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Immediately Below Slats Concentrating
Swine Manure Phosphorus In Solids

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Carrie Lynn Tengman

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GRAVITATIONAL LIQUID-SOLID SEPARATION IMMEDIATELY BELOW SLATS CONCENTRATING SWINE MANURE PHOSPHORUS IN SOLIDS

By

Carrie Lynn Tengman

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ABSTRACT

GRAVITATIONAL LIQUID-SOLID SEPARATION
IMMEDIATELY BELOW SLATS CONCENTRATING SWINE MANURE
PHOSPHORUS IN SOLIDS

By

Carrie Lynn Tengman

This study evaluated a system design concept to separate swine manure liquids and solids immediately following excretion and passage through slotted flooring of a grow-finish facility. Manure was produced by four crossbred barrows (33 to 83 kg) fed a standard corn-soybean meal grower diet. Treatments were various pit floor slopes (31.5%, 16.7%, 11.8%, 8%, and 2%) with slope orientations parallel and perpendicular to slats . Solids (feces and wasted feed) and liquids (urine and waste water) were collected manually. Daily production of liquids and solids was measured along with moisture content (MC), total phosphorus and total Kjeldahl nitrogen collected daily over a 4 day period. Solids accounted for 27% to 39% of the total manure wet mass, and contained 87% to 98% of the total phosphorus and 37% to 76% of the total nitrogen. The solids carbon:nitrogen ratio was 14:1 with a MC average of 65%. With over 90% of the phosphorus retained in the solid fraction gravitational liquid-solid separation immediately below slats offers an efficient management alternative for manure nutrients.

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CHAPTER 1

INTRODUCTION

Livestock production continues to change rapidly with intense competition world-wide and increasing environmental protection regulations facing producers. One of the major environmental concerns facing livestock producers is effective management of their manure resource. No longer is manure simply a fertilizer source or waste product, it is a potential pollutant and must be managed properly.

The importance of good manure management practices has been growing over the past thirty years, because of sociological changes and increased livestock production. More urbanites are moving into agricultural areas and are frequently not willing to settle for the rural environmental qualities which includes livestock production. Neighbors of livestock producers, non-farmers and other farmers, are filing complaints about manure management practices. During the same period of time manufactured fertilizers became the fertilizer of choice. Commercial fertilizers are easier to handle and have known nutrient contents. The use of commercial fertilizers has decreased the use of manure nutrients for crop production. Specialization of agricultural producers in either livestock or crop production has caused an increase in the size of production units, concentrating crop or livestock production resulting in the displacement of nutrients.

There are three nutrient balance categories, one to describe every farm. The first category is a nutrient deficient operation. Second, are the farms which are nutrient balanced. The last category includes the farms which are in nutrient excess. These are often specialized livestock operations and have more than enough manure nutrients to produce competitive crop yields, and potentially pose pollution problems. In many cases, nitrogen and phosphorus manure nutrients are applied in excess of what the crop can utilize, thus creating high nutrient loads on agricultural soils and possibly creating surface water or groundwater pollution. Phosphorus is the nutrient of greatest interest in Michigan because it is most often is the limiting nutrient and has the potential to pollute surface waters causing eutrophication when applied to soil exceeding the crop requirements.

The challenge for producers and researchers is to find a way to efficiently utilize the manure nutrients in order to protect the soil and water from excessive loading of nutrients and accomplish this in an economically feasible process to help insure the sustainablity of agriculture.

OBJECTIVES

1 Evaluate the effectiveness of gravitational separation immediate below slats of swine manure to concentrate nutrients in liquids and solids.

2 Determine of there is any significant difference in performance between sub-floor slope and orientations within the constraints of the open working area.

