one-third empty and again when two-thirds empty. The sampling time did vary in some cases. Sometimes only a single sample was obtained and occasionally there were three samples. At five farms samples were collected from different points in the handling system, e.g. where the "fresh" manure was moved from the gutter to long term storage and again where it was pumped from the long term storage. At 15 farms, samples were taken in 1984-85 and again at these same farms in 1985-86.

Samples were frozen in the farmer's freezer to minimize changes in nutrient content and later collected by the extension engineer when in the area. The frozen samples were packed in ice and shipped via air freight to the University of Minnesota Agricultural Engineering Analytical Laboratory. This laboratory regularly analyzes manure samples for a nominal fee for researchers in several states. Analyses included determination of concentration of solids, nutrients, and salts.

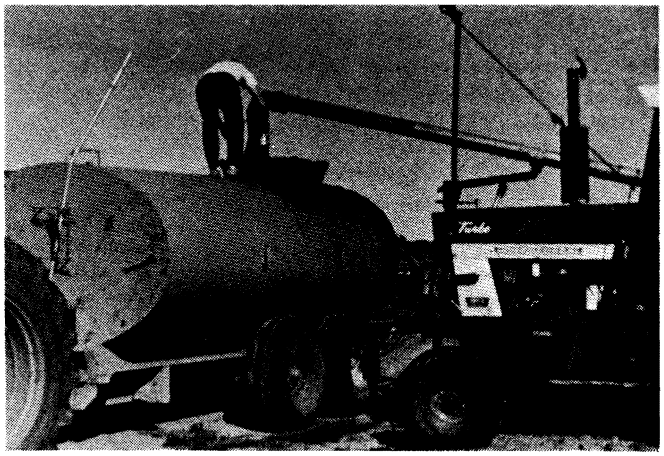


Figure 5. Sampling of liquid manure was done after tank contents were agitated and about one-third of the storage volume had been pumped and hauled.

RESULTS AND DISCUSSION

A total of 120 manure samples were collected from 46 livestock operations around North Dakota including 34 dairy farms, 9 swine farms, and 3 beef cattle feedyards. Two swine operations were sampled at the farrowing barn, finishing barn, and long term storage. One sample was taken after anhydrous ammonia had been added in a loaded tank wagon (Fig. 6).

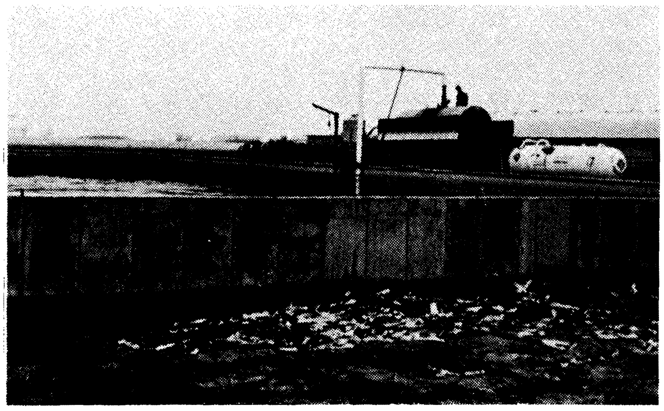


Figure 6. Anhydrous ammonia was added to liquid manure as it was pumped from storage on the West farm. The nitrogen content of the manure was estimated and the desired amount of ammonia added using the tank gauge as an indicator.

Independent variables used to analyze the variations in manure quality were animal species, housing type, manure storage, transport to storage, bedding used, and whether or not extra water was added. The dairy housing systems included: cold free stall, warm free stall, and warm tie stall (Table 2). Most manure storages were earthen (E), covered concrete tanks (Ct), or concrete tanks in combination with earthen storages (Ct&E). Other long term storages sampled were an open-top above-ground metal tank (OMT), two open-top concrete tanks, a bedded pack, open feedlot and a manure pile. Manure transport to the storage was classified as chopper pumps, piston pumps, flushing, or none. The chopper pump mixes together liquid and broken-up solids as they are moved; the piston pump simply forces the mass along. Barley straw, wheat straw, oat straw, unidentified straw, or none were bedding types.

