Utilization of Animal Manure for Crop Production Part II. Manure Application to Cropland
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Introduction

The following management practices are suggested for livestock producers to help them achieve the type of management that will accomplish desired animal production as well as environmental quality goals. In addition to water quality concerns, applying manure to land warrants close attention to management practices so potential odor problems can be minimized or avoided. For example, irrigation of manure to land can be an effective method for delivering manure to land in a short period of time, without damaging the soil structure which can occur with other application methods. However, the process can be odorous.

The reader is referred to the most recent version of the "Generally Accepted Agricultural and Management Practices (GAAMP) for Manure Management and Utilization" adopted by the Michigan Agriculture Commission under the Right To Farm Act. This set of voluntary management practices contains guidance for livestock producers regarding (a) runoff control and wastewater management, (b) odor management, (c) construction design for manure ponds and lagoons, and (d) manure application to land. Please refer to this document for the specific management practices that producers are encouraged to follow.

The GAAMP for Manure Management and Utilization that pertain to manure application to land are discussed in this bulletin. Michigan State University Extension (MSUE) encourages MI livestock producers to follow these recommended manure management practices. The task force responsible for writing these practices feel they are reasonable and can be accomplished by the majority of producers without creating a competitive disadvantage to the MI livestock industry.

As was discussed in Bulletin MM-1 (Jacobs, 1995a), producers often can obtain economic benefits by making better utilization of manure nutrients in crop production. However, Bulletin MM-1 also discusses the need to evaluate the balance between manure nutrients generated on the farm and the capability of the land base associated with the livestock operation to utilize these nutrients. Such an evaluation will ensure responsible management of animal manure that will protect MI's surface and groundwater resources.

Manure Analysis

Manure should be analyzed for the percent dry matter (i.e., solids), total nitrogen (N), ammonium-N (NH_4-N), and the total phosphate (P_2O_5) and potash (K_2O) to determine its nutrient content. As discussed in Bulletin MM-1, the levels of nutrients found in manure can be quite variable.

Experience has shown that whenever a group of manures are collected and tested for their nutrient content, a range of nutrient values are found. Average nutrient values can be calculated, but these averages can vary by plus or minus 100% or more from the actual nutrient content in the manure generated on your farm.

Therefore, a manure analysis will provide farm-specific information that can assist with the proper management of manure nutrients. More information about sampling manures and how and where to send manure samples for analysis can be found in Bulletin MM-4 (Jacobs and MacKellar, 1995) and NCR Extension Pub. #567 (Rieck and Miller, 1995). Manure Management Sheet #2 (MSUE Bull. E-2344 by Jacobs et al, 1992c) may be helpful for recording results of manure analyses. When manure analysis information is not available, average manure nutrient values from Table 1 can be used to help determine nutrient loadings from manure applications.

Soil Fertility Testing and Fertilizer Recommendations

All fields within a livestock operation should be sampled at least every two-three years and the soils tested to determine where manure nutrients can best be utilized. One goal of a well-managed application program is to utilize soil testing and fertilizer recommendations as a guide for applying manures. Soil testing and

Table 1. Average values for characteristics of different manure types (MWPS, 1985).

Animal Species	Manure Type	% Dry Matter	Total N	NH_4-N	Total P_2O_5	Total K_2O	Manure Density*	Mineralization Factor**
			- - lb/ton for solids; lb/1000 gal for liquids - -				- lb/cu ft -	
Dairy	Solid w/o bedding	18	9	4	4	10	62	0.35
	Solid w/ bedding	21	9	5	4	10	62	0.25
	Anaerobic liquid	8	24	12	18	29	62	0.30
	Flushed liquid	1	4	2.5	4	5	62	0.30
Beef	Solid w/o bedding	15	11	4	7	10	60	0.35
	Solid w/ bedding	50	21	8	18	26	60	0.25
	Anaerobic liquid	11	40	24	27	34	62	0.30
	Flushed liquid	1	4	2	9	5	62	0.30
Swine	Fresh w/o bedding	18	10	6	9	8	60	0.50
	Anaerobic liquid	4	36	26	27	22	62	0.35
	Flushed liquid	1	4	3	2	4	62	0.35
Poultry	Deep pit (solid)	76	68	44	64	45	60	0.45
	Solid w/o litter	45	33	26	48	34	60	0.35
	Solid w/ litter	75	56	36	45	34	60	0.30
Turkey	Solid w/o litter	22	27	17	20	17	60	0.35
	Solid w/ litter	29	20	13	16	13	60	0.30
Sheep	Solid	28	14	5	9	25	65	0.25
Horses	Solid w/ bedding	46	14	4	4	14	60	0.20

* Manure Density default values can be significantly different than listed, if a large quantity of bedding has been mixed with manure.

