A MODELING STUDY OF THE WATER QUALITY RAMIFICATIONS OF INSTALLING A METHANE RECOVERY SYSTEM ON A SWINE FARM IN CARROLL COUNTY, MARYLAND

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Introduction

Typically certain features of animal waste storage are modified when a methane recovery system (MRS) is incorporated into livestock facility operations. These changes affect the amount of manure slurry available for spreading at different times and the nutrient content of the slurry. This study addresses the questions of what effect does the new technology have on a farmer's nutrient management plan, and how does this affect the resultant quality of runoff and ground water leaving his fields.

One way to approach this question is to mathematically model the water quality emanating from a farm under normal operating conditions and to contrast those results to the water quality predicted for the same farm operating a methane recovery system. This approach is economical in terms of time and resources relative to on-site measurements of water quality.

An actual farm was chosen for this modeling exercise, to impose realistic constraints on the modeling in terms of crops grown, yield estimates, number of acres planted, manure analysis, amount of manure generated, etc. The farm is located in Carroll County Maryland.

Farm Description

The farm houses 2,400 grower to finish swine per year. Six hundred growers are brought in every two weeks and 600 finishers are shipped out. Feed is provided by the company which provides the animals so all crops grown are purely for profit, not for feed or bedding. Though 550 acres are available, in 1995 only 386 acres were cropped: 100 acres of turf grass, 108 acres of hay, and 178 acres in grain crops (corn, milo, beans, or wheat).

The animals are confined in a building with a slatted floor. Waste is generated at a rate of 395 cubic feet per day, which includes 200 gallons/day of waste water. The waste falls into a storage pit which is emptied by gravity (pull plug without recycle) every month. The manure flows into an earthen pit with a rubberized liner.

The rectangular pit has top dimensions of 135 x 128 feet and bottom dimensions of 75 x 68 feet. The side slopes are 3:1 and the depth, 10 feet. The volume when full is 124,800 cubic feet, not counting freeboard.

The pit has a 205 day retention time, but the contents are removed roughly every six months and applied to cropland. The lagoon is pumped from the bottom, so there is no sludge buildup, and the slurry contains significant amounts of nutrients. The only time there are odor complaints are when the lagoon is emptied.

Table 1 contains manure analyses used in this study. Sample "a" was taken from the manure spreader. It contains a mixture of sludge and supernatant and is assumed to be typical of the slurry applied to the fields under normal operating conditions. The other two samples are used in the model MRS scenario. The sample marked "b" was taken from the supernatant of the lagoon and was assumed to be similar to the effluent that would flow from Cell 1 to Cell 2 (see next section)[1]. Sample "c" is taken from a literature source, Fulhage, 1980, and represents aged swine lagoon sludge (5 to 20 years old).

During normal operations the farm produces more than enough slurry to supply most[2] crop nutrient needs and slurry is often wasted. Despite this frequent slurry wastage, the farm is considered to be well managed, complying with nutrient management plan recommendations from the extension service when practicable. For this farm nutrient management plans for the use of manure are written to the nitrogen requirement of the crop. Fertilizer and manure recommendations for the three slurry types in Table 1 are found in Table 3. They were generated using the University of Maryland fertilizer recommendation software, FERTREC PLUS version 2.1, the program used by nutrient management specialists in Maryland's Cooperative Extension Services. Inputs to the model included manure and soil analyses. Actual soil analyses from a 1992 nutrient management plan of the swine farm were compiled, sorted by crop type, and averaged, resulting in a single soil type for each of the three cropping categories (Table 6 and Appendix A-3).

In order to prevent lagoon overflow, excess slurry is applied to crops at the regular fertilization times. A flow chart of slurry generation and use for normal operations is found in Appendix 1. The last column of Table A-1 contains the wasted volume of slurry, *i.e.* the amount of slurry applied to the crop in excess of the recommendation. It was assumed than whenever slurry was being removed from the lagoon for application to crops, volumes in excess of 1,000,000 gallons would be applied to the crop, regardless of the crop nutrient requirement. This rule of thumb represents the farmer's necessity to sufficiently drain the lagoon twice a year to accommodate the anticipated slurry generation occurring between application times. From the table in Appendix A-1 a generalized pattern of slurry use and fertilizer application over a 30-year period was determined (Table 2).

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[1]This is a conservative assumption. It is conceivable (but not inevitable) that 2-year old supernatant would contain even less nitrogen than this sample.

[2]Slurry is not applied to established sod because the ammonia and solids might damage the plants and commercial fertilizer is used for maintenance. Also a small amount of commercial P is applied before planting wheat.