The fertilizing constituents in manure come from the feedstuffs consumed. Operators were queried about the rations that had been fed to the animals producing the manure. The information regarding feedstuffs used was provided but form (e.g. chopped, long, pelleted, etc.) was not recorded. Neither the quantity nor quality of rations or water was determined.

Manure samples in this study were produced from growing animals or those producing milk and would be somewhat lower in N, P, and K than manure from mature animals not producing milk.

Although corn or corn silage was part of nearly all rations in the study, its quality may differ from that in the cornbelt. Because of the shorter growing season, corn is not a major North Dakota crop (North Dakota Agric. Statistics, 1986). Shelled corn was in 24 of the 46 rations. All but six of the 46 fed oats, barley, or both cereal grains. All swine producers fed some barley. The manure from animals fed oats and barley may be expected to contain higher concentrations of N, P, and K than manure from animals on a corn ration. (Morrison, 1957). The commercial pumper and others reported that manure from animals being fed corn agitates and pumps much easier than when barley or oats are being fed. Hulls and fiber from the later feeds separate and forms a solid mass this is difficult to suspend.

All but two of the 34 dairy operations fed alfalfa hay or haylage and those two used sweet clover silage. Alfalfa hay contains higher levels of N and K than shelled corn, oats, or barley. Prairie hay was included in seven dairy rations. Oats, barley, and wheat straw (often chopped) were used for dairy freestall bedding. Some millet straw, corn stover, and sawdust had been used in individual dairy operations.

Table 2. Types of housing-handling systems in study.

Livestock/Housing	Manure handling	Storage Type	Number of Facilities	Number of Samples
Dairy cold free stall	Scraper, CT, Ch pump	ES or OMT	19	53
Dairy cold free stall	Scraper, PPump	ES	8	19
Dairy warm free stall	Scraper, PPump	ES	1	3
Dairy warm free stall	Scraped	CCt	1	2
Dairy warm tie stall	B. cleaner, PPump	stack	1	1
Dairy warm tie stall	B. cleaner, PPump	ES	1	2
Dairy warm tie stall	B. cleaner, Ct, Ch pump	ES	2	4
Dairy warm tie stall	B. cleaner	stack	1	2
Beef outside feedyard	Scraped	pile	1	2
Beef manure pack	Bedded pole barn		1	2
Beef confinement	Sl floor over	CT	1	3
Swine breeding to finish	S or Fl gutter, Ct, Ch pump	ES	6	17
Swine farrow	S or G. gutter	Ct	3	4
Swine finish	Various		5	6

**Note some operations have more than one facility included.

Manure quality - Nutrients in manure are part of the total solids content. The percentage of the manure composed of solids will vary with the amount of water added or allowed to enter the storage. Water is sometimes added to help liquefy manure and make it easier to convey and pump. Additions of bedding materials and any evaporation will result in higher percent total solids. The mean total solids (TS) concentration was 8.2% for all samples and also 8.2% for the 87 dairy manure samples (Table 3). The value published by the Midwest Plan Service for dairy manure from liquid storage is 8%. The cold free stall systems had a mean of 7.9%. Manure from the warm dairy housing systems was drier; the warm free stall systems produced manure with an average of 10% TS and the warm tie stall systems produced 8.9% TS manure.

Table 3. Average nutrient values in manure samples.

