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WASTEWATER REUSE LAGOON SYSTEMS FOR SWINE — A LABORATORY STUDY

The reuse of wastewater from the second lagoon of a two cell system can reduce fresh water consumption by at least one-half. However, accumulation will still require land application. The salt concentration will be the limiting factor when applying wastewaters from the second lagoon to cropland.

1. INTRODUCTION

The use of hydraulic transport (flushing) for cleaning manures from animal feeding facilities has presented new problems in management and design. These systems feature low labor, low initial investment, low maintenance, and good odor control within the buildings. However, the high rate of water usage normally dictates the need for reusing wastewaters to reduce costs and to avoid high rates of discharge of highly polluted effluent to streams. Using wastewater from the second of two-stage non-overflow lagoon system to flush has the potential of reducing the accumulation in the second lagoon by about 50 percent when all rainwater from the roof is directed to the lagoons. Diverting roof waters can reduce accumulation by another 25%. Effluent from animal waste treatment systems normally is not of sufficient quality to permit direct discharge to streams. In most cases, land must be utilized as a final acceptor or treatment for animal waste being discharged from feeding operations.

Establishing the minimum requirements for storage and treatment of wastewater in a hydraulic collection system which would utilize land (under crop production) as a final treatment was the purpose of this study. This laboratory study was designed to evaluate a wide range of loading rates to include ranges reviewed by ASAE [2].

The influent loading rate of lagoons for swine manure treatment can be calculated several ways. The Biochemical Oxygen Demand (BOD), Chemical Oxygen Demand (COD)

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and live weight of animals, number of animals, volatile solids or the total solids of the organic matter and the nitrogen concentration have been used by researchers. BOD is not a reliable parameter because of difficulty in measuring the parameter and the wide range of variability of measurements on the same material. Research data [1] indicate a relationships between COD, live weight, total solids, and volatile solids excreted by animals on similar diets. Any of these parameters could be measured and a close estimate made of the other parameters. For a large feeding facility, the live weight or number of hogs at a given time can be measured easier than the amount of waste being produced. For a model study, the characteristics of the waste are needed and are easier to measure than the live weight. For this study the percent volatile solids was used to determine the amount of raw waste needed for loading the models. The results of the experiment can be related to the pounds of live weight of animals to produce a given volatile solids loading rate.

There is considerable disagreement as to the most desirable loading rate for anearobic lagoons. It is generally accepted that lagoons in southern regions can be loaded at higher rates than in northern regions [2]. The allowable loading rate appears to depend directly on the expected performance and the ability of people to evaluate the performance. Most evaluations are based on appearance and odor emissions and are quite subjective. However, most researchers evaluate the performance by measuring the ability to degrade or stabilize organic matter. The resulting odor emissions can be measured quantitatively but are normally evaluated on a subjective basis.

The Standards Sub-Committee of SE-412 Committee of ASAE has evaluated the loading rates being recommended across the United States [2]. An average was established and is now being considered as a recommended engineering practice for USA. Recommendations actually vary from 50% to 200% of these averages. The recommended loading rate for Alabama is 88 g V.S./m^3d.

2. EXPERIMENTAL APPARATUS

A laboratory study was conducted to evaluate the use of a two-stage non-overflow lagoon system for treating swine manure from a facility incorporating a flushing system using wastewater from the second lagoon. The model lagoons were constructed of Plexiglas cylinders 15.24 cm in diameter and about 183 cm high. The cylinders were paired by matching the depth-volume relationships as closely as possible. The cylinders were then joined at mid-depth by tubing and clamps to allow flow between the tubes and a tee to allow either lagoon model to be sampled as shown in fig. 1. Funnels with plastic tube extensions were placed in the top of each tube to allow loading without disturbing the floating solids. Evaporation due to the uneven air flow pattern in the room caused by the location of window air conditioners was controlled by placing a 6 mm plastic cover over the top of the tubes which was taped on one end to allow ready access and unrestricted exchange of gases.

