Nutrient composition of Kansas swine lagoons and hoop barn manure[1,2]

J. M. DeRouchey[3], R. D. Goodband, J. L. Nelssen, M. D. Tokach, S. S. Dritz, and J. P. Murphy[4]

Department of Animal Sciences and Industry, Kansas State University, Manhattan 66506-0201

ABSTRACT: A total of 312 samples in two experiments were analyzed to determine mean nutrient concentrations of swine lagoons and hoop barns in Kansas. First, in a retrospective study (Exp. 1), we obtained 41 sample analyses from the Kansas Department of Agriculture of sow, nursery, wean-to-finish, finish, and farrow-to-finish operations in 1999. The average total N concentration was 899 ppm (SD = 584 ppm), while the total P concentration was 163 ppm (SD = 241 ppm). In an attempt to reduce the variation, we conducted a prospective experiment standardizing collection procedure, laboratory techniques, phase of production, and season of year to more accurately determine the nutrient concentrations of swine lagoons in Kansas. In Exp. 2, we used 236 lagoon and 35 hoop barn manure samples taken in 2000 from Kansas swine operations to determine the impacts of production phase and season of the year on nutrient concentration. The different operations with swine lagoons were: 1) sow; 2) nursery; 3) wean-to-finish; 4) finish; and 5) farrow-to-finish, with a total of 9, 8, 7, 10, and 8 lagoons sampled from each phase of production, respectively. The total N and P concentrations from lagoons were 1,402 and 204 ppm, respectively, averaged over all samples. Concentrations of total N were higher in wean-to-finish and finishing lagoons ($P < 0.05$) compared with sow and farrow-to-finish lagoons. Lagoon analyses also revealed that N concentrations decreased (linear, $P < 0.05$) during the summer and fall compared with winter and early spring. The concentration of P was greater ($P < 0.05$) for wean-to-finish compared with farrow-to-finish lagoons. Phosphorus concentrations for all lagoons increased (quadratic, $P < 0.05$) from February until June, but then declined steady throughout the remainder of the year. Average total N and P in hoop barns were 8,678 and 4,364 ppm, respectively. No seasonal changes in N and P concentrations were observed in manure from hoop barns. Season and type of production phase affect the nutrient content of Kansas swine lagoons, and producers will benefit from obtaining individual analyses from their lagoons when developing nutrient management plans rather than utilizing published reference values.

Key Words: Animal Housing, Animal Manures, Lagoons, Pigs, Waste Management

 J. Anim. Sci. 2002. 80:2051–2061

Introduction

Environmental stewardship by livestock producers to help preserve and maintain the environment throughout the world has become an emerging issue. To ensure proper management of livestock waste, nutrient profiles of various forms and types of manure have been established to help livestock operators accurately apply manure to land. This practice allows crops or forages to utilize the nutrients from the manure, thereby decreasing the need for chemical fertilizers. Thus, accurate and detailed nutrient profiles must be obtained to correctly distribute manure so that a deficiency or excess of a given nutrient does not occur. Currently, sources of nutrient reference values are available that provide average concentrations of various types of manure from different livestock species (Nelson and Shapiro, 1989; MWPS, 1993).

Published values are a source of information that producers can use to determine the amount of land needed for manure application or for comparison to their on-farm manure analyses. However, these reference values represent manure samples from different graphical regions of the United States and are from samples compiled over the past two decades. The majority of these published values may not reflect current manure nutrient profiles resulting from changes in

[1]Contribution no. 2-219-J of the Kansas Agric. Exp. Stn., Manhattan 66506-0210.

[2]Appreciation is expressed to Kansas Center for Agricultural Resources and the Environment, Manhattan, KS, for partial funding of these experiments.

[3]Correspondence: phone: 785-532-5833; fax: 785-532-5887; E-mail: jderouch@oznet.ksu.edu.

[4]Department of Biological and Agricultural Engineering.

Received August 21, 2001.

Accepted April 19, 2002.

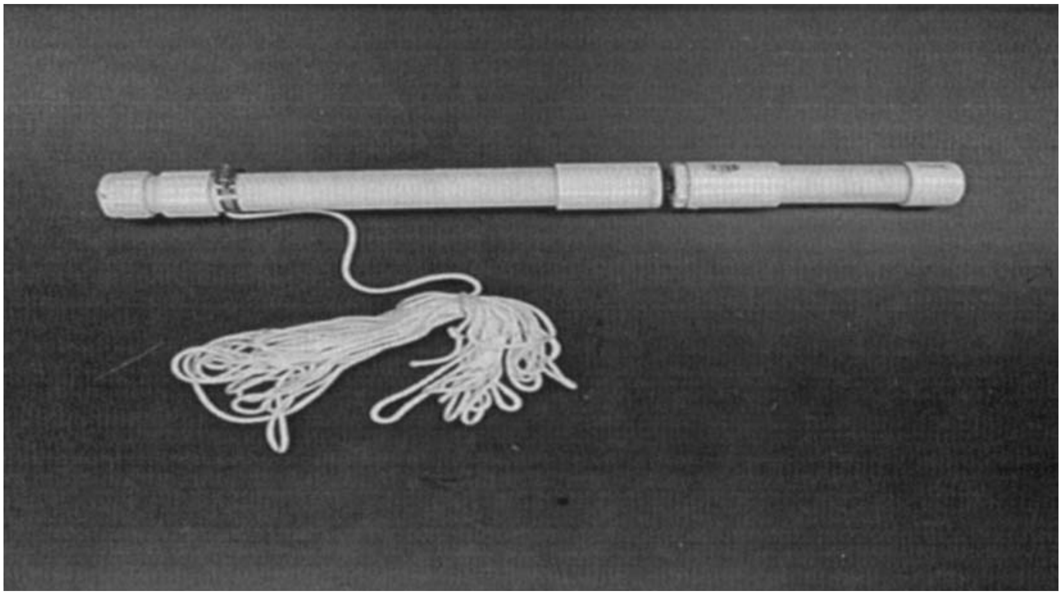

Figure 1. Lagoon sampler.