Table 1. Sludge and Slurry: Nutrient, Metal, and Moisture Content

a. *Sample taken from manure spreader 5/96*

Percent Wet Weight

N	NH4-N	P2O5	K2O	Ca	Mg	S	Mn	Zn	Cu	Moist.	Liquid
%	%	%	%	%	%	%	ppm	ppm	ppm	%	lb/100gal
0.38	0.21	0.39	0.19	0.09	0.1	0.04	18.3	19.6	11.5	95.7	852

Nutrient Content lbs/1000 gal

N	NH4-N	P2O5	K2O	Ca	Mg	S	Mn	Zn	Cu	Available Nitrogen	
										Incorp.	Not incorp.
32.08	17.86	28.79	16.05	8.04	8.33	3.01	0.16	0.17	0.1	24.97	7.11

Percent Dry Weight

N	NH4-N	P2O5	K2O	Ca	Mg	S	Mn	Zn	Cu	Moist.	Solids
%	%	%	%	%	%	%	%	ppm	ppm	%	lb/1000gal
8.837209	4.883721	9.069767	4.418605	2.093023	2.325581	0.930233	425.5814	455.814	267.4419	95.7	366.36

b. *Sample of lagoon supernatant 5/95*

Percent Wet Weight

N	NH4-N	P2O5	K2O	Ca	Mg	S	Mn	Zn	Cu	Moist.	Liquid
%	%	%	%	%	%	%	%	ppm	ppm	%	lb/100gal
0.12	0.1	0.02	0.17	0.01	0.004	0.003	0.8	1.6	2.7	99.2	835.2

Nutrient Content lbs/1000 gal

N	NH4-N	P2O5	K2O	Ca	Mg	S	Mn	Zn	Cu	Available Nitrogen	
										Incorp.	Not incorp.
10	8.35	2	14.1	1	0.3	0.2	0.01	0.01	0.02	8.9	0.5

Percent Dry Weight

N	NH4-N	P2O5	K2O	Ca	Mg	S	Mn	Zn	Cu	Moist.	Solids
%	%	%	%	%	%	%	%	ppm	ppm	%	lb/1000gal
15	12.5	2.5	21.25	1.25	0.5	0.375	100	200	337.5	99.2	66.816

c. *Aged sludge, after Fulhage, 1980*

Percent Wet Weight

N	NH4-N	P2O5	K2O	Ca	Mg	S	Mn	Zn	Cu	Moist.	Liquid
%	%	%	%	%	%	%	%	ppm	ppm	%	lb/100gal
0.45	0.113	0.3723	0.1773							95	855

Nutrient Content lbs/1000 gal

N	NH4-N	P2O5	K2O	Ca	Mg	S	Mn	Zn	Cu	Available Nitrogen	
										Incorp.	Not incorp.
37.5	9.39	37.23	14.71							8.9	0.5

Percent Dry Weight

N	NH4-N	P2O5	K2O	Ca	Mg	S	Mn	Zn	Cu	Moist.	Solids
%	%	%	%	%	%	%	%	ppm	ppm	%	lb/1000gal
9	2.25	7.446	3.546							95	427.5

Methane Recovery System

The methane recovery system designed for this farm consists of two lagoons, a primary covered treatment lagoon and a storage lagoon. Cell 1 is charged from the finishing buildings via pull plug at a rate of 395 cubic feet per day, and, once filled, discharges to the storage lagoon, Cell 2. The storage lagoon is designed for a daily load of 690 cubic feet per day (a rate based on 397 cubic feet per day rainfall and -102 cubic feet per day of solids digestion). Cell 1 is kept a constant level, as the discharge to Cell 2 is made through a surface level overflow pipe. Like the existing lagoon, Cell 2 has a 205 day storage capacity. See Table 4. The lagoons were designed following NRCS Interim Practice Standard #360 for covered anaerobic lagoons using the U.S.E.P.A. AgSTAR FarmWare computer program.

The calculated slurry application schedule for the MRS scenario is found in Appendix A-2. Under MRS, no slurry is wasted: slurry is not accumulated in excess of one million gallons between scheduled applications, and in fact, not enough manure is generated to fertilize all the crops. The last column of Table A-2 shows the number of acres which have to be fertilized entirely by commercial fertilizer. (Remember that zero acres fell into this category in the "normal" operation scenario).

Unlike in the"normal" system, sludge accumulates in Cell 1. This is necessary so that the microbiological community responsible for methane generation is not disrupted by semi-annual lagoon emptying. This obviates the periodic startup efficiency losses observed in single celled systems. Cell 1 is not emptied until it fails, after 25 to 30 years. It maintains a constant volume by discharging overflow to Cell 2. This allows the methane producing microorganisms to function uninterruptedly for that period of time. Cell 2, however, is emptied every fall and spring for use on crops.