** Mineralization Factors are used to estimate the amount of manure organic N that becomes available for plants to use in the first growing season after the manure has been applied.

manure analysis information can assist the producer in using manure nutrients to supply as much of the crop nutrient needs as possible and to achieve the greatest economic benefit. Additional information on soil sampling and soil testing can be found in MSUE Bulletins E-498 (Warncke, 1988), E-550A (Christenson et al, 1992), E-550B (Warncke et al, 1992), and E-1616 (Meints and Robertson, 1983).

MSUE fertilizer recommendations, based on the soil fertility test, soil texture, crop to be grown, a realistic yield goal (average for past 3-5 yrs.), and past crop management, should be followed (see MSUE Bull. E-550A and E-550B). Producers can use the fertilizer recommendations to identify on which fields manure nutrients will have the greatest value in reducing the amounts of commercial fertilizers that must be purchased.

Manure Nutrient Loadings

Excessive manure applications to soils can: (1) result in excess nitrate-N (NO_3-N) not being used by plants or the soil biology, thereby increasing the risk of NO_3-N being leached down through the soil and into groundwater (see Figure 1) or (2) cause P to accumulate in the upper soil profile, which will increase the risk of nonpoint source pollution losses of P to surface waters (see Figure 2). The greatest water quality concern from excessive manure loadings, particularly where soil erosion and runoff is controlled, is NO_3-N losses to groundwater. Therefore, the agronomic fertilizer N recommendation should never be exceeded.

The availability of N in manure for plant uptake will not be the same as highly soluble, fertilizer N. Therefore, total manure N cannot be automatically substituted for those in fertilizers on a pound-for-pound basis. Reasons for this are that (1) a portion of the N is present in manure organic matter which must be decomposed before mineral (i.e., inorganic) forms of this nutrient are available for plant uptake (see Figure 1) and (2) manure nutrients usually cannot be applied as efficiently as fertilizer nutrients.

The rate of decomposition (or mineralization) of manure organic matter will be less than 100% during the first year and will vary depending on the type of manure and the method of manure handling. In order to estimate the amount of available N that will be provided by each ton or 1000 gallons of manure, the total N and NH_4-N content from the manure analysis can be used with the appropriate mineralization factors (see Table 1) to calculate this value, using the following equations:

$$\text{Total N} - NH_4\text{-N} = \text{Organic N}$$

$$\text{Organic N} \times \text{Min. Factor} = \text{Avail. Organic N}$$

Also, additional portions of the residual organic matter not decomposed the first year will be decomposed the second, third and fourth years and should be estimated to avoid excessive N additions to the soil-plant system. At the present time, organic N released (mineralized) during the second, third and fourth cropping years is estimated to be 50%, 25% and 12.5%, respectively, of the amount released the first year. Further discussion of decomposition and appropriate mineralization factors to use in estimating available N from manure can be found in MSUE Bulletin E-2340 (Jacobs et al, 1992a) and in the User's Manual for the MSU Nutrient Management computer program (MacKellar et al, 1994).

While the availability of N in manure may be considerably less than 100%, the availability of P and K in manure has normally been considered to be closer to 100%. Knowing the percent availability of P and K is not as critical as for N, because periodic soil testing can be used to provide a basis for determining P and K fertilizer recommendations. Soil testing, however, has not been very effective to determine the amount of N that a soil can provide for plant growth, particularly in humid climates like MI.

Where manures are applied to meet the N needs of crops, the P needs of crops will usually be exceeded, and soil test levels for P