swine operation management practices (phase feeding, use of phytase, reduced particle size) or from differences in nutrient concentrations associated with different types of production phases or manure handling systems. Published values also fail to account for differences that may occur with the season of the year, which may lead to a misrepresentation of the actual nutrient profile. Also, nutrient profiles of solid manure from swine raised in hoop barns have not been widely established. Therefore, the objective of this study was to determine the effect of production phase and season of the year on nutrient concentra-

Table 1. 1999 nutrient and mineral concentrations of Kansas swine lagoons[a]

Item, ppm	Mean	SD	Minimum	Maximum
Nitrogen				
Total nitrogen	899	584	76	2,361
Organic-nitrogen	190	209	12	1,107
Ammonium-nitrogen	709	398	64	1,702
Nitrate-nitrogen	<1	0.0	<1	<1
Major nutrients				
Phosphorus	163	241	13	1,209
Phosphate	371	549	30	2,748
Potassium	847	519	164	2,069
Potash	1,043	617	190	2,400
Sulfur	44	43	10	200
Calcium	154	85	40	345
Magnesium	60	82	6	226
Magnesium oxide	76	81	10	330
Zinc	6.2	8.9	1	32
Iron	19.0	25.4	2	67
Manganese	2.0	2.9	0	9
Copper	1.6	2.3	0	12
Boron	1.2	0.8	0	3
Sodium	243	112	90	400
Chloride	390	248	73	1,149
Other constituents				
Carbonate	<1	0.0	<1	<1
Bicarbonate	3,943	1,609	714	5,868
pH	8.0	0.6	6.1	8.8

[a]Values represent the means of 41 swine lagoon samples. These analyses were obtained from Kansas Department of Agriculture (Topeka, KS).

Table 2. Effects of production phase on mean nutrient concentration of Kansas swine lagoons for 2000[a]

Item	Sow	Nursery	Wean-to-finish	Finish	Farrow-to-finish	SEM	Overall mean
Number of samples	50	44	41	56	45		236
Nitrogen, ppm							
Nitrate	<1	<1	<1	<1	<1	0.33	<1
Ammonium	841[fg]	1,252[fg]	1,506[f]	1,469[f]	643[g]	250	1,142
Organic N[b]	125[h]	312[fg]	346[f]	351[f]	166[gh]	86	260
Total N	967[g]	1,563[fg]	1,852[f]	1,820[f]	810[g]	420	1,402
Major nutrients, ppm							
Phosphorus, P	141[fg]	223[fg]	302[f]	246[fg]	106[g]	80	204
Phosphate[c]	320[fg]	503[fg]	686[f]	559[fg]	241[g]	185	462
Potassium	856[g]	1,351[fg]	1,750[f]	1,786[f]	1,125[fg]	432	1,374
Potash[d]	1,030[g]	1,625[fg]	2,106[f]	2,150[f]	1,354[fg]	517	1,653
Calcium	225[gh]	463[fg]	465[fg]	500[f]	198[h]	120	370
Sodium	284	282	437	439	281	90	345
Chloride	509[h]	647[fgh]	994[fg]	1,013[f]	671[fgh]	219	767
Magnesium	30[h]	89[fgh]	112[f]	97[fg]	43[gh]	30	74
Sulfur	30[g]	105[f]	110[f]	94[f]	36[g]	30	75
Copper	1.0[g]	6.1[f]	3.1[fg]	3.7[fg]	1.5[g]	1.6	3.1
Zinc	3.1[g]	40.7[f]	20.2[g]	16.2[g]	4.0[g]	9.7	16.8
Iron	14.8[gh]	58.0[f]	41.0[fg]	35.4[fgh]	10.7[h]	13.9	32.0
Manganese	1.3[g]	4.2[f]	4.4[f]	4.4[f]	1.2[g]	1.3	2.5
Other constituents							
Carbonate, ppm	<1	<1	<1	<1	<1	0.1	<1
Bicarbonate, ppm	4,840[g]	7,380[fg]	8,817[f]	9,199[f]	4,645[g]	1,830	6,976
Solids, %	0.5[g]	1.2[fg]	1.3[f]	1.3[f]	0.6[g]	0.3	1.0
pH	7.8	7.7	7.8	7.8	7.7	0.1	7.8
EC, mmho cm^{-1}[e]	6.9[gh]	9.0[fgh]	9.5[f]	9.1[fg]	6.4[h]	1.3	8.1

[a]A total of 236 samples representing 42 lagoons sampled from February through December.
[b]Calculated (Organic N = Total N – $[NH_4^+\text{-N}]$ — $[NO_3^-\text{-N}]$).
[c]Calculated (P_2O_5 = P/0.44).
[d]Calculated (K_2O = K/0.83).
[e]Electrical conductivity, mmho·cm^{-1}.
[f,g,h]Means in same row with superscripts differ ($P < 0.05$).

tion of swine lagoons and hoop barn manure from Kansas swine operations.

Materials and Methods

Experiment 1

Analyses of manure from 41 Kansas swine lagoons were obtained from the Kansas Department of Agriculture. Lagoon samples were taken in 1999 from farrow-to-finish, sow, nursery, wean-to-finish, and finishing operations, and were filed in compliance with Kansas House Bill 2950, which requires swine producers with more than 1,000 animal units to submit a nutrient profile for a nutrient management plan. The manure samples were collected by the individual operations for chemical analysis. Therefore, the sampling technique, time of year, type of lagoon, sample handling prior to analysis, and the laboratory used were not controlled among operations participating in this survey. The nutrients and properties that were summarized include: total N, ammonium (**NH_4-N**), nitrate (**NO_3-N**), organic N (total N – NH_4-N – NO_3-N = organic N), P, P_2O_5, K, K_2O, S, Ca, Mg, MgO, Zn, Fe, Mn, B, Na, Cl, CO_3, HCO_3, and pH. Analytical procedures and methods for determination of individual nutrients and properties were not specified on the individual laboratory reports.