	TS	N	NH_3	P_2O_5	K_2O
	% w.b.	-----------lbs/1000 gal			-----------
All species (120)*	8.2	33.0	23.2	12.9	22.2
Dairy, As-produced (MWPS)**	12.7	41.3		16.8	33.1
Dairy, liquid (MWPS)	8.0	24.0	12.0	18.0	29.0
Dairy samples (87)	8.2	31.0	13.1	9.4	22.2
Dairy CFS (68)	7.9	20.8	8.3	8.3	24.1
Dairy WFS (10)	10.0	30.8	12.8	14.7	24.7
Dairy WTS (7)	8.9	81.9	37.9	21.5	26.1
Dairy WTS (5)***	7.2	34.0	20.4	15.6	25.0
Cold Free Stall Dairies:					
No water added (18)	10.0	23.1	9.8	8.9	25.5
Piston pump (5)	10.8	24.1	11.3	10.3	24.1
Chopper pump with					
oats straw (8)	7.5	19.2	7.7	6.0	22.0
w/barley (4)	14.6	25.4	10.6	13.5	27.6
Water Added (16)	7.0	19.0	7.8	7.1	21.5
Piston pump (7)	5.5	17.1	5.3	8.0	19.2
Chopper pump (9)	8.1	19.5	9.3	9.1	22.2
Ct&E (6)	7.7	16.1	8.0	9.4	23.7
Swine, As-produced (MWPS)	9.2	57.9		42.5	45.8
Swine, liquid (MWPS)	4.0	36.0	26.0	27.0	22.0
Swine Finishing (7)	4.0	27.4	7.9	18.3	25.3
Swine Farrowing (4)	3.6	24.0	11.3	25.5	11.2
Swine breed. thru finishing (15)	4.0	39.9	9.3	21.8	15.7
Beef, As-produced (MWPS)	11.6	47.6		34.9	40.3
Beef, solid (MWPS)	15.0	45.7	16.6	29.1	41.5
Beef outside lot (2)	41.2	46.0	3.0	38.5	62.0
Beef manure pack	24.0	53.0	23.6	13.0	18.5
Beef confinement	11.7	57.4	—	22.2	38.1

*Numbers in parens are the number of samples represented.
**Midwest Plan Service Committee (1985) values are provided for comparison.
***Two samples with extreme variation were excluded.

Generally the TS was higher for manure moved via a piston pump. It may be that the agitation by a chopper pump enhances the settling process and the settled solids are not readily resuspended. When no water was added, the manure was drier (10.8% TS) when pumped through a piston pump compared to the use of a chopper pump and the use of oats straw for bedding (7.5% TS). However, the four samples from chopper pumps where barley straw had been used had a mean of 14.6% TS. Systems using a piston pump and adding water either from the milking center or during agitation and pumping had a mean of 5.5% TS.

Mean total solids concentration of the swine manure samples was about the same as the value published by the Midwest Plan Service Committee (1985), 3.6 to 4.0% for the samples compared to a published value of 4.0%. The flushed swine manure was the most liquid with 1.8% TS. Water is commonly used in cleaning swine barns and also to aid manure flushing.

The mean nitrogen content of all dairy manure samples (31 lbs/1000 gal) was slightly higher than reported by the Midwest Plan Service of 24 lbs/1000 gal. However, the samples from the cold free stall systems had a nitrogen content (21 lbs/1000 gal) which was below the published value. Cold free stall housing systems often provide outside yard space; this reduces the need for daily cleaning and leaves the manure spread thinly and exposed for a longer time, which may result in greater nitrogen loss. The 10 samples from warm free stalls had a mean of 31 lbs/1000 gal and the seven from warm tie stall had a mean of 81.9 lbs/1000 gal. Manure in the warm systems was subjected to minimum exposure.

Storage of manure in a more dilute state appeared to help conserve nitrogen. The nitrogen concentration when no water was added was 2.8% d.b. compared to 3.3% d.b. when water was added. The four dairy systems that used barley straw produced manure with 2.1% nitrogen. Manure pumped from cold free stall systems using a piston pump and with added water had a nitrogen concentration of 3.7% d.b. As would be expected because of dilution, when calculated on a wet basis (as the manure was applied), the manure with water added had lower nitrogen concentrations.

The mean phosphorous content for the 87 North Dakota dairy samples was 48% less than the value given by Midwest Plan Service (9.4 compared to 18.0 lbs/1000 gal). The only North Dakota housing system which produced phosphorous concentrations above 18.0 lbs/1000 gal was the warm tie stalls.

Potassium content in North Dakota manure was generally lower than the published values. On a dry basis, manure from cold free stall systems using barley straw for bedding and handling the manure with a chopper pump had a potassium concentration of only one-half of that given in the Midwest Plan Service handbook (1.9% compared to 3.6%).

The nitrogen concentration measured in the swine manure was slightly lower than the MWPS values except the breeding through finish group (samples were from storages that had manure from all phases of production). The ammonia found was about one-half for all swine categories. Phosphorous and potassium were also similar.