3 Estimates the potential economic benefits of this gravitational separation process to swine producers.

CHAPTER 2

LITERATURE REVIEW

Phosphorus Adsorption and Movement in Soils

Laboratory experiments using soil columns (Hill and Sawhney, 1981) attest that phosphorus is easily adsorbed by soil and therefore is transported very slowly through the soil. Movement of phosphorus can occur through surface water runoff and the erosion of the soil particles to which phosphorus is attached (Sharpley et al., 1994). Ellis (personal communication, 1995) stated that control over this type of phosphorus movement can be achieved when proper soil conservation is practiced, diverting water flow down rather than across the soil. Phosphorus application to tile drained fields or sandy soils with a shallow water table can cause the movement of phosphorus to surface waters (Ellis and Remus, 1995) if application time, and amount are not considered along with the weather. It has been found (Ellis and Remus, 1995) that high phosphorus soil test levels can be found deep in the soil profile depending upon the soil type and environmental conditions. As the surface soil has become saturated, phosphorus has moved to soil layers below and the process continues if phosphorus is continuously over applied to the soil. As Ellis (1995) states that the reduction of phosphorus through cropping soils is a very slow process after soils are saturated with phosphorus. Saturation is the point at which all soil phosphorus sorbtion sites are taken. Movement of phosphorus into surface water causes accelerated eutrophication which involves four phenomena that impact the quality and recreational use of surface water. The phenomena include, "increased plant growth, oxygen depletion, pH variability, and plant species quality and food-chain effects"(Sharpley et al., 1994).

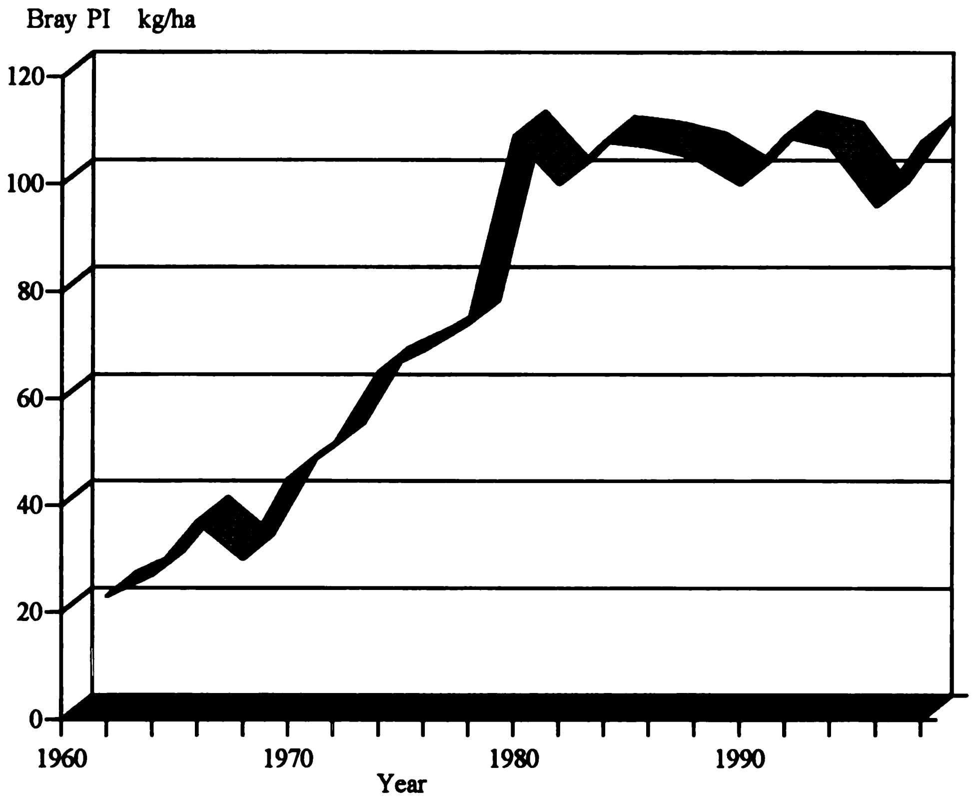

Figure 1. **Median Phosphorus Soil Test Levels for Michigan from Summary of Soil Samples Tested by the Michigan State University Soil Laboratory (Dahl and Warncke, 1962-1994)**

Michigan Soil Phosphorus Increases

Soil phosphorus levels in Michigan have increased over the past thirty years as shown in Figure 1, due to the following most significant factors:

1. Fertilizing agricultural crops without soil testing and applying phosphorus for reasons other than yield increases.

2. Not giving the correct or any credit to manure nutrients applied when determining application rates of commercial fertilizer.

3. Excessive application of manure nutrients to land based on convenience and lack of suitable alternatives for disposal.

Michigan Soil Phosphorus Recommendations

In an effort to protect and support the well managed livestock operations of Michigan from nuisance lawsuits, the Michigan Right to Farm statute, P.A. 93, was enacted in 1981. This statute gave the Michigan Commission of Agriculture the authority to develop generally accepted agricultural and management practices, including recommendations for phosphorus management. The Generally Accepted Agricultural and Management Practices for Manure Management and Utilization (1993) that was adopted June of 1993 and recommends that:

1. If soil phosphorus test levels (Bray P_1) reach 168 kg/ha, manure application rates should be reduced to the phosphorus removal of the harvested crop.