Experiment 2

Lagoons. Samples from five different types of production systems were taken six times over the year 2000 to determine changes in nutrient and mineral concentrations. The different operations were classified as: 1) sow; 2) nursery; 3) wean-to-finish; 4) finish; and 5) farrow-to-finish, with a total of 9, 8, 7, 10, and 8 lagoons sampled, respectively, from each phase of production. Our classification was based on the type of facility depositing effluent into the lagoon. The lagoons collected waste from only gestation and farrowing facilities (sow), from only nursery facilities (weaning to 30 kg; nursery), from only nursery and finishing facilities (weaning to 115 kg; wean-to-finish), from only finishing facilities (25 to 115 kg; finishing), or from combined gestation, farrowing, nursery, and finishing facilities (farrow-to-finish). Lagoons were sampled in February, April, June, August, October, and December. The lagoons were located in different geographic locations across Kansas. Because our

Table 3. Effects of season on nutrient concentration of Kansas swine lagoons for 2000[a]

Item	February	April	June	August	October	December
Number of samples	42	42	41	42	40	29
Nitrogen, ppm						
Nitrate	<1	<1	<1	<1	<1	<1
Ammonium[f]	1,348	1,303	1,315	953	894	1,041
Organic N[bg]	223	275	321	286	255	201
Total N[f]	1,571	1,579	1,635	1,239	1,151	1,241
Major nutrients, ppm						
Phosphorus[g]	152	199	287	240	212	131
Phosphate[cg]	344	453	651	546	482	297
Potassium[f]	1,286	1,284	1,353	1,343	1,604	1,370
Potash[df]	1,549	1,547	1,624	1,617	1,933	1,649
Calcium[g]	309	411	390	440	413	258
Sodium[g]	393	305	318	321	391	339
Chloride[f]	754	647	774	784	891	748
Magnesium[g]	38	80	102	115	73	39
Sulfur[g]	46	85	95	99	77	47
Copper[g]	1.3	3.2	5.1	4.0	2.8	2.0
Zinc[g]	8.2	16.8	23.1	26.6	18.5	8.0
Iron[g]	18.0	30.4	40.9	55.5	34.3	12.9
Manganese[g]	1.6	3.1	4.7	4.5	3.3	1.4
Other constituents						
Carbonate, ppm	<1	<1	<1	<1	<1	<1
Bicarbonate, ppm[fg]	7,039	7,013	8,288	6,814	6,460	6,244
Solids, %[g]	0.8	1.0	1.2	1.1	1.1	0.8
pH[f]	7.7	7.5	7.8	7.7	7.9	7.9
EC, $mmho \cdot cm^{-1}$ [efg]	4.8	8.5	8.9	8.7	10.1	8.2

[a]A total of 236 samples representing 42 lagoons sampled from February through December.
[b]Calculated (Organic N = Total N − (NH_4^+-N) − (NO_3^--N)).
[c]Calculated (P_2O_5 = P/0.44).
[d]Calculated (K_2O = K/0.83).
[e]Electrical conductivity, $mmho \cdot cm^{-1}$.
[f]Linear effect of month ($P < 0.05$).
[g]Quadratic effect of month ($P < 0.05$).

goal in this experiment was to develop average nutrient concentrations from lagoons within a classification, we did not distinguish between waste handling systems within a classification.

For collecting samples, we designed and constructed a sampler that was distributed to all project participants (Figure 1). The sampler contained two separate pieces of 2.54-cm plastic pipe (PVC). First, a 15.24-cm piece of pipe was capped at one end and filled to volume with sand. This weighted the entire sampler so that it would sink approximately 1.8 to 2.4 m before the second piece of pipe, which held the liquid, would be filled to volume. The pieces of pipe were attached via a 1.27-cm threaded solid-centered coupler. The second piece of pipe, which held the liquid sample from the lagoons, was 30.48 cm in length. In addition, a 2.54-cm threaded screw cap was attached to the top of the 30.48-cm pipe with five 8.7-mm holes drilled into the cap to allow liquid to enter the pipe once it was submerged in the lagoon. The total sample volume was 350 mL when the screw cap was attached. A 12.2-m nylon rope was attached with a galvanized metal clamp just below the screw cap. Positioning the rope in this manner prevented loss of liquid during retrieval from the lagoon. At each location, an on-farm demonstration of the technique used to sample lagoons was provided. Thus, all swine operations had employees trained in proper sampling technique. Four samples were taken from different locations throughout each lagoon. Samples were thoroughly mixed and subsampled into a 525-mL plastic bottle and mailed to the laboratory for chemical analysis. No samples were taken within 12.2 m of any inlet pipes entering the lagoon from the production facilities. All samples were collected on a uniform day (2nd Tuesday of the month being sampled), with all samples shipped to the laboratory on the day of collection via next-day shipment. Upon arrival to the laboratory, all samples were analyzed for the following nutrients and properties: total N, NH_4-N, NO_3-N, organic N (total N − NH_4-N − NO_3-N = organic N), P, P_2O_5, K, K_2O, Ca, Na, Cl, Mg, S, Cu, Zn, Fe, Mn, CO_3, HCO_3, percentage solids, electrical conductivity (**EC**), and pH (APHA, 1992; AOAC, 1995).