Beef manure quality was maintained where slotted floor confinement housing/handling was used. Generally there was greater variation in quality and lower quality where manure was exposed to air during storage. Manure from open lots had a very low ammonia concentration. The correlation between MWPS values and those found in this study for beef was almost the same as for swine. A major difference was the nitrogen content, which was much less for the beef; the measured mean was only one-sixth of the published value.

Variation in manure characteristics. The results of quality analyses exhibited wide variation as measured by coefficient of variation (CV = ratio of standard deviation to the mean; Ostle, 1963). When all 120 samples were considered, the largest CV was 1.43 for nitrogen (Table 4). Ammonium had a CV of 1.92, but since ammonia analysis was not included the first year, this was for only 63 samples. Many factors can cause variation in the nitrogen forms. The amount of nitrogen originally in the manure is affected by the ration and the animal's state of productivity. Microbial transforms and ammonia volatilization will cause further changes.

Coefficients of variation for phosphorous and potassium for the 120 samples were 0.91 and 0.52. Total solids and volatile solids concentrations had CVs of 0.75 and 0.79, respectively. Very little variation was noted in pH, which had a mean of 7.4 and a CV of 0.09. Most samples were between 6.4 and 8.0. Two samples were below 6.0 and two were above 10.0. One of the high samples was taken after the addition of anhydrous ammonia.

The 87 dairy manure samples had CV's of 0.95, 0.72, and 0.26 for N, P, and K. Similar variation was observed in our review of 35 samples (data not included in this report) analyzed by a commercial laboratory in Minnesota (Olsen, 1984). Analyses of those samples were shared with us but not identified as to source, kind of livestock, etc. The CVs for N, P, and K were 0.53, 0.98 and 0.43, respectively. The 15 swine samples had similar variation with CVs of 0.80, 0.64, and 0.43 for N, P, and K. Because of the low number of beef samples CVs were not calculated.

Table 4. Manure characteristics and variation.

	Number of samples	Total solids	Volatile solids	Nitrogen	Phosphorous	Potassium
		%	%	----------lb/1000 gal----------		
All samples:	120					
Mean		8.21	5.79	32.96	12.88	22.18
CV		0.75	0.79	1.43	0.91	0.52
Dairy:	87					
Mean		8.24	5.70	30.27	9.41	22.17
CV		0.77	0.81	1.75	0.72	0.26
Dairy (CFS, chopper pump):	50					
Mean		7.99	5.30	20.19	8.41	22.98
CV		0.38	0.26	0.21	0.34	0.18
Dairy (CFS, piston pump):	20					
Mean		7.80	5.30	20.58	7.19	20.61
CV		1.76	2.52	3.34	2.42	0.82
Dairy (WFS):	3					
Mean		9.90	7.23	30.83	14.65	24.73
CV		0.26	0.27	0.28	0.34	0.34
Dairy (WTS):	4					
Mean		4.84	3.29	17.01	5.51	16.37
CV		0.28	0.30	0.19	0.26	0.13
Dairy (oats straw bedding):	25					
Mean		6.65	4.59	18.40	6.69	20.93
CV		0.15	0.36	0.03	0.40	0.25
Dairy (oats straw, no water):	10					
Mean		8.09	5.76	20.99	7.64	24.04
CV		1.66	0.18	0.21	0.44	0.17
Dairy (oats straw, water):	7					
Mean		4.49	2.82	12.95	4.46	14.84
CV		0.83	0.29	0.21	0.34	0.14
Dairy (barley straw bedd.):	10					
Mean		10.24	5.61	21.23	10.16	23.56
CV		0.39	0.09	0.09	0.24	0.13
Swine:	15					
Mean		4.02	2.88	39.94	21.83	15.68
CV		0.66	0.77	0.80	0.64	0.43
Swine (farrowing):	4					
Mean		3.56	2.38	24.04	25.53	11.17
CV		1.01	1.11	0.43	1.07	0.39
Swine (finishing):	7					
Mean		4.03	2.68	27.35	18.25	25.25
CV		0.67	0.95	0.49	0.76	1.21

The mean nutrient contents (N, P_2O_5, and K_2O) for the 120 samples were 33, 13, and 22 lbs/1000 gallons (Table 3). The 35 Minnesota samples averaged 36, 16, and 31. For the 87 North Dakota dairy samples these were 31, 9, and 22 compared to the MWPS published values of 24, 18, and 29.