It was assumed that Cell 1 failed when slightly more than half its depth was filled with sludge, and that this stage was reached according to the rule of thumb proposed by Fulhage, 1980 (which he concedes somewhat underestimates the filling time):

$$\frac{\textit{sludge volume}}{\textit{total lagoon volume}} = 0.02 \cdot \textit{years of lagoon operation} \qquad (1)$$

By this equation Cell 1 will be half full in 25 years. The nutrient content of the sludge from Cell 1 (Table 1.c) was also borrowed from Fulhage, 1980, who sampled various anaerobic swine

Table 2. Fertilizer and Slurry Application Schedules for Model

a. Slurry Application Schedule

Normal Operation

Crop	Cycle Length	Year	Recommended	Additional	Total	# Acres
Corn	6 years	1	5,000 gal/ac	900 gal/ac	5,900 gal/ac	178
Corn	6 years	4	5,000 gal/ac	400 gal/ac	5,400 gal/ac	178
Milo	6 years	3	5,000 gal/ac	6,200 gal/ac	11,200 gal/ac	178
Milo	6 years	6	5,000 gal/ac	2,800 gal/ac	7,800 gal/ac	178
Turf	6 years	1	2,000 gal/ac	14,500 gal/ac	16,500 gal/ac	100
Turf	6 years	3 & 5	2,000 gal/ac	0	2,000 gal/ac	100
Hay	8 years	1	2,000 gal/ac	7,700 gal/ac	9,700 gal/ac	108
Hay	8 years	2-4	6,000 gal/ac	0	6,000 gal/ac	108
Hay	8 years	5	2,000 gal/ac	0	2,000 gal/ac	108
Hay	8 years	6-8	6,000 gal/ac	0	6,000 gal/ac	108

MRS Scenario

Crop	Cycle Length	Year	Recommended	Additional	Total	# Acres
Corn	30 years	30	5,000 gal/ac	5,000 gal/ac	10,000 gal/ac	178
Milo	6 years	3 & 6	5,000 gal/ac*	0	5,000 gal/ac	30
Turf	6 years	3 & 5	7,000 gal/ac*	0	7,000 gal/ac	40
Hay	4 years	1	6,000 gal/ac	0	6,000 gal/ac	43

*plus commercial P

b. Fertilization Application Schedule

Normal Operation

Crop	Cycle Length	Year	N:P lbs/acre	# Acres
Wheat	6 years	4	0:20	178
Turf	6 years	2,4,6	160:0	100

MRS Scenario

Crop	Cycle Length	Year	N:P lbs/acre	# Acres
Corn	6 years	1,4	120:25	178
Milo	6 years	3,6	40:155	148
Turf	6 years	1	170:30	100
Turf	6 years	2,4,6	160:0	100
Turf	6 years	3,5	60:30	60
Hay	4 years	1	150:20	65
Hay	4 years	2-4	150:0	108

lagoon sludges of a minimum age of 5 years.

When the hypothetical Cell 1 fails, the entire contents are spread on the first available crop, regardless of the nutrient requirement.

Nutrient Management Plan with MRS

The nutrient management plan of this farm did not change radically with the conceptual installation of a methane recovery system. There was no shift in crop mix, from fall fertilized grasses to spring fertilized grains, because the crop mix is determined by market forces (hay or sod may bring in more than corn, depending on the prices of each crop in a given year). The timing of manure application did not change. The only things that changed were there was no slurry wasted and the amount of commercial fertilizer needed was increased. The N and P content of slurry digested for 2 years is lower than the N and P content of slurry digested for six months. Since the farm under "normal" operation did not have enough manure to fertilize all the crops when needed, there was even a greater deficit under the MRS scenario, due to the lower nutrient content of the MRS effluent. This resulted in an added cost[3] to the farmer for the purchase of commercial fertilizer of $9,847 per year. (Table 5).

Modeling Water Quality Effects

All water quality modeling was done using the EPIC Model, created by scientists from the USDA Agricultural Research Service, the Natural Resource Conservation Service and the Economic Research Service. It is currently supported out of the Texas Agricultural Experiment Station. The model is capable of simulating relevant biophysical processes simultaneously and realistically. It is applicable to a wide range of soils, climates and crops. The major components of the model are weather, hydrology, erosion, nutrient cycling (N and P, but not K), pesticide fate, soil temperature, tillage, crop growth, and crop and soil management.

The complex farm operations were generalized into modelable simplifications. It was assumed that the acreage of each crop type did not change over the 30 year model horizon, with 100 acres in turf production, 108 acres of hay, and 178 acres in other crops (a 6 year rotation of corn, soybeans, milo, corn, wheat, short season soybeans, milo). It was assumed that the sod was harvested every other year and that the hay was replanted every fourth year.

For the MRS scenario it was assumed that it took 2 years after the lagoons were built to fill them, so for the first two years of the MRS model run all crops were grown with commercial fertilizer and no manure slurry. Twenty-seven years of manure and fertilizer use (when manure stores were

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[3]Assuming the cost of N and P fertilizer to be $0.25 per pound each.