2. No manure phosphorus should be applied when Bray P_1 test is 336 kg/ha or greater.

In order to implement these recommended practices, livestock, dairy, and poultry producers need cost effective alternatives for transporting and disposing of manure to land that can efficiently utilize phosphorus. This may involve application to land that is not controlled by the producer. The economic feasibility of hauling manure further or treating the separated phosphorus rich solids by composting needs to be accounted for. Nutrient values of manure and hauling cost would break-even and composting would result in a dryer and less offensive organic solid.

Liquid-Solid Separation Technology

The process of separating liquids and solids in livestock slurry has been used for many years. Solids could be dried and used as bedding or as a feedstuff and the organic load of liquids entering lagoon storage would be reduced; pumping and irrigation is easier. Additional water is required to dilute the slurry so that many of the mechanical separation processes can be performed.

Liquid-solid separation has involved various technologies, including screens, settling tanks, and cylinders (Verly and Miner, 1974; Shutt et al., 1975; Moore et al., 1975; Gilbertson et al., 1979; Hegg et al., 1981). The total solids removal of each technology and some moisture contents are given in Table 1. Once feces and urine are mixed into a swine slurry with spilled water, wash water and other water sources, most modern liquid-solid separation technology has only been able to remove up to 40 % of the solids. Settling is most effective, however it requires dilution to allow for less particle interaction during the process (Shutt et al., 1975). Gilbertson and Schulte (1987) reported that the total solids content of settled solids was 14.9% to 24.3% when removed from the settling tank. The original dry matter or total solids of slurries can range from less than 4% to 15%.

Table 1. Total Solids Removal of Modern Mechanical Liquid-Solid Separation Technology.

Manure Type	Total Solids Removed %	Moisture Content %	Separator Type	Source
Dairy	29		flighted cylinder	Verly and Miner, 1974
Swine	2-22		vibrating screen	Shutt et al.,1975
"	3-35		sloping screen	"
"	90		settling	"
"	36-70		"	Moore et al., 1975
Beet Pulp	59-62		flighted cylinder	Verly and Miner, 1974
Swine	78		settling	Gilbertson and Nienaber, 1979
Beef	4-6	89	rotating screen	Hegg et al.,1981
Dairy	0-14	92	"	"
Swine	4-8	94	"	"
Beef	1-28		stationary screen	"
Dairy	1-32		"	"
Swine	1-31		"	"
Beef	6-16	84	vibrating screen	"
Dairy	8-16	89	"	"
Swine	3-27	81	"	"

The separation studies in Table 1 did not analyzed the separated fractions for their nutrient content, so a comparison cannot be made with the gravitational liquid-solid separation technology used in this study.

Michigan Pig Inventory

In 1993 Michigan ranked eleventh in hog and pig inventory for the United States with 1.2 million which makes up 2.1% of the United States production (1994 Michigan Agricultural Statistics). Michigan now has the opportunity to increase total production to 4.4 million from a market agreement between Thorn Apple Valley and Michigan Livestock Exchange. The average farm size for 1994 was 83.4 ha.

Phosphorus Utilization Example

Using a 1000 head grow-finish operation as an example the amount of phosphorus produced and potentially utilized will be calculated and results in the following information:

1. 1000 head of hogs averaging 68 kg produce about 8165 kg of P_2O_5, 11340 kg of N and 9072 kg of K_2O in a year (MWPS-18, 1985).

2. Corn yielding 122 m^3/ha will remove 22 kg of P_2O_5, 57 kg of N, and 17 kg of K_2O per acre (Ext. Bul. E-550A, 1992).

3. The acreage needed for application would be 149 ha when applied as phosphorus being the rate limiting nutrient.

4. Since half of the agricultural soils in Michigan are already high in phosphorus (Ext. Bul. E-550A, 1992), only 74 ha of the 149 ha could utilize the phosphorus and 297 ha would be needed for total utilization.

Thus, the 83.4 ha average farm size of Michigan is too small and many of these soils are already saturated with phosphorus and others are increasing. Hog production is confined to a small land area in many cases and compared to other livestock, hogs produce a third more phosphorus than beef cattle on a per pound of body weight basis, and twice as much as dairy cattle.