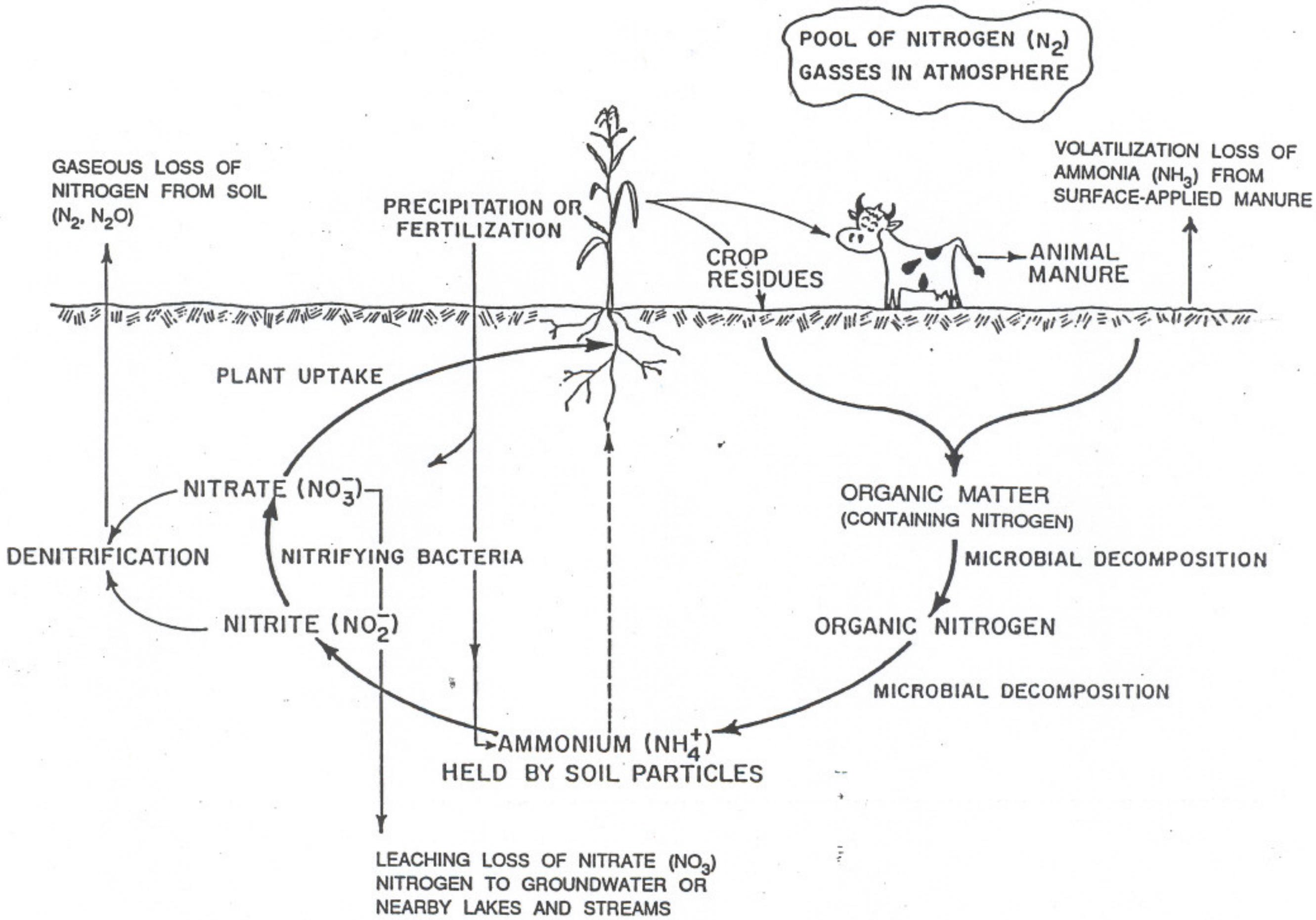

Figure 1. Nitrogen cycle showing how N changes from organic to inorganic (mineral) forms in the soil-plant system and how N may be lost from the soil.

will increase over time. If soil test levels for P become very high, the risk of losing soluble P and sediment-bound P by runoff and erosion (i.e., nonpoint source pollution) increases (see Figure 2). The GAAMP for Manure Management and Utilization suggests that when soil test levels reach 300 lb P/acre (Bray P1), no more manure (or fertilizer) P should be applied until nutrient harvest by crops, or a change in soil chemistry conditions, reduces P test levels to less than 300 lb P/acre.

If over-fertilization of P has occurred from excessive manure and/or fertilizer applications, availability or solubility of P in soils increases its mobility (see Figure 2). Depending on site conditions (e.g., depth to water table or drainage tile, slope, distance to surface waters, etc.), it becomes more critical that proper soil and water conservation practices are implemented to control runoff and erosion. This will reduce the risk of nonpoint source pollution due to P losses. For example, conservation tillage can enhance infiltration of water into soils, thereby reducing runoff, soil erosion, and associated P loadings to surface waters.