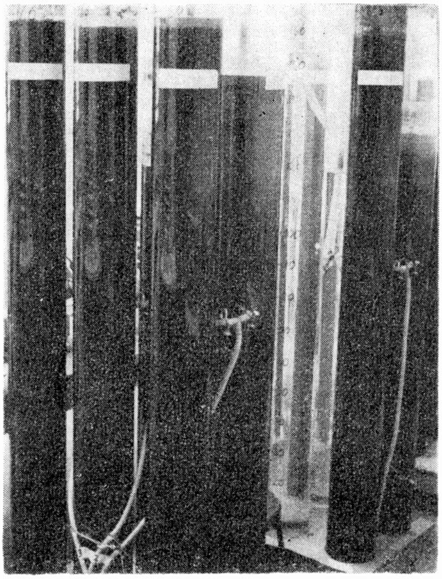

Fig. 1. Lagoon models for swine manure treatment studies

Rys. 1. Modele lagunowe do oczyszczania ścieków dla ferm trzody chlewnej

3. PROCEDURE

The amount of water removed from the second lagoon models to simulate flushing was estimated by considering building and lagoon dimensions and practices at the new swine research center and average weather conditions for the Auburn, Alabama area. Flushing twice per day results in about 22 dm^3/hog·day at the research center which uses 6.6 m^3 of flushwater each time it flushes. A proportional amount was calculated for each lagoon model based on the amount of volatile soilds (V. S.) being placed into each set of models. This laboratory study was designed to investigate a wide range of loading rates to include the ranges being considered as a recommended Engineering Practice by ASAE. The ranges selected are shown in table 1.

Table 1

Loading rates used for swine lagoon models

Daily, g V.S.		Thrice/Weekly, for 24 liter volume		
g V.S./m^3·d	24 dm^3	V. S. added (q)	Fresh water[1] added, (cm^3)	Mixed liquid recycled, (cm^3)
40	0.96	2.24	36	154
80	1.92	4.48	18	308
160	3.84	8.96	9	616
320	7.68	17.92	5	1232

1) Deionized water added to both cells to account for rainfall-less-evaporation accumulation based on yearly average in Auburn, Alabama.

The manure was collected from swine on a partially slatted floor receiving a fattening diet consisting of 76.4% ground corn, 21% soybean meal, 1.2% Dicalcium phosphate, 0.8%$CaCO_3$, 0.5 trace mineral salt and 0.1% Vitamin premix. This is a 16% crude protein ration with 0.6% calcium and 0.5% phosphorous. The raw manure was sampled and analyzed for nitrogen, percent solids, and percent volatile solids.

Lagoon sampling was accomplished by withdrawing at least 200 cm^3 from each of the first and the second lagoons every 4 weeks. This sample was used to measure the pH and electrical conductivity. Subsamples were taken to analyze for nitrogen, chemical oxygen demand (COD) and solids. These samples represent the mixed liquor between the settled sludge and the floating solids found in lagoons. The mixed liquor consisted of liquid, dissolved solids and suspended solids.

Researchers have reported no difference between loading a lagoon 3 times per week and loading semi-continuously [5]. To reduce labor requirements and the chance for error the model lagoons were loaded each Monday, Wednesday, and Friday. The quantity of volatile solids (g V.S.) required for each loading was 2.33 times the daily loading rate. The loading rate for 40 g V.S./m^3 for the 24 dm^3 model loaded thrice weekly is : $40 \times \times 0.024 \times 2.33 = 2.24$ g V.S.