Samples were collected from 11 dairy and two swine farms in both 1984 and 1985. The averages for the two years and differences are given in Table 5. A comparison of the analyses from the dairy cooperators, excluding the swine samples, indicated little difference in the quality from year to year. This could be explained in that dairy feeding, bedding and general management tend to be more consistent from year to year whereas swine manure handling systems, rations fed and general management can be more flexible because of greater animal turnover and the use of purchased feed grains.

Housing-handling system effect. Grouping the sample values by type of housing system reduced the variation. The largest CV for any parameter considered for the cold free stall housing systems was .45 for ammonia. There were fewer samples for the other types of housing and the CVs were slightly larger. Nitrogen had a CV of .28 for the warm free stall systems (Table 4). In general, including more specifications in defining the system and management reduced the coefficient of variation. Therefore one might conclude that the characteristics of manure are related to the system and management used.

A subjective comparison of the samples and their origins also indicated that overall management was perhaps as important a factor as the design or type of housing-handling system. For example, one WFS dairy scraped daily to storage below the floor and had average N, P, K of 3.0, 0.6, 2.0% d.b. (dry basis). For comparison a dairy with outdoor earthen storage and alleys sporadically scraped had an average manure quality of 2.7, 0.4 2.8%. Another example is one swine finishing producer with below-slat floor manure storage that had a manure quality of 5.8, 2.3, 9.7% for N, P, and K as compared to another producer using open flush gutters to open outdoor storage whose manure quality averaged 3.8, 1.2, 1.2% for N, P, and K, respectively. Other similar comparisons were indicated in the individual analyses.

The effect of system on manure quality was investigated using a general linear model (GLM) procedure developed by SAS Institute, Cary, North Carolina. The concentrations of N, P, K, and total solids were all found to be affected by the type of housing, kind of handling system, storage type, bedding used, and pumping date. When dairy manure samples only were analyzed similar effects were found, except there was no significant effect for storage type and the housing type and handling system did not significantly affect the potash concentration. A model using the class variables of housing type, handling/pumping method, bedding type, and date the storage was emptied gave an R-squared value of 0.75 for dairy manure total solids concentration ($Pr > F = .0001$). These findings suggest that the system design and management affect the manure quality.

Manure was sampled at different places in one WFS manure system and four swine systems. Generally the nutrient values decreased as manure progressed through the system; however, this varied among operations and among nutrients (Table 6).

Effects of Feed Ration. The manure quality data was sorted according to the ration ingredients and the mean determined for each group of samples. Ration content had been obtained for 73 of the 120 manure samples. Mean nitrogen, phosphate, potash, and total solids concentrations of the manure were determined for each ration ingredient and for several ingredient combinations. Very little variation was observed in total solids or potash concentrations (Figures 7 and 8). The overall mean TS was 8.7% (std. dev. 6.6). Ration combinations of corn and alfalfa resulted in 12.3% TS as a high group mean and the combination of barley, corn silage, and sweet clover gave 5.4% TS. The overall mean for K_2O was 22 lb/1000 gallons. All rations containing sorghum-

Table 5. Comparison of manure quality sampled for two years.

	pH	TS	% VS	N	P	K
		%w.b.	%d.b.	mg/kg d.b.		
Dairy and swine (13 cooperators, 47 samples):						
1984 average	7.44	7.4	69	31414	5937	33099
1985 average	7.68	6.9	68	63135	13414	39641
Overall average	7.54	7.1	68	46263	9437	36161
Difference in means	0.24	0.5	1	31721	7478	6542
Ratio difference/means	.03	.07	.01	.69	.79	.18
Dairy only (11 cooperators, 41 samples):						
1984 average	7.44	7.4	69	31414	5937	33099
1985 average	7.68	8.0	70	32109	5927	29967
Overall average	7.54	7.6	69	31685	5933	31877
Difference in means	.24	.60	1	695	10	3132
Ratio difference/means	.03	.08	.01	.02	.00	.10

Table 6. Manure sampled at different places in system.