Swine Digestive System

The monogastric digestive system of swine lacks the phosphorus enzyme phytase, causing a high level of phosphorus excretion per kg of body weight in the form of phytate. Due to this lack of phytase nutritional studies have found that the phosphorus in swine manure is mainly found in the feces ranging from, 83% to 94% (Bridges et al., 1994) of the total produced, depending on feed ingredients. Another study found 53% to 99% (Vipperman et al., 1974) at excretion depending upon the calcium:phosphorus ratio. With high fecal phosphorus concentrations upon excretion, it seems valuable to keep the concentrations high. One way could be by not allowing the formation of a swine slurry. This then lead to the motivation for this study.

CHAPTER 3

MATERIALS AND METHODS

Apparatus

A 1.8 m square pen was built on concrete slats raised by concrete block walls 81 cm above a concrete floor providing an open working area below the slats. Within the open working area below the slats, three sub-floors were constructed and used for the gravitational separation design. Constraints tested were slope, slope orientation and slope length:

Trial 1 - Four slope treatments
One meter V-shaped sub-floor sloped parallel with the slats at 31.5%, 11.8%, 8%, and 2% (Figure 2).
Trial 2 - Two slope treatments
Two meter sub-floor sloped parallel with the slats at 8% and 11.8% (Figure 3).
Trial 3 - Two slope treatments
Two meter sub-floor sloped perpendicular to the slats at 11.8% and 16.7% (Figure 4).