The swine lagoon models were operated in a room maintained at 21 °C and operated to closely simulate a prototype system. Basing the water used for flushing on 22.7 $dm^3$68 kg hog/day (0.338 dm^3/kg live weight/day), the mixed liquor removed from cell no. 2, mixed with the fresh manure, and placed into cell no. 1 with a loading rate of 40 g V.S./m^3 and a manure production of 2.2 kg V.S./454 kg liveweight (L.W.) [1] is :

$$\frac{0.338\ \mathrm{dm}^3}{\mathrm{kgL.W.}} \times \frac{454\ \mathrm{kgL.W.}}{2.2\ \mathrm{kgV.S.}} \times \frac{2.24\ \mathrm{gV.S.}}{\mathrm{loading}} = 0.154\ \mathrm{dm}^3 .$$

Since the laboratory models were all the same size, the grams of volatile solids was increased to increase the loading rate. The volume of mixed liquor from reactor no. 2 was increased proportionally to simulate the same amount of flush water per hog required for cleaning a house regardless of lagoon size. The volume of solids in the manure samples vary somewhat due to solids content and would influence the amount of water to be added to reactor no. 1 for each of the four loading levels. Preliminary tests indicated this difference was small and should not influence the results of the experiment. This variability is also representative of actual conditions. The loading rate and the mixed liquor recycled 3 days each week are listed in table 1.

To simulate the difference in rainfall and evaporation from the lagoons, water was added to each cell proportional to the average rainfall less 70% of the average pan evaporation for the Auburn, Alabama area (i.e. 33° latt. and 86° long.). The amount added is listed in table 1. This figure was calculated by comparing the laboratory models with the size of lagoons needed (surface area) for a 10-foot (3.048 meter) deep lagoon for the respective loading rates. Since the lagoon size (surface area) required decreases with increased loading rate, the accumulation of water from rainfall-less-evaporation also decreases. The initial volume of mixed liquor in the second cell was established at 18 liters to allow for this accumulation. The mixed liquor was removed as needed as the level approached the full mark.

4. DISCUSSION AND RESULTS

The results of the chemical analysis [7] of the laboratory models are shown in tables 3 and 4.

4.1. REACTION pH

The pH in the first and second lagoon for each loading rate was about the same for the first 10 months. A slightly higher pH occurred after that time in the second lagoon. The pH steadily increased then decreased slightly in both cells over the corresponding time periods.

4.2. ELECTRICAL CONDUCTIVITY

The electrical conductivity (EC) is an indication of the amount of soluble salts present. High conductance indicates high salt concentrations. It is normally accepted that irrigation water for crops should not exceed 3 to 4 millimhos per centimeter [3, 4]. This may not be a satisfactory parameter for selecting the size of area and crop to use in a wastewater reuse system because discharges from the lagoon will normally occur only twice per year. Therefore, the total salts applied each irrigation period must be considered to avoid polluting the soil or destroying the plants.

The relationship between electrical conductivity and salt concentration (shown in fig. 2) can be estimated from existing data [6]. For example, a conductivity of 20.5 millimhos/cm would have a salt concentration of about 1.73 percent (1.73 g per 100 g water). Assuming the tolerance level of the crop to be 1905 kg/ha·year, the maximum effluent to be applied would be 446/3 kg of water or 1.09 cm as irrigated. This would be somewhat typical of effluent from lagoon systems receiving high loading rates as shown in tables 2 and 3. For the loading rate 40 g V.S./m^3 after 1 year of operation the salt concentration in cell no. 2 was only about 0.20 percent (0.20 g per 100 g water). About 9 cm of effluent could be applied to reach a 1905 kg salt/ha restriction. These data are shown in table 2. It should be noted that the amount of salt a plant can tolerate at one time must be considered. Tolerance varies widely with plant species.

The conductivity of all cells increased with loading rate. The difference in the conductivity between the first and second cell decreased as loading rate increased. This could have resulted from the higher flow from cell no. 1 to cell no. 2 used to represent the amount