Hoop Barns. Samples from six hoop barn sites were collected at the same times as lagoons were sampled. All manure from the production sites used in this study originated from growing and(or) finishing pigs with straw used as the bedding source. Five manure samples (2,270 g/sample) at each site were collected approximately 45.7 cm from the outside of the manure pile, which reduced the possible effects of weather

Table 4. Effects of season on mean nutrient concentration of Kansas sow lagoons[a]

Item	February	April	June	August	October	December	Mean
Number of samples	9	9	8	9	9	6	50
Nitrogen, ppm							
Nitrate	<1	<1	<1	<1	<1	<1	<1
Ammonium	1,034	1,203	889	639	595	687	841
Organic N[b]	103	149	147	104	139	108	125
Total N	1,137	1,352	1,037	743	747	797	969
Major nutrients, ppm							
Phosphorus	138	139	158	135	196	80	141
Phosphate[c]	313	316	357	306	445	182	320
Potassium	867	861	892	855	951	707	856
Potash[d]	1,044	1,037	1,070	1,029	1,146	851	1,030
Calcium	217	418	183	163	268	100	224
Sodium	348	261	272	254	298	274	285
Chloride	476	429	524	554	576	497	509
Magnesium	20	32	34	33	50	13	19
Sulfur	23	47	35	22	44	8	30
Copper	0.3	1.2	2.0	0.5	1.0	1.0	1.0
Zinc	1.6	3.9	4.2	2.0	6.4	0.7	3.1
Iron	11.6	20.0	23.0	13.4	18.3	2.6	14.8
Manganese	0.7	1.4	2.4	1.1	2.1	0.4	1.4
Other constituents							
Carbonate, ppm	<1	<1	<1	<1	<1	<1	<1
Bicarbonate, ppm	5,337	5,162	5,977	4,405	4,127	4,035	4,841
Solids, %	0.5	0.6	0.6	0.5	0.6	0.3	0.5
pH	7.7	7.6	7.8	7.7	7.9	8.0	7.8
EC, $mmho \cdot cm^{-1}$ [e]	4.5	7.4	7.6	7.1	7.9	6.7	6.9

[a]Lagoons sampled from February to December.
[b]Calculated (Organic N = total N – [NH_4^+-N) – (NO_3^--N]).
[c]Calculated (P_2O_5 = P/0.44).
[d]Calculated (K_2O = K/0.83).
[e]Electrical conductivity, $mmho \cdot cm^{-1}$.

and volatilization. The samples were combined, mixed thoroughly, and approximately 1,362 g were randomly separated and mailed to the laboratory on the day of collection. The manure piles sampled throughout the year ranged from newly removed manure from the hoop barn to manure piles that had been stored for more than 1 yr. The samples were mailed to and analyzed by the laboratory for the same nutrients and properties as previously mentioned for lagoons.

Statistical Analyses

For both experiments, the GLM procedure of SAS (SAS Inst. Inc., Cary, NC) was used with individual lagoons or hoop barns as experimental units. For Exp. 1, mean nutrient concentration and standard deviation were determined. For Exp. 2, Least Square Difference test was used to determine differences among production phases ($P < 0.05$) for lagoons. Also, linear and quadratic polynomial contrasts were used to determine the effects of season on nutrient composition of both lagoon and hoop barn manure.

Results

Experiment 1

The average total N in the manure was 899 ppm (SD = 584 ppm; Table 1). For NH_4-N, which is available to plants during the growing season, lagoon concentrations were 709 ppm (SD = 398 ppm). This indicates that 68% of the samples have a range of 310 to 1,107 ppm concentration of NH_4-N. The amount of organic N, which is nitrogen that is slowly released from the manure into the soil, was 190 ppm (SD = 209 ppm). The amount of nitrogen in the NO_3 form was less than 1 ppm.

Elemental P had a mean of 163 ppm (SD = 241 ppm), while the level of P_2O_5 was 371 ppm (SD = 549 ppm). Potash (K_2O) levels were 1,043 ppm, while mean K was 847 ppm. However, the SD of 617 ppm for K_2O and 519 ppm for K indicates a high degree of variability among samples in this survey.

The degree of variation present was very high for all other mineral concentrations summarized in this experiment. In fact, the SD of some minerals (Mg, MgO, Zn, Fe, Mn, Cu) was higher than the mean itself.

Experiment 2

Lagoon Concentration by Production Phase. For total N, lagoons from finishing and wean-to-finish facilities had greater concentrations ($P < 0.05$) compared with sow and farrow-to-finish lagoons (Table 2). In addition, lagoons from sow and farrow-to-finish operations had numerically less total N, respectively, compared with nursery lagoons, although the differences were

Table 5. Effects of season on mean nutrient concentration of Kansas nursery lagoons[a]

Item	February	April	June	August	October	December	Mean
Number of samples	8	8	8	8	7	5	44
Nitrogen, ppm							
Nitrate	<1	<1	<1	<1	<1	<1	<1
Ammonium	1,356	1,370	1,449	1,143	1,117	1,077	1,252
Organic N[b]	226	307	342	520	294	186	312
Total N	1,582	1,676	1,791	1,664	1,409	1,257	1,563
Major nutrients, ppm							
Phosphorus	145	217	257	396	250	67	223
Phosphate[c]	328	492	582	899	569	151	503
Potassium	1,233	1,328	1,369	1,282	1,550	1,315	1,351
Potash[d]	1,486	1,599	1,675	1,544	1,867	1,582	1,625
Calcium	317	410	431	875	562	183	463
Sodium	328	262	257	263	308	274	282
Chloride	561	554	662	741	706	656	647
Magnesium	43	90	82	212	94	15	89
Sulfur	54	123	117	213	106	16	105
Copper	2.4	6.5	7.8	9.9	6.6	3.2	6.1
Zinc	16.2	41.0	41.5	85.7	51.1	8.9	40.7
Iron	22.0	50.0	54.7	152.5	59.8	9.1	58.0
Manganese	1.5	3.7	4.7	10.6	4.5	0.6	1.3
Other constituents							
Carbonate, ppm	<1	<1	<1	<1	<1	<1	<1
Bicarbonate, ppm	6,873	7,618	8,911	7,761	7,141	5,979	7,380
Solids, %	0.8	1.2	1.2	1.8	1.3	0.7	1.2
pH	7.5	7.4	7.8	7.8	7.9	7.9	7.7
EC, $mmho·cm^{-1}$ [e]	4.8	9.5	9.8	9.2	11.0	9.6	9.0