To avoid reaching the 300 lb P/acre Bray P1 test level, manure application rates should be reduced to provide the P needs of crops rather than providing all of the N needs of crops, which will usually add excess P. As discussed in Bulletin MM-1, applying manure to meet the N needs of crops will work fine over the short-term. But over the long-term, efforts will be needed to balance manure P_2O_5 additions with the amount of P_2O_5 removed by harvested crops. This management strategy will maintain soil P

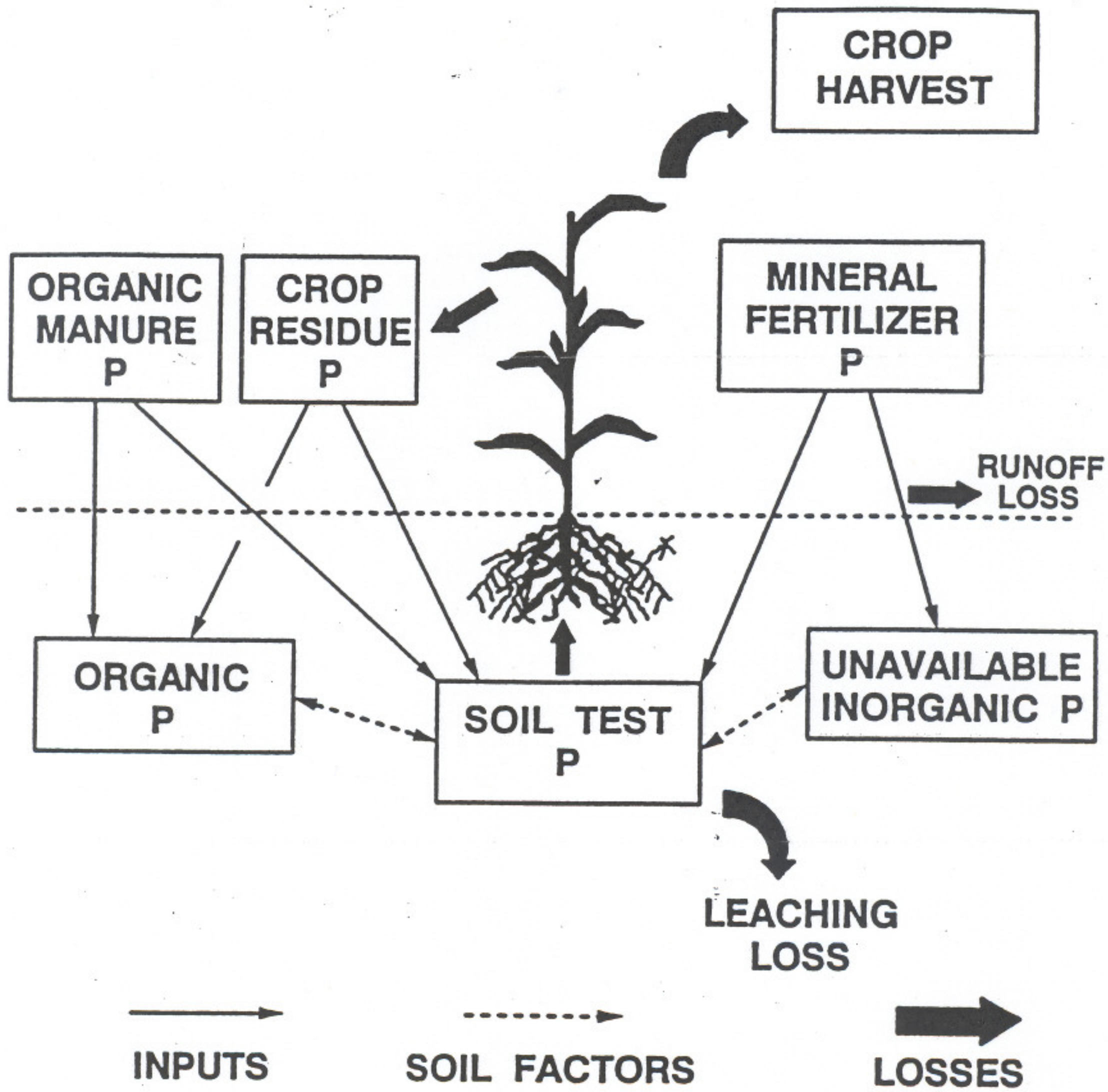

Figure 2. Phosphorus cycle showing the inputs and potential losses of P from the soil-plant system (Sharpley et al, 1993).

fertility levels but will not further increase the soil P test closer to the 300 lb P/acre level.

Therefore, the GAAMP for Manure Management and Utilization suggests that, if the soil test level for P reaches 150 lb P/acre (Bray P1), manure applications should be reduced to a rate where manure P added does not exceed the P removed by the harvested crop. The quantity of manure P_2O_5 that should be added can be estimated from Table 2, using a realistic yield goal for the crop to be grown. For example, if a yield of 120 bu/acre of corn grain is anticipated, the amount of manure P_2O_5 added to this field should be limited to no more than 42 lb/acre (120 bu/acre X 0.35 lb P_2O_5/bu, the nutrient removal rate).