Table 3. Fertilizer and Slurry Manure Recommendations

a. Slurry Recommendations

Crop	Normal Slurry Sample "a" gal/ac	MRS Slurry Sample "b" gal/ac	MRS, sludge Slurry Sample "c" gal/ac
Corn	5,000	14,000 plus 1 lb/ac commercial P	10,000
Milo	5,000	5,000 plus 147 lb/ac commercial P	3,000 plus 47 lb/ac commercial P
Establish turf	2,000	7,000 plus 18 lbs/ac commercial P	5,000
Maintain turf	6,000	19,000	13,000
Establish hay	2,000	6,000	4,000
Maintain hay	6,000	18,000	12,000

b. Commercial Fertilizer Recommendations

Crop	N pounds/acre	P pounds/acre
Corn	120	25
Milo	50	155
Establish turf	60	30
Maintain turf	160	
Establish hay	50	
Maintain hay	150	
Small grain	50	20
Full Season Soybeans	20	35
Double Crop Soybeans	20	40

exhausted) followed, culminated by one year when crops were fertilized by sludge from the cleaning of Cell 1 of the lagoon system supplemented by commercial fertilizer as needed.

The final result represents 90 years of simulation.

Simulation Results

The results of the simulation are listed in Table 7. Total farm-wide nitrogen losses to surface water and ground water average 40% lower in the MRS scenario than in the Normal Operations scenario. Crop by crop there is some variation in the TN result. The least TN reduction (10%) was observed for hay, and the most (70%) was seen in turf. The rotated crops averaged a 40% TN reduction per year. The bulk of the TN reduction came from subsurface N losses, which averaged farm-wide 50% (with a range from 20 to 70% for the individual crops).

Surface nitrogen losses were only about one fifth as large as subsurface nitrogen losses. Under the MRS scenario surface nitrogen losses were not changed on a farm-wide basis, but were increased for hay, decreased for turf, and unchanged for rotated crops. Total phosphorus, surface phosphorus, and subsurface phosphorus losses were also not much affected by the MRS scenario.

The nitrogen volatilization losses were two orders of magnitude smaller than nitrogen losses to surface and subsurface water flow in the Normal Operation scenario, and three orders of magnitude smaller in the MRS scenario. Though quite small relative to hydrological losses, it is interesting to note that the NH_3 losses to the atmosphere from MRS were less than 10% of those emitted from land under the normal farm operations.

Discussion and Conclusions

This modeling exercise found significant water quality benefits derived from the installation of a methane recovery system on the clean, well operated farm studied. Subsurface nitrogen losses were reduced by 50%. In situations where the contamination of aquifers by agriculturally derived nitrate is an issue, MRS installation would be expected to exert a tangible beneficial water quality effect. Also nitrogen contamination of shallow ground water is an issue where the receiving surface water body is in danger of eutrophying.

A significant decrease in gaseous ammonia emitted from the fields into the atmosphere was predicted by the model, not to mention the reduced ammonia emissions from Cell 1 of the lagoon system which were not quantified in this study. This may have a small, indirect water quality result, as ammonia from ground level sources is believed to be rained out rather locally.

The farmer had to pay an additional $9,847 in fertilizer costs per year under MRS (about $25.50

Table 4. Key Design Elements for a Hypothetical Covered Anaerobic Lagoon System

Parameter	Covered Treatment Lagoon Cell 1	Storage Lagoon Cell 2
Hydraulic Retention Time (HRT)	574	205
Loading Rate lbs. VS/1000 ft3	9	2.6
Daily Influent cubic feet	395	690
Percent Total Solids	9% influent	3% influent
Side Slope	3:1	3:1
Length feet	165	147
Width feet	165	147
Depth feet	20	20
Total Volume cubic feet	250000	180000
Surface area square feet	27225	21609

Table 5. Annual Commercial Fertilizer Use

fertilizer use	N	P
Normal operation, lbs	8,000	593
MRS, lbs	35,714	12,265
Annual average difference, lbs	27,714	11,672
Annual Average Cost	$6,929	$2,918

Table 6. Average Soil Characteristics by Field Type

Field type	soil texture	pH	Mg	P2O4	K2O	Ca lb/ac	O+M %	#obs
Hay	SiL	6.5	289	233	260	2254	3.7	23
Turf	SiL	7.0	281	288	295	2577	3.1	9
Crops	SiL	6.5	288	202	246	2068	2.8	25

Table 7. Model Results:
Average Annual Nutrient Export in Pounds/Year Lost to the Environment

	Subsurface N	Surface N	Subsurface P	Surface P	N Volatilization	TN	TP
Normal							
Crops	16639.5	7160.8	28.3	806.5	131.1	23800.4	834.8
Hay	16152.6	782.4	16.3	60.5	51.3	16935.0	76.8
Turf	9578.2	1512.5	15.6	35.6	26.0	11090.6	51.2
total	42370.3	9455.7	60.2	902.6	208.4	51825.9	962.9
MRS							
Crops	7433.0	6986.0	28.3	806.3	5.4	14419.0	834.5
Hay	12681.9	1939.5	11.0	41.8	3.8	14621.4	52.8
Turf	2536.0	957.1	15.2	73.1	6.7	3493.0	88.3
total	22650.9	9882.5	54.5	921.2	15.8	32533.4	975.6

per cultivated acre). Though this is a very soft number, if you assume that all capital and O&M costs are offset by electricity production revenue and that labor costs for field operations are the same for both scenarios, this comes to an astonishingly inexpensive $0.51 per pound of nitrogen prevented from entering the hydrosphere.[4]

The main reason for the superior water quality performance of the farm employing a methane recovery system is that slurry had to be wasted only one year in thirty (when Cell 1 failed), contrasted to the "normal" scenario where manure was wasted nearly every year. Less nitrogen was applied overall during the thirty years of continuous operation of MRS and less nitrogen found its way into ground and surface water.