[a]Lagoons sampled from February to December.
[b]Calculated (Organic N = Total N − [NH_4^+-N] − [NO_3^--N]).
[c]Calculated (P_2O_5 = P/0.44).
[d]Calculated (K_2O = K/0.83).
[e]Electrical conductivity, $mmho·cm^{-1}$.

not significant ($P > 0.05$). For NH_4, farrow-to-finish lagoons had lower ($P < 0.05$) levels than wean-to-finish and finishing lagoons. The level of NO_3-N was less than 1 ppm for all production phases, indicating that nitrates are of little concentration in the liquid portion sampled from the lagoons. This would be expected, as these lagoons were anaerobic and therefore should be low in NHO_3-N.

Phosphorus concentrations in farrow-to-finish lagoons were lower ($P < 0.05$) by approximately 65% compared with lagoons from wean-to-finish operations (Table 2). Phosphate levels followed an identical pattern as that of P, as it is simply a calculation based on P levels. For K, sow lagoons contained lower ($P < 0.05$) concentrations than wean-to-finish and finishing lagoons, while levels in nursery and farrow-to-finish lagoons were intermediate. Potash concentrations were calculated from the analyzed K concentrations; thus, differences followed the same pattern as K. Furthermore, farrow-to-finish lagoons had lower ($P < 0.05$) concentrations of Ca than nursery, wean-to-finish, and finishing lagoons, while sow lagoons had lower ($P < 0.05$) levels than finishing lagoons. There were no differences between phases of production for Na. However, sow lagoons had a lower concentration ($P < 0.05$) of Cl and Mg compared with wean-to-finish and finishing lagoons, with nursery and farrow-to-finish lagoons having intermediate concentrations. In addition, S concentrations were lower ($P < 0.05$) in lagoons from sow and farrow-to-finish operations compared with that of the other three production phases.

For the trace minerals (Cu, Zn, Fe, and Mn), sow and farrow-to-finish lagoons had the lowest concentrations compared with the other production phases (Table 2). In addition, concentrations of all minor nutrients except Mn were the highest in nursery lagoons. Nursery lagoons had higher levels of Cu and Fe ($P < 0.05$) compared with sow and farrow-to-finish lagoons, and the Zn concentration in nursery lagoons was higher ($P < 0.05$) than all other phases of production. For Mg, sow and farrow-to-finish lagoons contained lower ($P < 0.05$) concentrations compared with lagoons from the other three production phases.

Bicarbonate, which is an indicator of dissolved CO_2 when the pH of the sample is between 6.4 and 10.2, was lower ($P < 0.05$) for sow and farrow-to-finish lagoons compared with the other production phases (Table 2). The CO_3 level, which is an indicator of dissolved CO_2 when the pH of the sample is over 10.2, was less than 1 ppm for all samples. Average pH ranged from 7.7 to 7.8 for samples from different production phases. Electrical conductivity, which measures the ability of a substance to carry an electrical current, is directly correlated to the amount of dissolved salts

Table 6. Effects of season on mean nutrient concentration of Kansas wean-to-finish lagoons[a]

Item	February	April	June	August	October	December	Mean
Number of samples	7	7	7	7	7	6	41
Nitrogen, ppm							
Nitrate	<1	<1	<1	<1	<1	<1	<1
Ammonium	1,740	1,625	1,735	1,137	1,452	1,350	1,506
Organic N[b]	304	327	441	317	493	190	346
Total N	2,004	1,952	2,175	1,455	1,945	1,543	1,852
Major nutrients, ppm							
Phosphorus	205	271	452	299	384	200	302
Phosphate[c]	466	616	1,026	1,680	874	454	686
Potassium	1,513	1,575	1,703	1,688	2,152	1,866	1,750
Potash[d]	1,823	1,898	2,043	2,033	2,592	2,245	2,106
Calcium	352	523	443	441	673	347	465
Sodium	466	391	404	404	514	442	437
Chloride	954	845	1,012	949	1,234	968	994
Magnesium	51	133	166	143	123	57	112
Sulfur	68	103	140	115	137	99	110
Copper	1.4	3.0	3.9	3.4	4.1	2.5	3.1
Zinc	12.0	19.7	21.9	26.2	24.7	17.0	20.2
Iron	28.1	38.4	43.7	56.3	56.4	24.3	41.0
Manganese	2.4	4.5	6.0	5.0	6.2	2.4	4.4
Other constituents							
Carbonate, ppm	<1	<1	<1	<1	<1	<1	<1
Bicarbonate, ppm	8,578	8,732	10,607	7,973	9,576	7,440	8,817
Solids, %	1.0	1.2	1.6	1.3	1.7	1.2	1.3
pH	7.6	7.5	7.9	7.7	7.9	7.8	7.8
EC, mmho·cm^{-1} [e]	5.5	10.5	10.1	9.9	12.4	9.0	9.5

[a]Lagoons sampled from February to December.
[b]Calculated (Organic N = Total N − [NH_4^+-N] − [NO_3^--N]).
[c]Calculated (P_2O_5 = P/0.44).
[d]Calculated (K_2O = K/0.83).
[e]Electrical conductivity, mmho·cm^{-1}.

in the sample. The electrical conductivity was higher ($P < 0.05$) for wean-to-finish and finish lagoons compared with farrow-to-finish lagoons. The percentage of solids in the samples was higher ($P < 0.05$) for wean-to-finish and finishing lagoons than sow and farrow-to-finish lagoons.