Operator	Type	Where Sampled	Storage Type	Moisture Content	N	P_2O_5	K_2O
				%	----lbs/1000 gal----		
Swine 1	Comb.*	Flush gutter	—	98	31	8	16
1	Comb.	Collection Tank	C. Conc. Tank	98	20	5	9
1	Comb.	Outside Aerator	Open C. Tank	97	32	18	18
1	Comb.	Liquids Lagoon	Earthen	99	11	1	12
Swine 2	Farrow	Collection Tank	Cov. C. Tank	90	32	72	9
2	Finish	Collection Tank	Cov. C. Tank	95	23	33	9
2	Comb.	When Hauled	Earthen	95	37	30	20
Swine 3	Comb.	Collection Tank	C. Conc. Tank	93	44	37	20
3	Comb.	When Hauled	O.C. Tank	94	54	33	24
Swine 4	Farrow	Collection Tank	C. Conc. Tank	97	36	18	18
	Finish	Collection Tank	C. Conc. Tank	95	23	33	9
	Comb.	When Hauled	Earthen	95	43	30	17
	Comb.	Near bottom	Earthen	89	67	57	24
Dairy 1	WFS	Collection Gutter	—	85	173	23	34
1	WFS	When Hauled	Earthen	91	37	21	33

*Comb. refers to swine operators where manure from all phases of production was combined in storage.

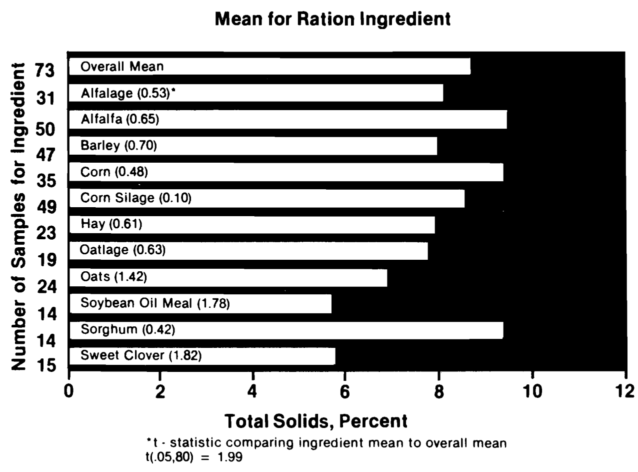


Figure 7. Total Solids in Manure.

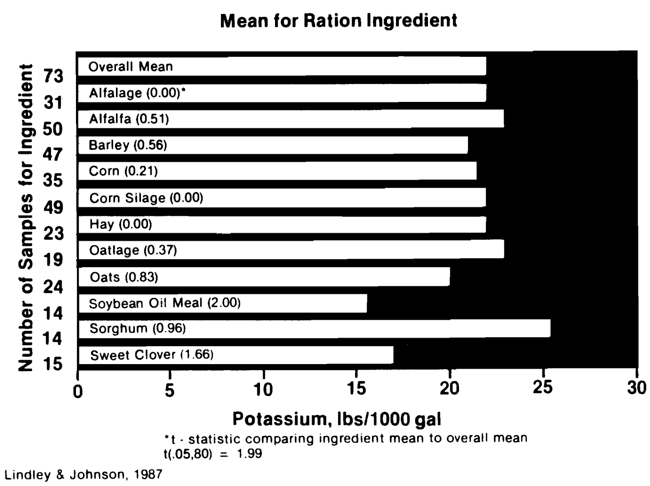
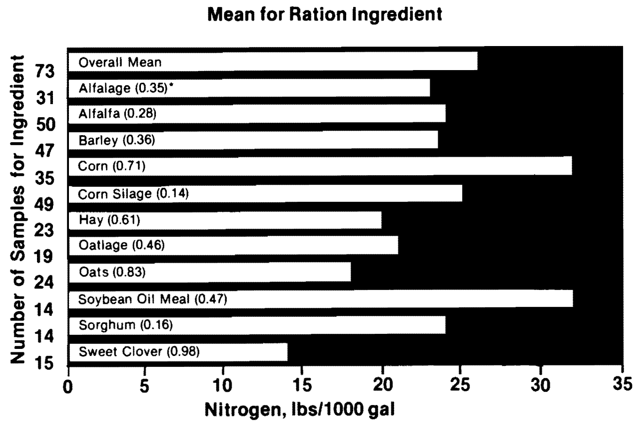


Figure 8. Potassium in Manure.

sudan had greater than 26 lb/1000 gallons with oatlage and sorghum giving 28 lb K_2O per 1000 gallons. The low group was corn with soybean oil meal at 15.6 lb/1000 gallons.