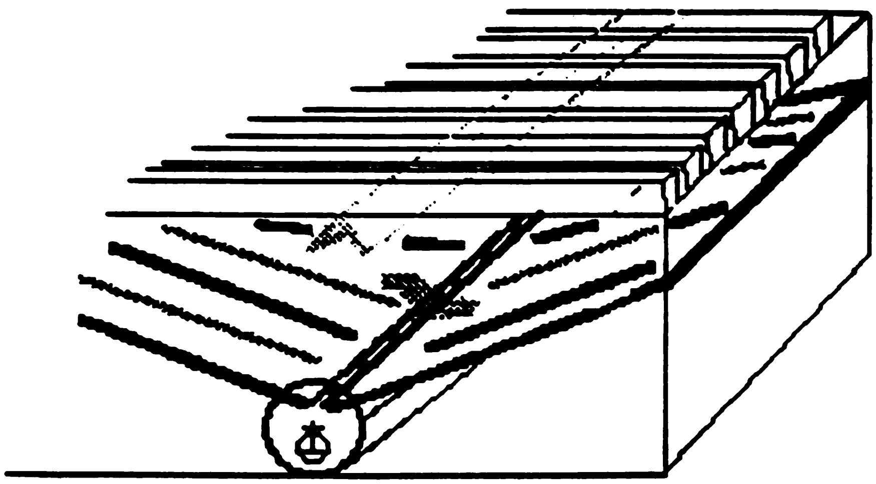

Figure 2. Trial 1

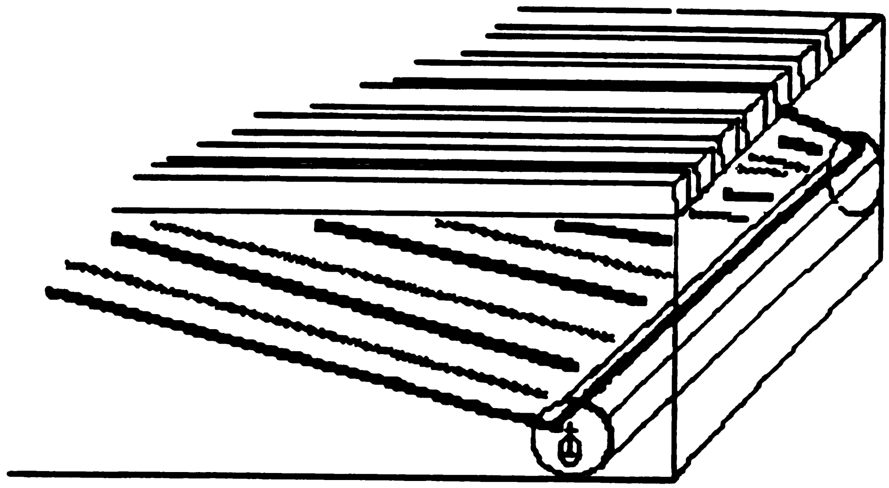

Figure 3. **Trial 2**

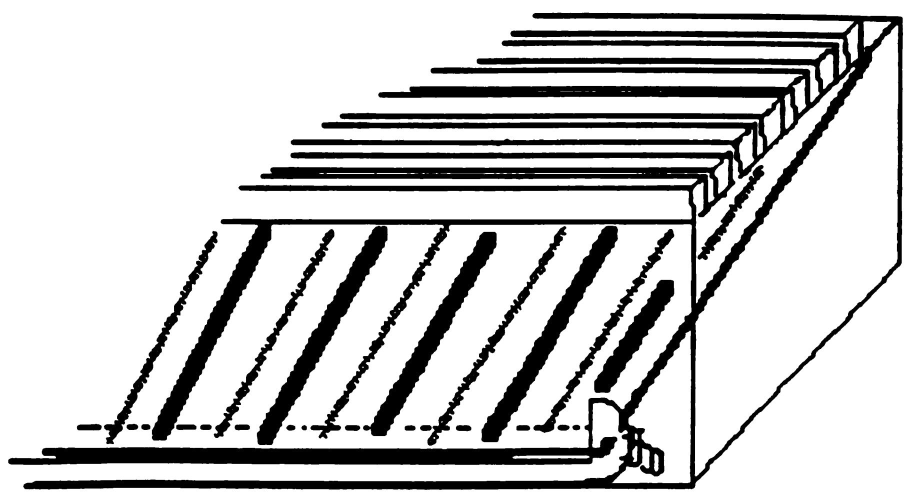

Figure 4. **Trial 3**

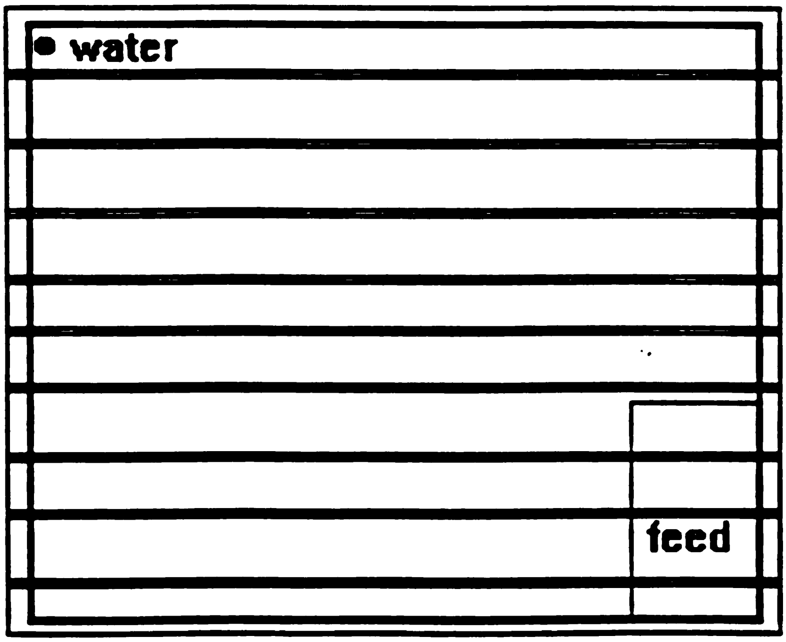

Figure 5. Feed and Water Position

All sub-floors were made of varnished plywood and placed in the open pit area. This study was conducted in an enclosed building 15.25 x 6.1 m square with slant windows and a 3.03 m ceiling. In all trials manure was produced by four randomly selected barrows weighing from 35 to 83 kg fed a standard corn-soybean meal grower diet. The beginning weights ranged from 35 to 42 kg. The feeder and nipple waterer were located at opposite corners of the pen (Figure 5).

Trial Differences

A single pig group was used throughout trial 1 and another throughout trial 2. Two pig groups were used in trial 3 because two became ill half way through trial 3. Four new pigs of similar weight were used which had weights slightly large than the weights of the ill pigs taken off trial. One way ANOVA tables were used to calculate the significant differences between treatments.

Liquid and Solid Collection

Solids (feces and wasted feed) accumulated on the plywood surface and were collected by manual scraping every 24 h. Liquids (urine and waste water) drained off the sloped plywood and were collected in an 20.3 cm diameter polyvinyl chloride pipe (PVC). Solid and liquid manure production, and respective nutrient concentrations were determined from daily collection and sub-sampling in triplicate for lab analysis. Each treatment was conducted over 4 days with a minimum 2 day acclimation period between treatments.