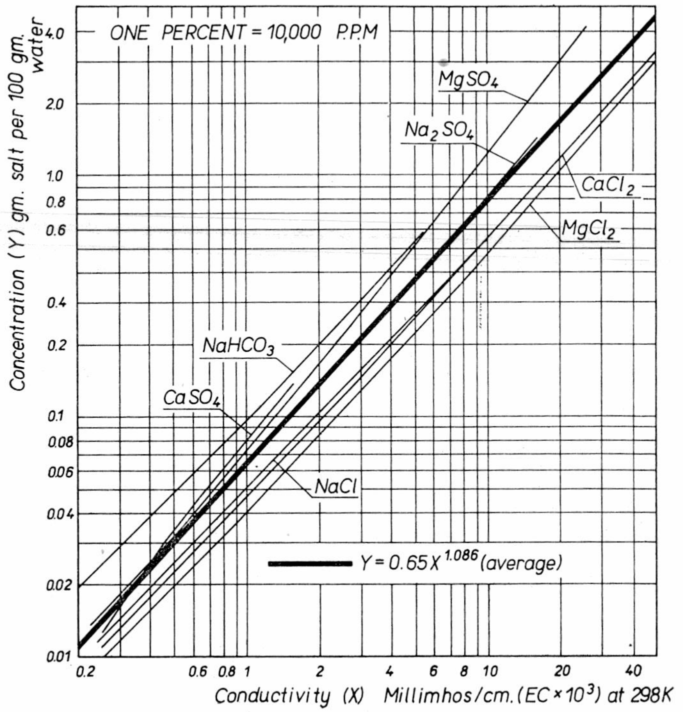

Fig. 2. Concentration of single-salt solutions in percent as related to electrical conductivity

Rys. 2. Procentowe stężenie roztworów pojedynczych soli w zależności od przewodnictwa elektrycznego

Table 2

Yearly salt and nitrogen limitations for a grass crop[1]

Lagoon loading rate g V.S./m^3	Salts			Nitrogen	
	EC$\times 10^3$	percent	Application per year, cm	TKN mg/dm^3	Application rate per year cm
320	20.5	1.73	1.09	2,600	4.32
160	12.0	0.97	1.96	1,300	8.64
80	5.5	0.41	4.64	550	20.42
40	3.0	0.21	9.08	300	37.42

of flush water required for various size lagoons. Another factor is the volume lost due to sludge accumulation. Tables 3 and 4 indicate the results of data at selected times during the experiment for the first lagoon and the second lagoon, respectively.

[1]) Limitation assumptions [1] 1905 kg/ha·year of salt and [2] 1120 kgN/ha·year

Table 3

Results of analysis of first lagoons at selected times during experiment

Weeks	Loading rate g V.S./m^3	pH	EC$\times 10^3$ mmhos/cm	C.O.D mg/dm^3	TKN mg/dm^3	Ammonium – N mg/dm^3	Percent solids
0	40	6.1	1.34	749	72		0.05
	80	6.1	1.57	957	71		0.07
	160	6.2	1.75	1,119	63		0.82
	320	6.3	2.50	1,853	70		0.14
4	40	6.5	1.95	357	160		0.09
	80	6.6	2.57	573	239		0.12
	160	6.8	3.57	1,238	372		0.19
	320	6.9	5.00	2,472	526		0.36
8	40	6.7	2.23	367	212		0.09
	80	6.9	3.27	568	327		0.12
	160	7.1	4.75	1,114	543		0.19
	320	7.3	6.70	2,292	823		0.30
12	40	6.8	2.55	399	232		0.11
	80	7.0	3.85	562	405		0.15
	160	7.2	5.80	968	652		0.22
	320	7.3	8.30	2,160	992		0.36
24	40	7.5	3.02	400	320		0.11
	80	7.7	4.60	831	539		0.16
	160	7.8	6.90	1,286	906		0.25
	320	7.9	11.00	2,274	1,480		0.39
36	40	8.0	4.20	800	498		0.14
	80	7.9	6.20	792	708		0.19
	160	8.1	10.00	1,505	1,300		0.32
	320	8.1	16.00	3,550	2,224		0.64
48	40	7.4	4.30	623	504	518	0.14
	80	7.7	6.20	864	799	785	0.21
	160	7.8	10.10	2,043	1,492	1,420	0.39
	320	7.8	16.20	4,670	2,414	2,386	0.78
60	40	7.6	5.00	583	552	519	0.14
	80	7.7	7.50	953	866	812	0.22
	160	7.8	12.40	2,224	1,719	1,548	0.41
	320	7.9	19.00	6,061	2,933	2,670	0.86
72	40	7.6	5.20	578	526	505	0.15
	80	7.5	8.00	1,100	797	841	0.26
	160	8.2	13.40	2,530	1,369	1,547	0.47
	320	7.9	21.5	7,350	2,462	2,358	1.05