It should be remembered that the test case was a clean, well run farm. Even larger water quality improvements with MRS would be anticipated from a "dirty" farm with an improper or insufficient manure handling system, or one that did not follow a scientific nutrient management plan.

It should also be emphasized that any changes in the assumptions or design of the methane recovery system would be expected to change the results of the simulation. For example, if instead of a two-cell lagoon a completely mixed mesophilic digester were installed, the effluent would be expected to retain most of the nitrogen of the influent, and there would probably be no water quality benefit achieved. Likewise if literature values for the effluent quality were used instead of the actual manure slurry analyses, it is likely that the simulation results would be different. The model results should therefore not be generalized past their limitations, and should be considered to represent a unique set of circumstances.

References

Camacho, R. (1991) *Financial Cost Effectiveness of Point and Nonpoint Source Nutrient Reduction Technologies in the Chesapeake Bay Basin,* Interstate Commission on the Potomac River Basin, ICPRB Report 91-8, Rockville.

Fulhage, C. D. (1980) Performance of Anaerobic Lagoons as Swine Waste Storage and Treatment Facilities in Missouri, IN *Livestock Waste: A Renewable Resource, Proceedings of the Fourth International Symposium on Livestock Wastes*, St. Joseph, MI, ASAE, p. 225-227.

[4] Camacho, 1991 reported annual costs per pound of nitrogen removed by animal waste management BMPs ranging from $1.70 to $7.90.

Appendix A-1 24 Year Manure Application Schedule under Normal Operation

date	Crop	gal/ac	ac	gallons required	gallons generated	gallons remaining	ac with fert.	overflow wasted
26-May-01					1,058,046	1,058,046		
27-May-01	corn	5,000	178	890,000		168,046	0	
06-Oct-01					686,440	854,486		
07-Oct-01	hay	2,000	108	216,000		638,486	0	
30-Sep-02					1,852,871	1,000,000		1,491,356
01-Oct-02	turf	2000	100	200,000		800,000	0	
31-Oct-02					159,997	959,997		
01-Nov-02	hay	6,000	108	648,000		311,997	0	
19-Jun-03					1,192,237	1,000,000		504,234
20-Jun-03	milo	5,000	178	890,000		110,000	0	
31-Oct-03					691,601	801,601		
01-Nov-03	hay	6,000	108	648,000		153,601	0	
26-May-04					1,073,530	1,000,000		227,130
27-May-04	corn	5,000	178	890,000		110,000	0	
30-Sep-04					655,472	765,472		
01-Oct-04	turf	2000	100	200,000		565,472	0	
31-Oct-04					159,997	725,470		
01-Nov-04	hay	6,000	108	648,000		77,470	0	
06-Oct-05					1,754,808	1,000,000		832,278
07-Oct-05	hay	2,000	108	216,000		784,000	0	
19-Jun-06					1,321,267	1,000,000		1,105,267
20-Jun-06	milo	5,000	178	890,000		110,000	0	
30-Sep-06					531,604	641,604		
01-Oct-06	turf	2000	100	200,000		441,604	0	
31-Oct-06					159,997	601,601		
01-Nov-06	hay	6,000	100	600,000		1,601	8	
26-May-07					1,068,368	1,000,000		69,969
27-May-07	corn	5,000	178	890,000		110,000	0	
06-Oct-07					686,440	796,440		
07-Oct-07	hay	2,000	108	216,000		580,440	0	
30-Sep-08					1,858,032	1,000,000		1,438,472
01-Oct-08	turf	2000	100	200,000		800,000	0	
31-Oct-08					159,997	959,997		
01-Nov-08	hay	6,000	108	648,000		311,997	0	
19-Jun-09					1,192,237	1,000,000		504,234
20-Jun-09	milo	5,000	178	890,000		110,000	0	
31-Oct-09					691,601	801,601		
01-Nov-09	hay	6,000	108	648,000		153,601	0	
26-May-10					1,068,368	1,000,000		221,969
27-May-10	corn	5,000	178	890,000		110,000	0	
30-Sep-10					655,472	765,472		
01-Oct-10	turf	2000	100	200,000		565,472	0	
31-Oct-10					159,997	725,470		
01-Nov-10	hay	6,000	108	648,000		77,470	0	
06-Oct-11					1,754,808	1,000,000		832,278
07-Oct-11	hay	2,000	108	216,000		784,000	0	