Lagoon Concentration by Season. Seasonal differences in the lagoon samples were found for a large number of the nutrients and other properties. Overall effects of season will be discussed (Table 3) since a similar pattern was observed for all nutrients, regardless of production phase (Tables 4 through 8). Due to cold environmental conditions during December, obtaining samples from some lagoons was delayed for up to 1 mo, while for others, no samples were taken due to surface freezing.

The amount of NH_4 and total N concentrations decreased (linear, $P < 0.05$) from February until December (Table 3). However, the largest decline occurred between June and August, with a moderate increase from October to December. In addition the concentration of organic N varied with season (quadratic, $P < 0.05$) with the months of December and February having the lowest, while June and August had the highest levels. The decrease in N during the warmer season can be explained by an increase in activity of bacteria in lagoons during this time, which would convert N into NH_3 that is then volatilized.

Phosphorus and P_2O_5 concentrations were influenced (quadratic, $P < 0.05$) by season, with the highest levels occurring during June and August, and the lowest during February and December. Also, the concentration K, K_2O, and Cl increased (linear, $P < 0.05$) throughout the year. A quadratic effect ($P < 0.05$) for all other macro (Ca, Na, Mg, and S) and trace (Cu, Zn, Fe, and Mn) minerals was observed. This response was indicated by an increase in nutrient concentration during warmer months followed by a decrease in the cooler months, except for Na, which had the opposite response. The concentration of HCO_3 (linear and quadratic, $P < 0.05$), percentage solids (quadratic, $P < 0.05$), pH (linear, $P < 0.05$), and electrical conductivity (linear and quadratic, $P < 0.05$) were affected by the season of the year.

Hoop Barn Manure Concentrations. All hoop barns sampled in this study housed grow-finish pigs; therefore, no effects of production phase could be determined. However, seasonal alterations in manure were analyzed (Table 9).

No seasonal differences ($P > 0.05$) for N characteristics, P, K, Ca, Mg, and S were detected (Table 8). However, Na (linear and quadratic, $P < 0.05$) and Cl

Table 7. Effects of season on mean nutrient concentration of Kansas finishing lagoons[a]

Item	February	April	June	August	October	December	Mean
Number of samples	10	10	10	10	9	7	56
Nitrogen, ppm							
Nitrate	<1	<1	<1	<1	<1	<1	<1
Ammonium	1,850	1,543	1,770	1,342	816	1,495	1,469
Organic N[b]	353	384	437	363	209	362	351
Total N	2,202	1,927	2,206	1,706	1,023	1,859	1,820
Major Nutrients, ppm							
Phosphorus	185	284	403	247	122	238	246
Phosphate[c]	420	644	914	560	278	538	559
Potassium	1,790	1,700	1,753	1,651	1,949	1,877	1,786
Potash[d]	2,156	2,048	2,103	1,987	2,348	2,259	2,150
Calcium	441	512	615	548	382	500	500
Sodium	513	366	413	399	490	452	439
Chloride	1,053	909	1,038	954	1,094	1,033	1,013
Magnesium	48	106	168	125	57	77	97
Sulfur	70	103	130	108	61	95	94
Copper	1.8	3.5	7.0	4.8	2.0	3.0	3.7
Zinc	8.6	15.4	38.1	15.2	7.6	12.5	16.2
Iron	22.6	36.7	60.0	41.2	26.2	25.9	35.4
Manganese	2.6	5.0	7.2	5.0	3.0	3.7	4.4
Other constituents							
Carbonate, ppm	<1	<1	<1	<1	<1	<1	<1
Bicarbonate, ppm	9,597	9,148	10,862	9,514	6,810	9,265	9,199
Solids, %	1.2	1.4	1.7	1.3	1.0	1.3	1.3
pH	7.7	7.6	7.8	7.8	7.9	7.9	7.8
EC, $mmho\cdot cm^{-1}$ [e]	5.3	9.2	9.9	10.2	11.1	9.4	9.1

[a]Lagoons sampled from February to December.
[b]Calculated (Organic N = total N − [NH_4^+-N) − [NO_3^--N]).
[c]Calculated (P_2O_5 = P/0.44).
[d]Calculated (K_2O = K/0.83).
[e]Electrical conductivity, $mmho\cdot cm^{-1}$.

(linear, $P < 0.05$) were influenced by season. For trace minerals, Zn and Fe were not affected ($P > 0.05$), but Cu (quadratic, $P < 0.05$) and Mn (linear, $P < 0.05$) differed by season. Percentage solids, pH, and electrical conductivity were not influenced by season ($P > 0.05$).

Discussion

Currently, published values for mean nutrient concentrations for swine lagoons vary considerably. The average total N concentration published by the MidWest Plan Service (MWPS, 1993) is 625 ppm. Nelson and Shapiro (1989) reported a mean total N value of 500, DeSutter et al. (2000) reported a mean value of 888 ppm, and Fulhage and Hoehne (1999) reported values of 1,373 and 725 ppm for deep and shallow swine lagoons, respectively. Within our experiments involving swine producers, the mean was approximately 55% higher (899 vs 1,402 ppm) in the second experiment. This may be due to several factors. First, in Exp. 1, the samples were all from swine operations with 1,000 animal units or more, whereas in Exp. 2, they were not. Assuming that larger swine operations would have larger lagoons or more properly sized lagoons that met state and federal permit requirements to hold the animal waste, the increased lagoon size may help lower N concentrations. Fulhage and Hoehne (1999) reported that lagoons with a higher surface/volume ratio had lower nutrient concentrations. Secondly, Exp. 2 concentrations were the values averaged over six samples from various months throughout the year, but time of the year was not specified from lagoons in Exp. 1. Our results show that season of the year had a significant impact on concentration, with the lowest concentration in October (1,151 ppm) and the highest concentration in June (1,624) differing by approximately 41%. Sample collection date would have a dramatic effect on the overall average if season of the year were not accounted for. Also, sampling technique may have caused a discrepancy between experiments, as a standardized procedure was used in Exp. 2, but not in Exp. 1.