Table 4

Results of analysis of second lagoons at selected times during the experiment

Weeks	Loading rate g V.S./m^3	pH	EC$\times 10^3$ mmhos cm	COD mg/dm^3	TKN mg/dm^3	Ammonium – N mg/dm^3	Percent solids
	40	6.0	1.14	710	69		0.04
0	80	6.1	1.44	834	69		0.06
	160	6.1	1.21	703	66		0.05
	320	6.2	1.36	795	67		0.06
	40	6.6	1.24	233	91		0.06
4	80	6.7	2.00	391	111		0.05
	160	6.8	2.20	391	161		0.09
	320	6.9	3.30	1,015	301		0.15
	40	6.7	1.31	285	105		0.05
8	80	6.8	1.75	347	158		0.07
	160	7.0	2.80	431	278		0.10
	320	7.2	4.75	792	516		0.16
	40	6.8	1.37	195	105		0.06
12	80	6.9	2.08	274	188		0.08
	160	7.2	3.60	400	365		0.13
	320	7.3	6.30	911	703		0.22
	40	7.4	1.42	165	115		0.06
24	80	7.4	2.58	251	264		0.08
	160	7.9	4.88	627	587		0.15
	320	7.8	9.00	1,160	1,157		0.28
	40	8.0	1.82	231	198		0.07
36	80	8.1	3.20	306	394		0.11
	160	8.3	6.90	972	901		0.23
	320	8.0	13.30	1,960	1,800		0.43
	40	8.0	2.10	272	246	246	0.07
48	80	8.2	3.90	424	487	480	0.13
	160	7.9	8.00	1,277	1,198	1,219	0.29
	320	7.9	15.00	2,880	2,277	2,213	0.59
	40	8.0	2.75	256	277	274	0.08
60	80	8.2	4.50	512	571	543	0.15
	160	8.0	10.60	1,464	1,456	1,358	0.32
	320	8.0	18.60	3,670	2,629	2,436	0.68
	40	8.2	2.90	273	294	276	0.09
72	80	7.7	5.70	546	481	593	0.19
	160	7.8	12.20	1,735	1,214	1,360	0.38
	320	8.2	20.50	4,458	2,686	2,375	0.81

4.3. CHEMICAL OXYGEN DEMAND (COD)

The COD increased with loading rate in both lagoons but stabilized reasonably well for the 40 and 80 g V.S./m^3 loadings.

4.4. TOTAL KJELDAHL NITROGEN (TKN)

TKN increased almost linearly with time for all loading rates and increased with loading rate in both cells. The TKN in the second cell followed the same trend as the first lagoon in all cases but was numerically less in all cases. The removal of effluent from the second lagoon did not significantly change TKN accumulation rates in either cell.

Based on irrigation on the 10-th month, and assuming a 454 kg nitrogen uptake for a grass crop, the amount of wastewater from the second lagoon which can be applied to grass turf is 37.3, 20.3, 8.6 and 4.3 cm respectively as the lagoon loading increases (table 2). Comparing these figures with the calculations on salt concentration indicates that salt concentration would be the limiting factor for land application on a grass crop. This would definitely be the case when less tolerant crops are considered.

AMMONIA NITROGEN

Ammonia nitrogen, as measured by the distillation method, was 88 to 100 percent of the TKN in both lagoon cells. This would indicate that the lagoons are functioning well as anaerobic digesters; that is, the nitrogen is in the ammonia or ammonium salt form. The lack of thermal currents, boiling action and wind may explain the high ammonia readings.

SOLIDS

The total dissolved and suspended solids in the wastewater increased with loading rate in both lagoons. Solids reduction was from about 1/2 to 1/3 from the first lagoon to the second lagoon depending on loading rate.