Although there appeared to be greater variation in nitrogen concentrations between groups (Figure 9), the variation was not found to be statistically significant using a t-test (alpha = 0.05). Corn or soybean oil meal in the ration tended to give high nitrogen concentrations in the manure produced. The highest N concentration of 38.6 lb/1000 gallons resulted for rations containing barley and soybean oil meal. Oats or sweet clover in the ration tended to give low nitrogen concentrations. The lowest group mean was 14.0 lb/1000 gallons for oats with sweet clover. This finding would support that higher protein rations result in higher N in the manure.

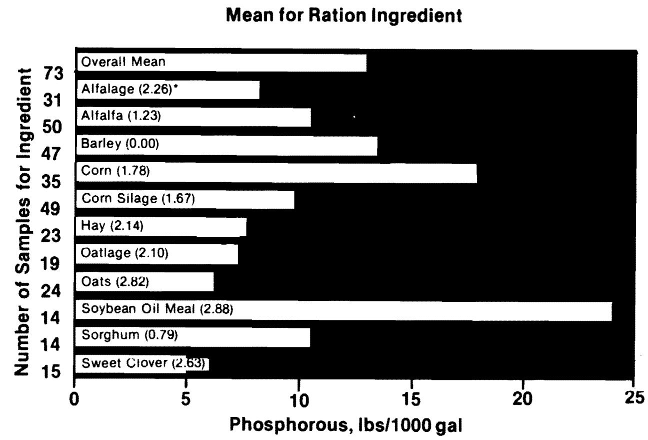
The only characteristic for which signficant differences were found was phosphorous (Figure 10). Table 7 lists the ration combinations which were found to have a significantly different group mean from the overall mean. The greatest difference from the overall mean was found for the samples from animals that had been fed rations containing barley and soybean oil meal. These samples had a group mean of 35.6 lb/1000 gallons compared to an overall mean of 13.0 lb/1000 gallons (t = 4.90, d.f. 8,73). The lowest group mean was 4.9 lbs/1000 gallons for ration with barley and sweet clover.



*t - statistic comparing ingredient mean to overall mean
t(.05,80) = 1.99

Lindley & Johnson, 1987

Figure 9. Nitrogen in Manure.



*t - statistic comparing ingredient mean to overall mean
t(.05,80) = 1.99

Lindley & Johnson, 1987

Figure 10. Phosphorous in Manure.

Nutrient Interrelationship. The mean nitrogen concentration (d.b.) decreased with increasing mean total solids concentrations for the cold free stall systems. A regression analysis using the six cold free stall categories gave a slope of −1469 and an R^2 of 0.717. When all 68 samples were used the R^2 dropped to 0.262; slope of −1728. Potassium was found to decrease with increasing solids concentration (slope was −2252, R^2 was .524).

Nutrient Value. An economic value of manure may be estimated based on the three major nutrients and current prices of commercial fertilizer. Using a fertilizer value of $115 per ton for 46-0-0, N is worth $0.13/lb (Fanning, 1987). If 18-46-0 cost $164 per ton, P_2O_5 is worth $0.13/lb. Potash, K_2O, is valued at $0.11/lb based on $130 per ton for 0-0-60. One thousand gallons of "average" North Dakota manure has 32 lb of N at $0.13/lb., 13 lb of P_2O_5 at $0.13/lb, and 22 of K_2O at $0.11/lb giving a total of $8.25 per 1000 gallons. Manure from the cold free stall housing systems would be estimated at $6.08. Swine manure would be valued at $9.75. These estimates do not consider the value of micronutrients which are in the manure. An Iowa study reported swine manure values from $7.08 from farrowing pits to $13.60 from finishing pits (Carlson, 1976). They used fertilizer values of $0.13/lb of N, $0.18 for P_2O_5, $0.08 for K_2O, and $0.12 for sulphur.

Table 7. Manure characteristics for different feed rations and t-values for phosphorous (P_2O_5).