If the rate of manure application based on P removal by the crop is lower than the manure spreader can physically apply, or is not realistic when planning for crop production management, the rate of manure application can be increased. The higher rate can be one that would apply manure P_2O_5 equivalent to the P_2O_5 removal for two crop years, as long as this rate does not apply more plant-available N than the N fertilizer rate recommended for the first crop that is grown after the manure is applied. If this higher rate is used, then no fertilizer or manure

Table 2. Quantities of N, P_2O_5, and K_2O removed by various Michigan field, vegetable and fruit crops (MSUE Exten. Bull. E-2343 by Jacobs et al, 1992c).

Nutrient Removal by Several Michigan Field Crops

Crop		Units	lb / unit of yield		
			N	P_2O_5	K_2O
Alfalfa	hay	ton	45	10	45
	haylage	ton	14	3.2	12
Barley	grain	bu (48 lb)	0.88	0.38	0.25
	straw	ton	13	3.2	52
Birdsfoot Trefoil	hay	ton	48	12	42
Bromegrass	hay	ton	33	13	51
Canola	grain	bu (60 lb)	1.9	0.91	0.46
	straw	ton	15	5.3	25
Clover-grass	hay	ton	41	13	39
Corn	grain	bu (56 lb)	0.90	0.35	0.27
	hi. moist. grain	ton	26	12	6.5
	stover	ton	22	8.2	32
	silage	ton	9.4	3.6	7.8
Dry Edible Beans	seed	cwt	3.6	1.2	1.6
Oats	grain	bu (32 lb)	0.62	0.25	0.19
	straw	ton	13	2.8	57
Orchardgrass	hay	ton	50	17	62
Potatoes	tubers	cwt	0.33	0.13	0.63
Red Clover	hay	ton	40	10	40
Rye	grain	bu (56 lb)	1.1	0.41	0.31
	straw	ton	8.6	3.7	21
Sorghum-sudangrass	hay	ton	40	15	58
	haylage	ton	12	4.6	18
Soybeans	seed	bu (60 lb)	3.8	0.88	1.4
Sugar Beets	roots	ton	4.0	1.3	3.3
Timothy	hay	ton	38	14	62
Wheat	grain	bu (60 lb)	1.2	0.62	0.38
	straw	ton	13	3.3	23

Reprinted from E-550A, "Fertilizer Recommendations for Field Crops in Michigan", Cooperative Extension Service, MSU, 1992.

Nutrient Removal by Several Michigan Vegetable Crops

Crop	Unit	lb / cwt		
		N	P_2O_5	K_2O
Asparagus	cwt	0.67	0.20	0.50
Beans, snap	cwt	1.2	0.12	0.55
Broccoli	cwt	0.20	0.05	0.55
Cabbage	cwt	0.35	0.08	0.35
Carrots	cwt	0.17	0.09	0.34
Cauliflower	cwt	0.33	0.13	0.33
Celery	cwt	0.25	0.10	0.80
Cucumbers	cwt	0.10	0.06	0.18
Lettuce	cwt	0.24	0.10	0.45
Muskmelon	cwt	0.42	0.10	0.55
Onions	cwt	0.25	0.13	0.24
Peas, shelled	cwt	1.0	0.23	0.50
Peppers	cwt	0.20	0.07	0.28
Pumpkins	cwt	0.20	0.06	0.34
Squash	cwt	0.18	0.08	0.33
Sweet Corn	cwt	0.42	0.14	0.28
Tomatoes	cwt	0.20	0.04	0.35

Reprinted from E-550B, "Fertilizer Recommendations for Vegetable Crops in Michigan", Cooperative Extension Service, MSU, 1992

Nutrient Removal by Several Michigan Fruit Crops

Crop	Unit	lb / cwt		
		N	P_2O_5	K_2O
Apples	cwt	0.03	0.016	0.14
Blueberries	cwt	0.11	0.023	0.11
Cherries - sweet	cwt	0.19	0.044	0.27
Cherries - tart	cwt	0.16	0.034	0.21
Grapes	cwt	0.10	0.023	0.23
Peaches	cwt	0.11	0.028	0.24
Pears	cwt	0.06	0.025	0.15
Plums	cwt	0.13	0.023	0.21
Strawberries	cwt	0.10	0.044	0.20

Compiled from: "Composition of Foods: Fruits and Fruit Juices", USDA Agriculture Handbook No 8-9, Revised 1982

Importance of Equipment Calibration

To apply the correct amount of fertilizers, pesticides, ag lime, and/or animal manures to your field, application equipment should be calibrated. For proper management of nutrients and pesticides, the amounts per acre applied should be known. This will ensure efficient utilization of these materials for crop production and minimal risk of environmental pollution.