Likewise for P concentrations, there is much variation in published values. The average total P concentration published by the MWPS (1993) is 165 ppm. Nelson and Shapiro (1989) reported a mean total N value of 110 ppm, DeSutter et al. (2000) reported a mean value of 90 ppm, and Fulhage and Hoehne (1999) reported values of 213 and 96 ppm for deep and shallow swine lagoons, respectively. The MWPS (1993) and Nelson and Shapiro (1989) do not describe how their values were derived, nor in what years the analyses were compiled. DeSutter et al. (2000) gener-

Table 8. Effects of season on mean nutrient concentration of Kansas farrow-to-finish lagoons[a]

Item	February	April	June	August	October	December	Mean
Number of samples	8	8	8	8	8	5	45
Nitrogen, ppm							
Nitrate	<1	<1	<1	<1	<1	<1	<1
Ammonium	764	779	731	505	488	594	643
Organic N[b]	127	208	240	125	138	157	166
Total N	891	987	970	630	630	753	810
Major nutrients, ppm							
Phosphorus	86	87	165	123	106	72	106
Phosphate[c]	194	197	375	279	241	162	241
Potassium	1,024	957	1,023	1,238	1,422	1,086	1,125
Potash[d]	1,234	1,153	1,228	1,490	1,713	1,308	1,354
Calcium	216	193	280	172	182	150	198
Sodium	311	246	246	287	345	256	281
Chloride	726	499	639	721	850	590	671
Magnesium	30	37	58	61	40	30	43
Sulfur	18	49	53	39	41	20	36
Copper	0.5	1.8	4.8	1.2	0.5	0.2	1.5
Zinc	2.5	4.1	9.8	3.8	2.7	0.8	4.0
Iron	6.0	7.0	23.9	14.2	10.7	2.8	10.7
Manganese	0.6	1.1	3.3	1.1	1.0	0.4	1.2
Other constituents							
Carbonate, ppm	<1	<1	<1	<1	<1	<1	<1
Bicarbonate, ppm	4,813	4,402	5,085	4,421	4,648	4,504	4,645
Solids, %	0.5	0.6	0.8	0.7	0.7	0.6	0.6
pH	7.7	7.7	7.7	7.7	7.9	7.8	7.7
EC, $mmho \cdot cm^{-1}$ [e]	3.9	5.8	7.2	7.2	8.1	6.4	6.4

[a]Lagoons sampled from February to December.
[b]Calculated (Organic N = total N − [NH_4^+-N] − [NO_3^--N]).
[c]Calculated (P_2O_5 = P/0.44).
[d]Calculated (K_2O = K/0.83).
[e]Electrical conductivity, $mmho \cdot cm^{-1}$.

ated their values from 24 samples of swine lagoons from 19 different sites in Kansas from 1998 to 2000. Fulhage and Hoehne (1999) sampled 100 swine lagoons in Missouri in the spring of 1998.

Due to extreme variation among and within classifications in our experiments, there were few significant differences ($P < 0.05$) between classifications, although there were wide differences in mean values. Sampling procedures were standardized in the second experiment to help control any variation that this process may cause. Lorimor and Kohl (2000) reported that concentrations of N and P are lowest at the surface and highest at the bottom of swine manure that is collected into pits. However, DeSutter et al. (2000) reported no apparent vertical stratification of either chemical or physical parameters in swine lagoons.

The level of variation among individual lagoons in this study reemphasizes the importance of obtaining individual analysis from each lagoon before land application. Wager et al. (1999) also demonstrated that high variability existed in nutrient profiles within dairy and swine manure handling systems, and the authors recommended that producers obtain nutrient values for each handling system rather than using published reference values for nutrient management plans.

Although high variation existed, we observed several differences in nutrient concentration among production phases, which may be associated with different management, nutrition, and type of lagoons associated with each phase. Many farrow-to-finish operations utilized both a primary and secondary lagoon system, or others had one large lagoon. Use of these types of lagoons with large liquid volumes may have resulted in reduced concentrations of nutrients as discussed previously. Sow lagoons also were typically lower in nutrient concentration than the other production phases, which may be because the breeding herds produce less manure per animal BW than growing-finishing pigs. This would also help explain the reduction in percentage solids with sow and farrow-to-finish lagoons compared with the other phases of production. As swine increase in age, they become less efficient in the utilization of nutrients (de Lange et. al, 2001) which may help explain the increased level of nutrients found in wean-to-finish and finishing lagoons. Also, improper management (feeder adjustment) and nutrition (over formulation of diets) may have increased nutrient levels for these two production phases. Because S is a larger contributor to the odors associated with hog production (Hamilton et al., 1997) and nursery, wean-to-finish, and finishing

Table 9. Effects of season on mean nutrient concentration of Kansas hoop barn manure[a]