Ration Ingredients	Number of samples	N	P_2O_5	K_2O	t-value
All samples with rations known	73	26	13	22.0	0.0
barley and soybean oil meal	8	38.6	35.6	16.8	4.90
Soybean oil meal	14	32	24	15.6	2.88
corn and barley	15	31	23	17.9	2.68
barley and alfalfa	36	20	8.3	21.6	2.36
alfalage	31	23	8.2	22	2.25
hay	23	20	7.7	22	2.14
oatlage	19	21	7.3	22	2.10
oats and barley and CornSilage	15	18.2	6.5	20.3	2.13
oatlage and alfalfa	15	19.4	6.5	21.2	2.14
oats and barley	16	18	6.4	20	2.23
oatlage and hay	13	17.8	6.3	20.8	2.05
oats	24	18	6.2	20	2.82
oats and Corn Silage	23	17.7	6.2	19.9	2.76
oats and alfalfa and Corn Silage	20	16.3	5.5	19.2	2.85
oats and alfalfa	21	16.3	5.5	19	2.92
oats and barley and alfalfa	13	16	5.4	18.9	2.33
alfalfa and Corn Silage and SwClover	13	14.3	5	17.2	2.45
oats and Corn Silage and SwClover	13	14.3	5	17.2	2.45
Sweet Clover	15	14	5	17	2.63
barley and Sweet Clover	9	14.2	4.9	17.5	2.06

SUMMARY AND CONCLUSIONS

A limited, statewide study was made of manure quality from beef, dairy and swine farms in North Dakota. The purpose of the study was to learn about North Dakota manure quality to aid more efficient handling, storage and utilization. One hundred twenty manure samples were collected during 1984 through 1986 as the manure was hauled to cropland for application. Separate samples were taken at different places in four swine operations to evaluate quality differences within systems.

Samples were immediately frozen to preserve their quality and later delivered for laboratory analyses. The procedure worked satisfactorily and especially so considering the amount of volunteer work involved in the study. Laboratoy analyses were conducted for pH, TS, VS, TKN, NH_3, P, K, and 18 micronutrients.

Manure nutrient variations among samples in this study were comparable to those of samples analyzed from 35 Minnesota operators by a commercial laboratory who shared analyses with the authors (Olsen, 1984). The data has shown that variations of 50% or more from the mean values are not uncommon. Ration alone was not a good indicator of manure quality.

Nitrogen is the major nutrient most likely to vary with time and may be of most concern with respect to crop production and pollution potential. Livestock operators might make an improved estimate of manure value by measuring the total solids concentration and the nitrogen content. Total solids concentrations can be determined by drying samples in an oven or microwave. The "Nitrogen Meter" provides a method of quick on-farm estimation of nitrogen content.

Loading, hauling, and spreading costs are a further consideration. On the one hand, manure disposal needs to be accomplished somehow; on the other hand, such a cost estimate is useful for buying or selling manure. One Texas feedlot study is known on this (Sweeten, 1979). There are custom haulers who can also provide cost estimates. An estimate could also be made using machinery cost estimating techniques.

Analysis of the data and the system descriptions suggest the following conclusions:

1. Manure quality was comparable from one year to the next for an individual dairy operation.
2. The solids concentrations for manure samples from North Dakota were similar to published values. The TS found for beef lot and bedded pack manure was higher than the value for solid manure published by Midwest Plan Service (1985); however, only one lot and one bedded pack operation were sampled.
3. Nutrient values in manure can vary by 50 to 100% from published values. The nitrogen content for the dairy manure samples was generally below the published value; however, it was higher for the warm buildings. The P_2O_5 and K_2O values in the manure samples was generally lower than the published values. A notable exception was the beef lot manure, and if this were calculated on a dry basis, it would also be lower.
4. Deviation from published nutrient values for North Dakota samples appeared to be related to housing-handling storage system and management. Use of information on the housing-handling system design and management program should provide more accurate predictions of manure values. This should allow better utilization of the manure resource.
5. Manure quality varies as it is handled and stored.
6. Manure characteristics other than phosphorous were not closely related to rations fed to the animals. Phosphorous concentrations were more closely related to ration than to other management factors. It should be noted that while a close correlation was not found between manure nutrients and rations, the generally lower manure quality may be related to the different between typical North Dakota rations and those used in the major corn belt areas.

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