Appendix A-1 continued

19-Jun-12					1,326,428	1,000,000		1,110,428
20-Jun-12	milo	5,000	178	890,000		110,000	0	
30-Sep-12					531,604	641,604		
01-Oct-12	turf	2000	100	200,000		441,604	0	
31-Oct-12					159,997	601,601		
01-Nov-12	hay	6,000	100	600,000		1,601	8	
26-May-13					1,068,368	1,000,000		69,969
27-May-13	corn	5,000	178	890,000		110,000	0	
06-Oct-13					686,440	796,440		
07-Oct-13	hay	2,000	108	216,000		580,440	0	
30-Sep-14					1,852,871	1,000,000		1,433,310
01-Oct-14	turf	2000	100	200,000		800,000	0	
31-Oct-14					159,997	959,997		
01-Nov-14	hay	6,000	108	648,000		311,997	0	
19-Jun-15					1,192,237	1,000,000		504,234
20-Jun-15	milo	5,000	178	890,000		110,000	0	
31-Oct-15					691,601	801,601		
01-Nov-15	hay	6,000	108	648,000		153,601	0	
26-May-16					1,073,530	1,000,000		227,130
27-May-16	corn	5,000	178	890,000		110,000	0	
30-Sep-16					655,472	765,472		
01-Oct-16	turf	2000	100	200,000		565,472	0	
31-Oct-16					159,997	725,470		
01-Nov-16	hay	6,000	108	648,000		77,470	0	
06-Oct-17					1,754,808	1,000,000		832,278
07-Oct-17	hay	2,000	108	216,000		784,000	0	
19-Jun-18					1,321,267	1,000,000		1,105,267
20-Jun-18	milo	5,000	178	890,000		110,000	0	
30-Sep-18					531,604	641,604		
01-Oct-18	turf	2000	100	200,000		441,604	0	
31-Oct-18					159,997	601,601		
01-Nov-18	hay	6,000	100	600,000		1,601	8	
26-May-19					1,068,368	1,000,000		69,969
27-May-19	corn	5,000	178	890,000		110,000	0	
06-Oct-19					686,440	796,440		
07-Oct-19	hay	2,000	108	216,000		580,440	0	
30-Sep-20					1,858,032	1,000,000		1,438,472
01-Oct-20	turf	2000	100	200,000		800,000	0	
31-Oct-20					159,997	959,997		
01-Nov-20	hay	6,000	108	648,000		311,997	0	
19-Jun-21					1,192,237	1,000,000		504,234
20-Jun-21	milo	5,000	178	890,000		110,000	0	
31-Oct-21					691,601	801,601		
01-Nov-21	hay	6,000	108	648,000		153,601	0	
26-May-22					1,068,368	1,000,000		221,969
27-May-22	corn	5,000	178	890,000		110,000	0	
30-Sep-22					655,472	765,472		
01-Oct-22	turf	2000	100	200,000		565,472	0	
31-Oct-22					159,997	725,470		
01-Nov-22	hay	6,000	108	648,000		77,470	0	
06-Oct-23					1,754,808	1,000,000		832,278
07-Oct-23	hay	2,000	108	216,000		784,000	0	
19-Jun-24					1,326,428	1,000,000		1,110,428
20-Jun-24	milo	5,000	178	890,000		110,000	0	
30-Sep-24					531,604	641,604		
01-Oct-24	turf	2000	100	200,000		441,604	0	
31-Oct-24					159,997	601,601		
01-Nov-24	hay	6,000	100	600,000		1,601	8	

Appendix A-2 24 Year Manure Application Schedule under MRS

date	Crop	recommended gallons/acre	acres	gallons required	gallons generated	gallons remaining	acres with fertilizer
06-May-01	corn				1,058,046	1,058,046	
07-May-01	corn	14,000	50	700,000		358,046	128
06-Oct-01	hay				105,570	463,616	
07-Oct-01	hay	6,000	0	0		463,616	108
30-Sep-02	turf				247,710	711,326	
01-Oct-02	turf	7,000	100	700,000		11,326	0
31-Oct-02	hay				21,390	32,716	
01-Nov-02	hay	18,000	0	0		32,716	108
19-May-03	milo				138,000	170,716	
20-May-03	milo	5,000	0	0		170,716	178
31-Oct-03	hay				113,850	284,566	
01-Nov-03	hay	18,000	0	0		284,566	108
06-May-04	corn				129,720	414,286	
07-May-04	corn	14,000	20	280,000		134,286	158
30-Sep-04	turf				101,430	235,716	
01-Oct-04	turf	7,000	30	210,000		25,716	70
31-Oct-04	hay				21,390	47,106	
01-Nov-04	hay	18,000	0	0		47,106	108
06-Oct-05	hay				234,600	281,706	
07-Oct-05	hay	6,000	40	240,000		41,706	68
19-May-06	milo				155,250	196,956	
20-May-06	milo	5,000	30	150,000		46,956	148
30-Sep-06	turf				92,460	139,416	
01-Oct-06	turf	7,000	0	0		139,416	100
31-Oct-06	hay				21,390	160,806	
01-Nov-06	hay	18,000	0	0		160,806	108
06-May-07	corn				129,030	289,836	
07-May-07	corn	14,000	0	0		289,836	178
06-Oct-07	hay				105,570	395,406	
07-Oct-07	hay	6,000	60	360,000		35,406	48
30-Sep-08	turf				248,400	283,806	
01-Oct-08	turf	7,000	40	280,000		3,806	60
31-Oct-08	hay				21,390	25,196	
01-Nov-08	hay	18,000	0	0		25,196	108
19-May-09	milo				138,000	163,196	
20-May-09	milo	5,000	30	150,000		13,196	148
31-Oct-09	hay				113,850	127,046	
01-Nov-09	hay	18,000	0	0		127,046	108
06-May-10	corn				129,030	256,076	
07-May-10	corn	14,000	0	0		256,076	178
30-Sep-10	turf				101,430	357,506	
01-Oct-10	turf	7,000	50	350,000		7,506	50
31-Oct-10	hay				21,390	28,896	
01-Nov-10	hay	18,000	0	0		28,896	108
06-Oct-11	hay				234,600	263,496	
07-Oct-11	hay	6,000	40	240,000		23,496	68