P should be applied the next year, i.e., for the second crop year following the manure application.

To assist the livestock producer in calculating the proper rates for manure application, worksheets such as the one in Bulletin MM-3 (Jacobs, 1995b) are helpful. Using such a worksheet helps the producer (1) identify the type of information needed, (2) estimate the amounts of available nutrients present per ton or 1000 gallons of his/her manure, and (3) calculate a rate of application compatible with the crop nutrient requirements for each field.

Manure Management Sheets #2, #3, and #4 (MSUE Bull. E-2344) and the Individual Field File (MSUE Bull. E-2343 by Jacobs et al, 1992b), components of a paper recordkeeping system for crop production, provides an alternative way to accomplish this task. If you are comfortable with using microcomputers, the MSU Nutrient Management program can also assist with manure nutrient management.

Method of Manure Application

As is true with fertilizers, lime and pesticides, animal manures should be spread uniformly for best results in crop production. Also, in order to manage the quantity of manure nutrients applied, the amount of manure applied must be known. Otherwise, responsible management of manure nutrients cannot be achieved.

At the present time, not knowing the rate of manure application is probably the greatest shortcoming in accomplishing effective management of manure nutrients. When livestock producers were surveyed in several states, they commonly underestimated their manure application rates by >300%. Refer to University of Wisconsin-Extension Bulletin A3587 (Combs et al, 1993) to see examples of what 20, 40 and 60 ton/acre rates of dairy manure look like on the ground.

Determining the gallons/acre or tons/acre applied by manure spreading equipment can be accomplished in a variety of ways. Determining the rate of application can be as simple as recording the number of loads of manure applied to a field or area of known size; then multiply the quantity per load times the number of loads and divide this total quantity (in tons or gallons) by the acres treated.

One method is to measure the area of land covered by one manure spreader load or one tank wagon of manure. A second method is to record the total number of spreader loads or tank wagons uniformly applied to a field of known acreage. With either approach, the capacity of the spreader (in tons) or the tank wagon (in gallons) must be known. In addition, some way to vary the rate of application will be needed by adjusting the speed of travel or changing the discharge settings on the manure spreading equipment, so different rates of manure nutrients can be applied.

Manure spreaders can be calibrated in a similar manner as when calibrating fertilizer or pesticide applicators. Bulletins MM-5 and MM-6 (MacKellar and Jacobs, 1995a, 1995b) can assist the livestock producer with this task. If the producer prefers to track the number of loads of manure, Manure Management Sheets #2, #3, and #4 (MSUE Bull. E-2344) or the MSU Nutrient Management program can be helpful to accomplish this task.

Incorporating manure immediately (i.e., within 24 hours following application) will minimize odors and ammonia (NH_3) loss. When manures are surface applied, NH_4-N in the manure can be lost by volatilization of NH_3. The potential for loss increases with time, temperature, wind, and low humidity, so estimating this loss is not easy, making it difficult to predict NH_4-N losses with much accuracy. After reviewing the literature, we selected the values shown in Table 3 for estimating losses of NH_4-N for manure applications in MI.

Therefore, injecting manures directly into the soil, or incorporating surface-applied manure immediately, will minimize NH_3 volatilization

Table 3. Estimated losses of NH_4-N by volatilization of ammonia gas when surface applying manure, followed by incorporation.

Days to Incorporation	NH_4-N Retained	NH_4-N Lost
Injection	100 %	0 %
0 - 1 day	70 %	30 %
2 - 3 days	40 %	60 %
4 - 7 days	20 %	80 %
> 7 days	10 %	90 %

losses and provide the greatest N value for crop production. However, surface application of manures, via irrigation or other methods without incorporation, provides alternatives for producers using reduced or no-tillage management, allows supplemental irrigation of crops, provides easy application to land with established pasture or other forages, etc.

Where liquid manures have very low solids content and application rates do not cause ponding on the soil surface, much of the NH_4-N will likely be retained as liquids soak into the soil. Under these conditions, a loss factor of 50% may be appropriate to use, even though no incorporation is utilized.

To reduce the risk of runoff/erosion losses of manure nutrients, manures should not be applied and left on the soil surface within 150 feet of surface waters. Manures that are injected or surface applied with immediate incorporation can be closer than 150 feet as long as conservation practices are used to protect against runoff and erosion. A vegetative buffer between the application area and any surface water is a desirable conservation practice. Manure should not be applied to grassed waterways or other areas where there may be a concentration of water flow, unless used to fertilize and/or mulch new seedlings following waterway construction.