MASS BALANCE

Wastewater accumulated more rapidly in the systems being loaded at 40 and 320 g V.S./m^3 d than for 80 and 160 g V.S./$m^3 \cdot$d. This resulted from the high volume of simulated rainwater in the former and the high volume of waste in the latter case. Only 59% of the volume of solids and liquids input could be accounted for in the discharge from these two loading rates. For the loading rates of 80 and 160 g V.S./$m^3 \cdot$d the volume accounted for was about 52% of the input volume. The results were closely grouped primarily due to similarity in size and total loading rates. These figures were arrived at by measuring the volume of discharge from cells number 2 and comparing these volumes with the volume of input. The volume of manure input was calculated by assuming 1 gram to equal 1 milliliter. The volume not accounted for obviously was converted to gases.

5. SUMMARY AND CONCLUSIONS

Experiments were conducted to determine the effects of loading on two-cell swine lagoons where wastewater from the second cell is reused for flushing manure from the buildings into the first lagoon. Loading rates were 40, 80, 160, and 320 g V.S./$m^3 \cdot d$. The data indicate that salt concentration would limit land application of wastewater from the second cell when plant uptake is the primary criteria.

The lower and the higher loading rates resulted in more rapid accumulation of wastewater due to more total rainwater on the lagoon receiving the lowest loading rate (larger surface area) and the higher volume of manure placed in the lagoon receiving the highest loading rate. Only about 50% of volume input can be accounted for in the discharge from the lagoon systems during the first year.

Ammonia nitrogen accounted for 88 to 100 percent of the total Kjeldahl Nitrogen (TKN) in the lagoon cells.

ACKNOWLEDGEMENT

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RECYRKULACJA ŚCIEKÓW W FERMACH TRZODY CHLEWNEJ

W pracy przedstawiono badania w skali półtechnicznej, dotyczące recyrkulacji odpływu z drugiej laguny (w układzie szeregowym) do płukania kanałów gnojowicowych w fermach tuczu trzody chlewnej. Obciążenia lagun ładunkiem związków organicznych wyniosło od 40–320 gZO/m^3d. Stwierdzono, że recyrkulacja powoduje wzrost zasolenia ścieków, będącego czynnikiem limitującym dawki ścieków kierowanych do nawodnień upraw. Ustalono zależności wzrostu zasolenia od wielkości recyrkulacji i obciążenia objętości laguny ładunkiem związków organicznych.

DIE RÜCKFÜHRUNG VON ABWASSER AUS SCHWEINEZUCHTBETRIEBEN

Die vorstehende Arbeit berichtet über die im Pilotmaßstab durchgeführten Versuche zur Rückführung des Ablaufs aus dem zweiten Abwasserteich (einer 2-stufigen Teichanlage) eines Schweinezuchtbetriebes. Die Belastung der Teiche beträgt 40–320 g organische Substanz/m^3d. Die Versuche ergaben, daß die Rückführung des Abwassers eine Aufhöhung des Salzgehaltes bewirkt, was ein begrenzender Faktor bei der landwirtschaftlichen Abwassernutzung sein kann. Bestimmt wurde die Abhängigkeit des Salzgehaltes von der Rückführrate und von der Belastung der Teiche mit organischen Substanzen.

ПОВТОРНОЕ ИСПОЛЬЗОВАНИЕ СТОЧНЫХ ВОД НА СВИНОВОДЧЕСКИХ ФЕРМАХ

Описаны проведенные в полузаводском масштабе исследования по возможности применения замкнутого цикла для сточных вод из второй лагуны (при последовательной схеме) для промывки каналов, отводящих навозную жижу, на свиноводческих фермах. Нагруженность лагун органическими соединениями составляло 40–320 г/$м^2$d. Установлено, что замкнутый цикл (рециркуляция) повышает засоленность сточных вод, что может стать фактором, ограничивающим дозы стоков, направляемых для орошения сельскохозяйственных культур. Определена зависимость засоленности от объема рециркуляции и нагруженности лагуны органическими соединениями.