Appendix A-2 continued

19-May-12	milo				155,940	179,436	
20-May-12	milo	5,000	30	150,000		29,436	148
30-Sep-12	turf				92,460	121,896	
01-Oct-12	turf	7,000	0	0		121,896	100
31-Oct-12	hay				21,390	143,286	
01-Nov-12	hay	18,000	0	0		143,286	108
06-May-13	corn				129,030	272,316	
07-May-13	corn	14,000	0	0		272,316	178
06-Oct-13	hay				105,570	377,886	
07-Oct-13	hay	6,000	60	360,000		17,886	48
30-Sep-14	turf				247,710	265,596	
01-Oct-14	turf	7,000	30	210,000		55,596	70
31-Oct-14	hay				21,390	76,986	
01-Nov-14	hay	18,000	0	0		76,986	108
19-May-15	milo				138,000	214,986	
20-May-15	milo	5,000	40	200,000		14,986	138
31-Oct-15	hay				113,850	128,836	
01-Nov-15	hay	18,000	0	0		128,836	108
06-May-16	corn				129,720	258,556	
07-May-16	corn	14,000	0	0		258,556	178
30-Sep-16	turf				101,430	359,986	
01-Oct-16	turf	7,000	50	350,000		9,986	50
31-Oct-16	hay				21,390	31,376	
01-Nov-16	hay	18,000	0	0		31,376	108
06-Oct-17	hay				234,600	265,976	
07-Oct-17	hay	6,000	40	240,000		25,976	68
19-May-18	milo				155,250	181,226	
20-May-18	milo	5,000	30	150,000		31,226	148
30-Sep-18	turf				92,460	123,686	
01-Oct-18	turf	7,000	0	0		123,686	100
31-Oct-18	hay				21,390	145,076	
01-Nov-18	hay	18,000	0	0		145,076	108
06-May-19	corn				129,030	274,106	
07-May-19	corn	14,000	0	0		274,106	178
06-Oct-19	hay				105,570	379,676	
07-Oct-19	hay	6,000	60	360,000		19,676	48
30-Sep-20	turf				248,400	268,076	
01-Oct-20	turf	7,000	30	210,000		58,076	70
31-Oct-20	hay				21,390	79,466	
01-Nov-20	hay	18,000	0	0		79,466	108
19-May-21	milo				138,000	217,466	
20-May-21	milo	5,000	40	200,000		17,466	138
31-Oct-21	hay				113,850	131,316	
01-Nov-21	hay	18,000	0	0		131,316	108
06-May-22	corn				129,030	260,346	
07-May-22	corn	14,000	0	0		260,346	178
30-Sep-22	turf				101,430	361,776	
01-Oct-22	turf	7,000	50	350,000		11,776	50
31-Oct-22	hay				21,390	33,166	
01-Nov-22	hay	18,000	0	0		33,166	108
06-Oct-23	hay				234,600	267,766	
07-Oct-23	hay	6,000	40	240,000		27,766	68
19-May-24	milo				155,940	183,706	
20-May-24	milo	5,000	30	150,000		33,706	148
30-Sep-24	turf				92,460	126,166	
01-Oct-24	turf	7,000	0	0		126,166	100
31-Oct-24	hay				21,390	147,556	
01-Nov-24	hay	18,000	0	0		147,556	108