Item	February	April	June	August	October	December	SEM	Mean
Number of samples	6	6	6	6	6	5		35
Nitrogen, ppm								
Nitrate	238	159	191	N/A	678	81	173	225
Ammonium	1,695	2,067	1,706	1,634	2,315	2,601	518	2,003
Organic N[b]	6,078	6,075	8,155	7,131	4,910	6,238	896	6,431
Total N	7,850	8,377	10,128	8,841	7,904	8,966	1,177	8,678
Major nutrients, ppm								
Phosphorus	4,194	3,677	3,786	4,963	4,710	4,851	645	4,364
Phosphate[c]	9,532	8,357	8,595	11,265	10,703	11,003	1,467	9,908
Potassium	7,835	8,426	8,662	8,131	9,534	10,616	1,184	8,867
Potash[d]	9,439	10,152	10,392	9,789	11,486	12,778	1,425	10,673
Calcium	46,279	29,764	36,569	36,625	52,254	60,564	10,554	43,676
Sodium[fg]	2,117	1,248	1,225	1,096	1,347	1,361	235	1,398
Chloride[f]	2,123	2,134	1,208	2,798	3,096	3,215	376	2,429
Magnesium	3,315	2,669	2,886	3,323	3,428	3,639	325	3,210
Sulfur	1,491	1,674	1,854	1,268	1,607	1,490	230	1,564
Copper[g]	81	75	575	38	29	40	54	140
Zinc	157	177	157	215	159	220	31	181
Iron	4,128	5,635	2,873	5,129	5,087	6,544	1,243	4,899
Manganese[f]	196	219	216	232	265	289	39	236
Other constituents								
Solids, %	51	55	60	47	57	69	6	57
pH	7.1	7.0	7.1	N/A	6.7	7.0	0.3	7.0
EC, mmho·cm^{-1} [e]	5.4	7.2	7.1	N/A	9.5	6.1	0.6	7.1

[a]Hoop barn manure sampled from February to December.
[b]Calculated (Organic N = Total N − [NH_4^+-N] − [NO_3^--N]).
[c]Calculated (P_2O_5 = P/0.44).
[d]Calculated (K_2O = K/0.83).
[e]Electrical conductivity, mmho·cm^{-1}.
[f]Linear effect of month, ($P < 0.05$).
[g]Quadratic effect of month, ($P < 0.05$).

operations had significantly higher S than sow and farrow-to-finish operations, odor from these facilities may be of greater concern. Increased concentrations of certain trace minerals in nursery lagoons, especially Zn and Cu, would be associated with nutrition practices that use these minerals as growth promoters (Hill et al., 1996; Kornegay et al., 1989) for pigs during this stage of growth.

Nutrient concentrations of lagoons based on production phase and season of the year (Tables 4 to 8) demonstrate that regulatory agencies should develop standards of nutrient management plans based on production phase, rather than having a single classification. In addition, this data can be utilized by producers, consultants, and academia as comparisons for swine farms as they develop farm-specific nutrient management plans.

To our knowledge, no studies have evaluated the effects of season on the nutrient concentration of swine lagoons. The rise in nutrient levels during the summer months may be associated with the increased agitation of solid materials from the lagoon bottom caused by an increased bacteria level associated with warmer temperatures. This is supported by the fact that the percentage solids were highest during the warmer months and lowest in the cooler months in this study. Furthermore, less rainfall is typically associated with the summer months with higher evaporation rates. This may allow for an increased concentration of nutrients in the lagoon.

Nutrient values for hoop barn manure determined in this study are the first to be published for Kansas. One striking observation from these results is the higher nutrient concentration associated with hoop barn manure compared with other published values of swine manure with bedding (Nelson and Shapiro, 1989). However, the percentage of solids for hoop barn manure is much higher compared with those values (57 vs 18%), which would contribute to higher nutrient concentrations.

Implications

Our data demonstrate that season and type of production phase affect the nutrient content of Kansas swine lagoons. Therefore, producers will benefit from obtaining individual analyses from their lagoons when developing nutrient management plans rather than utilizing published reference values. When samples are analyzed, producers should apply the manure to the land in a timely manner, as the composition of the lagoon will change over time.

Literature Cited

AOAC. 1995. Official Methods of Analysis. 16th ed. Association of Official Analytical Chemists, Arlington, VA.

APHA. 1992. Standard Methods. 18th ed. American Public Health Association, Washington, DC.

de Lange, C. F. M., S. H. Berkett, and P. C. H. Morel. Protein, fat, and bone tissue growth in swine. In: Swine Nutrtion. 2nd ed. CRC Press LLC, Boca Raton, FL.

DeSutter, T. M., J. M. Ham, and T. P. Trooien. 2000. Survey of waste chemistry of anaerobic lagoons at swine production facilities and cattle feedlots. In: Animal Waste Lagoon Water Quality Study. Kansas State University, Manhattan.

Fulhage, C., and J. Hoehne. 1999. A manure nutrient profile of 100 Missouri swine lagoons. ASAE paper No. 99-4026, American Society of Agricultural Engineers, St. Joseph, MI.

Hamilton, D. W., W. G. Luce, and A. D. Heald. 1997. Production and characteristics of swine manure. Oklahoma Cooperative Extension Service No. F-1735, Stillwater.

Hill, G. M., G. L. Cromwell, T. D. Crenshaw, R. C. Ewan, D. A. Knabe, A. J. Lewis, D. C. Manhan, G. C. Shurson, L. L. Southern, and T. L. Venum. 1996. Impact of pharmacological intakes of zinc and (or) copper on performance of weanling pigs. J. Anim. Sci. 74(Suppl. 1):181 (Abstr.).

Kornegay, E. T., P. H. G. van Heugton, M. D. Lindemann, and D. J. Blodgett. 1989. Effects of biotin and high copper levels on performance and immune response of weanling pigs. J. Anim. Sci. 67:1471–1477.

Lorimor, J. C., and K. Kohl. 2000. Obtaining representative samples of liquid swine manure. ASAE paper No. 00-2202, American Society of Agricultural Engineers, St. Joseph, MI.

MWPS. 1993. Livestock Waste Facilities Handbook. 3rd ed. MidWest Plan Service, Ames, IA.

Nelson, D. N., and C. A. Shapiro. 1989. Fertilizing crops with animal manure. Nebraska Cooperative Extension No. 89-117, Lincoln.

Wager, T., M. Schmitt, C. Clanton, and F. Bergsrud. 1999. Livestock manure sampling and testing. University of Minnesota Extension Service No. 6423, Minneapolis.