Manure should not be applied to areas subject to flooding unless injected or immediately incorporated. Liquid manures should not be applied in a manner that will result in ponding or runoff to adjacent property, drainage ditches or surface water. Therefore, application to saturated soils, such as during or after a rainfall, should be avoided.

As land slopes increase, the risk of runoff and erosion losses to drainage ways, and eventually to surface waters, also increases. Soil and water conservation practices should be used to control and minimize the risk of nonpoint source pollution to surface waters, particularly where manures are applied. Injection or surface application with immediate incorporation should generally be used when the land slope is greater than 6%. However, a number of factors such as liquid versus solid or semi-solid manures, amount of surface residues, soil texture, drainage, etc. can influence the degree of runoff and erosion associated with surface water pollution. Therefore, adequate soil and water conservation practices to control runoff and erosion at any particular site are more critical than the degree of slope itself.

Timing of Manure Application

Ideally, manure (or fertilizer) nutrients should be applied as close as possible to, or during, periods of maximum crop nutrient uptake to minimize any potential loss from the soil-plant system. Therefore, spring or early summer application is best for conserving nutrients, whereas fall application generally results in greater nutrient loss, particularly for NO_3-N on coarse soils (i.e., sands, loamy sands, sandy loams). Where application of manure is necessary in the fall, use as many of the following practices as possible to help minimize any potential loss of NO_3-N by leaching: (1) apply to medium or fine rather than to coarse textured soils; (2) delay applications until soil temperatures fall below 50 °F (10 °C); and/or (3) establish cover crops before or after manure application to help remove NO_3-N from soils by plant uptake.

Winter application of manure is the least desirable from a nutrient utilization and pollution point of view. Frozen soils and snow cover will limit nutrient movement into the soil and greatly increase the risk of manure being lost to surface waters by runoff and erosion during thaws or early spring rains. If winter application is necessary, solid manures should only be applied to areas where slopes are six (6) percent or less and liquid manures should only be applied to soils where slopes are three (3) percent or less.

In either situation, provisions must be made to control runoff and erosion with soil and water conservation practices. For example, buffer strips of an appropriate size should be established between surface waters and frozen soils treated with manure, to prevent any runoff and erosion of manure from reaching surface waters.

Management of Manure Applications to Land

Developing a manure management plan can help ensure the long-term success of a livestock operation. Records should be kept of manure analyses, soil test reports, and rates of manure application for individual fields. Good recordkeeping demonstrates good management and will be beneficial for the producer. Records should include manure analysis reports and the following information for individual fields:

a. soil fertility test reports;

b. date(s) of manure application(s);

c. rate of manure applied (e.g., gallons or wet tons per acre);

d. previous crop grown on the field; and

e. yields of past harvested crops.

An important ingredient of a successful program for managing the animal manure generated by a livestock operation is "planning ahead". An early step of a manure application plan is to determine whether enough acres of cropland are available for utilizing manure nutrients without resulting in excess nutrient loadings to soils.

Several tables in the "Livestock Waste Facilities Handbook" (MWPS, 1985), or similar sources, can help in making preliminary estimates of manure and manure nutrient production for different types of livestock and different manure types. This information (or preferably manure analyses and actual manure quantities for a particular farm) can be used to compare the quantity of available manure nutrients generated on a farm against the quantity of nutrients needed (i.e., fertilizer requirements) to grow crops on the farm.

If the quantity of manure nutrients being generated greatly exceed the annual crop nutrient needs, then alternative methods for manure nutrient utilization should be identified. For example, cooperative agreements with neighboring landowners, that would provide additional land areas to properly utilize all of the manure nutrients, may be necessary.

Another consideration for your management plan is to use good judgment when planning manure applications in conjunction with (1) normal weather patterns, (2) the availability of land at different times during the growing season for different crops, and (3) the availability of manpower and equipment relative to other activities on the farm which compete for these resources. Having adequate storage capacity to temporarily hold manures can add flexibility to a management plan when unanticipated weather occurs, preventing timely applications. Nevertheless, unusual weather conditions do occur and can create problems for the best of management plans.

Finally, good recordkeeping is the "back bone" of a good management plan. Past manure analysis results will be good predictors of the nutrient content in manures being applied today. Records of past manure application rates for individual fields will be helpful for estimating the amount of residual N that will be available for crops to use in the upcoming growing season. Changes in the P test levels of soils over time, resulting from manure P additions, can be monitored by using good records. That information can be helpful in anticipating where manure application rates may need to be reduced, and when additional land areas may be needed to utilize manure nutrients.