Appendix A-3 Soil Analyses Sorted by Crop Type

Hay

soil texture	pH	Mg	P2O4	K2O	Ca lb/ac	O+M %	Date	Lab no
Silt Loam	6	298	63	172	2114	4.7	16-Apr-92	7840-7842
Silt Loam	5.5	257	48	174	1778	4.6	16-Apr-92	7840-7842
Silt Loam	7.3	300	326	298	2559	2.8	16-Apr-92	7848-7840
Silt Loam	6.5	300	107	386	2755	5.5	16-Apr-92	7856-7839
Silt Loam	7.2	300	278	248	3000	3.1	16-Apr-92	7856-7839
Silt Loam	7.2	300	476	284	3000	3.2	16-Apr-92	7844-7847
Silt Loam	5.9	259	93	247	1547	2.8	16-Apr-92	7864-7838
Silt Loam	7.2	251	247	348	3000	3.1	16-Apr-92	7864-7838
Silt Loam	6.1	298	343	165	993	3.2	16-Apr-92	7868-7837
Silt Loam	6.1	300	135	363	1771	3.7	16-Apr-92	7852-7836
Silt Loam	6.1	300	750	333	1138	3.9	16-Apr-92	7852-7836
Silt Loam	7	300	420	348	2667	2.9	16-Apr-92	7852-7836
Silt Loam	7.2	300	306	409	3000	3.1	16-Apr-92	7860-7835
Silt Loam	6	295	114	271	2097	4.2	16-Apr-92	7818-7834
Silt Loam	6.6	300	165	291	3000	5.3	16-Apr-92	7818-7834
Silt Loam	6.6	300	170	191	2306	3.5	16-Apr-92	7828-7832
Silt Loam	6.9	237	187	136	2219	2.6	16-Apr-92	7836-7830
Silt Loam	5.8	292	69	178	1851	4.3	16-Apr-92	7836-7830
Silt Loam	6	300	123	100	2030	3.5	16-Apr-92	7824-7829

means	6.5	289	233	260	2254	3.7

Turf

soil texture	pH	Mg	P2O4	K2O	Ca lb/ac	O+M %	Date	lab no.
Silt Loam	7.1	169	750	320	3000	3.9	16-Apr-92	7840-7842
Silt Loam	7.2	300	268	304	2925	3	16-Apr-92	7848-7840
Silt Loam	6.5	300	75	239	2009	3.9	16-Apr-92	7856-7839
Silt Loam	6.7	300	220	299	3000	2.8	16-Apr-92	7844-7847
Silt Loam	7.8	273	242	283	3000	2.9	16-Apr-92	7864-7838
Silt Loam	7	300	382	239	2091	3	16-Apr-92	7868-7837
Silt Loam	5.6	299	105	253	1166	2.8	16-Apr-92	7852-7836
Silt Loam	7.6	300	291	376	3000	2.8	16-Apr-92	7860-7835
Silt Loam	7.6	285	255	338	3000	2.9	16-Apr-92	7860-7835

means	6.9798	281	288	295	2577	3.1

Appendix A-3 continued

Soybeans, Milo, Corn, Wheat

soil texture	pH	Mg	P2O4	K2O	Ca lb/ac	O+M %	date	lab no.
Silt Loam	5.8	245	79	233	1963	3.3	16-Apr-92	7820-7833
Silt Loam	6.4	255	95	209	1799	2.3	16-Apr-92	7820-7833
Silt Loam	6.7	300	443	350	2073	3.1	16-Apr-92	7868-7837
Silt Loam	5.9	287	128	369	1839	2.6	16-Apr-92	7820-7833
Silt Loam	6.6	300	173	145	2077	2.8	16-Apr-92	7836-7830
Silt Loam	6.1	239	111	131	1941	2.6	16-Apr-92	7832-7831
Silt Loam	6.1	300	125	270	219	2.7	16-Apr-92	7820-7833
Silt Loam	6.8	300	412	322	1587	2.5	16-Apr-92	7844-7847
Silt Loam	6.4	297	409	300	2360	2.6	16-Apr-92	7840-7842
Silt Loam	6.6	300	187	222	2656	2.8	16-Apr-92	7832-7831
Silt Loam	6.9	300	193	318	1598	2.3	16-Apr-92	7848-7840
Silt Loam	5.9	285	118	209	1918	2.9	16-Apr-92	7832-7831
Silt Loam	5.7	300	156	212	2135	2.9	16-Apr-92	7824-7829
Silt Loam	5.7	300	121	207	1918	2.8	16-Apr-92	7824-7829
Silt Loam	6.2	281	59	141	1856	3	16-Apr-92	7836-7830
Silt Loam	6.3	300	193	209	2402	2.8	16-Apr-92	7824-7829
Silt Loam	6.7	300	210	217	2508	2.7	16-Apr-92	7832-7831
Silt Loam	6.8	300	424	188	1887	2.6	16-Apr-92	7844-7847
Silt Loam	6.9	300	193	318	1598	2.3	16-Apr-92	7848-7840
Silt Loam	6.9	272	275	361	2426	3	16-Apr-92	7864-7838
Silt Loam	7.7	292	281	284	3000	3.3	16-Apr-92	7868-7837
Silt Loam	6.5	300	93	148	2050	2.9	16-Apr-92	7828-7832
Silt Loam	6.6	245	189	234	2840	2.8	16-Apr-92	7828-7832
Silt Loam	7.2	300	228	260	3000	2.9	16-Apr-92	7848-7840
Silt Loam	6.3	300	163	295	2051	2.8	16-Apr-92	7828-7832

means	6.5	288	202	246	2068	2.8
milo only	6.3	278	196	254	1687	2.7
soy only	6.5	292	205	243	2247	2.8