A number of recordkeeping options are available for crop and livestock producers to help them accomplish better manure nutrient management for the crop production enterprise of their farm. In Michigan, we have developed a paper recordkeeping system (Jacobs et al, 1992a) and the MSUNM computer program (MacKellar et al, 1994), both of which can not only assist with nutrient management, but also with pesticide application recordkeeping.

References

Christenson, D.C., D.D. Warncke, M.L. Vitosh, L.W. Jacobs, and J.G. Dahl. 1992. Fertilizer recommendations for field crops in Michigan. Extension Bulletin E-550A, Michigan State University Extension, East Lansing, MI.

Combs, S.M., D.H. Mueller, and L.W. Good. 1993. Looking at dairy manure application rates. Extension Bulletin A3587, University of Wisconsin-Extension, Madison, WI.

Jacobs, L.W. 1995a. Utilization of animal manure for crop production. Part I. Management of manure nutrients and water quality. Bulletin MM-1, Dept. of Crop and Soil Sciences, Michigan State University, East Lansing, MI.

Jacobs, L.W. 1995b. Utilization of animal manure for crop production. Part III. Worksheet to calculate manure application rates. Bulletin MM-3, Dept. of Crop and Soil Sciences, Michigan State University, East Lansing, MI.

Jacobs, L.W., S.U. Böhm, and B.A. MacKellar. 1992a. Recordkeeping system for crop production. Extension Bulletin E-2340, Michigan State University Extension, East Lansing, MI.

Jacobs, L.W., S.U. Böhm, and B.A. MacKellar. 1992b. Recordkeeping system for crop production -- Individual Field File. Extension Bulletin E-2343, Michigan State University Extension, East Lansing, MI.

Jacobs, L.W., S.U. Böhm, and B.A. MacKellar. 1992c. Recordkeeping system for crop production -- Manure management sheets. Extension Bulletin E-2344, Michigan State University Extension, East Lansing, MI.

Jacobs, L.W., and B.A. MacKellar. 1995. Analysis and utilization of manure for crop production. Bulletin MM-4, Dept. of Crop and Soil Sciences, Michigan State University, East Lansing, MI.

MacKellar, B.A., and L.W. Jacobs. 1995a. Manure spreader calibration and spreader capacities. Bulletin MM-5, Dept. of Crop and Soil Sciences, Michigan State University, East Lansing, MI.

MacKellar, B.A., and L.W. Jacobs. 1995b. Worksheet to calculate manure spreader capacities. Bulletin MM-6, Dept. of Crop and Soil Sciences, Michigan State University, East Lansing, MI.

MacKellar, B.A., L.W. Jacobs, and S.U. Böhm. 1994. Michigan State University Nutrient Management (MSUNM). CP-036, Version 1.1. MSU Bulletin Office, 10B Agriculture Hall, Michigan State University, East Lansing, MI 48824-1039.

Meints, V.W., and L.S. Robertson. 1983. Soil sampling for no-till and conservation tillage crops. Extension Bulletin E-1616, Michigan State University Extension, East Lansing, MI.

MWPS. 1985. Livestock waste facilities handbook, 2nd Ed. Publication MWPS-18, Midwest Plan Service, Iowa State University, Ames, IA 50011.

Rieck, A., and G. Miller. 1995. How to sample manure for nutrient analysis. North Central Regional Extension Publication #567. Iowa State University, Publications Distribution, Extension Distribution Center, Ames, IA 50011.

Sharpley, A.N., T.C. Daniel, and D.R. Edwards. 1993. Phosphorus movement in the landscape. J. Production Agriculture 6:492-500.

USDA. 1975. Agricultural waste management field handbook. U.S. Dept. of Agriculture, Natural Resource Conservation Service, Washington, DC.

USDA. 1979. Animal waste utilization on cropland and pastureland. A manual for evaluating agronomic and environmental effects. USDA Utilization Res. Rep. No. 6, October, 1979 (also EPA-600/2-79-059), U.S. Dept. of Agriculture, Washington, DC.

Warncke, D.D. 1988. Sampling soils for fertilizer and lime recommendations. Extension Bulletin E-498, Michigan State University Extension, East Lansing, MI.

Warncke, D.D., D.R. Christenson, L.W. Jacobs, M.L. Vitosh, and B.H. Zandstra. 1992. Fertilizer recommendations for vegetable crops in Michigan. Extension Bulletin E-550B, Michigan State University Extension, East Lansing, MI.

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