During the collection process the PVC pipe was drained from one end by a faucet fixture along with any solids which settled out. Liquids were stirred by hand in a five gallon bucket to homogenize and triplicate 90 ml samples were taken with a 50 ml syringe, while stirring, placed in a 120 ml specimen cup and stored at -20C.

The solids collection was also done manually with a 40 cm plexiglass scraper attached to an aluminum pipe. Caution was taken in capturing the solids held on the sloped surface starting at the bottom of the slope. Solids were placed in a 34 x 49 cm tin pan, to weigh daily production, and then homogenized before sub-sampling. Triplicate 200 g sub-samples were obtained, place in 9 x 14 cm tins, covered with cheese cloth and stored at -20C.

Lab Analysis

The frozen liquids were removed from the freezer and stored at 4C overnight and allowed to reach room temperature before analysis.

Fecal samples were freeze dried at 30C (VirTis Model 25-SRC-3, Gardiner, New York) for a three day period and dry weights were recorded. Samples were ground with a two millimeter screen Wiley Mill and stored at 4C until sub-sampled for analysis.

Urine dry matter was determined by using a 10 ml sub-sample oven dried at 70C until samples were at a constant weight.

Two milliliters urine and one gram fecal sub-samples were analyzed for elemental phosphorus concentrations using a colormetric method (Gomori, 1942) by a spectrometer (Beckman DU 7400) with automatic sipper. After perchloric digestion, fecal samples were brought to an 80 ml volume and 20 ml volume for urine. Phosphorus values were converted to phosphate (P_2O_5) using the following equation: Elemental Phosphorus= 0.44 * P_2O_5. A one gram sample of bovine liver was digested, brought to 100 ml volume and analyzed as validation for the procedure.

Five milliliters urine and 0.8 g fecal sub-samples were analyzed for TKN concentrations (AOAC, 1990) using a Technicon™ Autoanalyzer™ II Continuous-Flow Analytical Instrument. A two tenth gram sample of bovine liver and one gram sample citrus leaf were analyzed as validation for the procedure. All samples were brought to 250 ml volume. The equation used to calculate the graph reading (GR) to the nitrogen content of the sample was, adjusted for the concentration of the standard used, as follows:

GR * 0.3125/sample weight = % crude protein (CP)

Nitrogen = % CP/6.25

Ten gram fecal sub-samples were ashed in a Thermolyne Type 30400 Furnace at 600C overnight and then weighed. Calculations were made using the volatile solids value to determine the carbon to nitrogen ratio, which is an important factor in the compost design process. The equation used to determine the carbon content of the samples was, percent carbon = (100 - % ash)/1.8 (Haug, 1993).

Estimation of Transportation Break-even Analysis in a Commercial Setting

A transportation break even analysis was performed under the assumption that the entire nutrient value of the manure be balanced with the cost for transportation of the manure to the land application site to illustrate the improved feasibility of transporting the separated fecal solids to remote locations compared to the slurry mixture.

Manure nutrient analysis was based upon the average N and phosphorus analyses measured from samples of fecal solids and urine liquids from trial 1. The partitioning of ammonia nitrogen and organic nitrogen was calculated assuming that the ammonia nitrogen would be $^2/_3$ of nitrogen. The mineralization rate of organic nitrogen was assumed to be 0.35. Losses of ammonia during storage, loading and spreading were not accounted for.

Since potassium (K) analyses were not performed in this experiment, published values (MWPS-18) were used for the mixture at 3.6 kg K_2O/1000L. The partitioning between urine liquids and fecal solids was assumed to be $^2/_3$ of the K_2O in the urine liquids.

Fertilizer recommendations were based upon assumed soil tests of 56 kg/ha and 239 kg/ha for phosphorus and potassium, respectively; growing corn yielding 122 m^3/ha (140 bu/acre) (Ext. Bul. E-550A):

Nitrogen = 140 kg/ha
P_2O_5 Removal = 55 kg/ha
P_2O_5 Recommended = 45 kg/ha
K_2O Recommended = 84 kg/ha

Assumed fertilizer nutrient prices were:

Nitrogen=$0.09/kg
P_2O_5 =$0.11/kg
K_2O =$0.05/kg

Application cost for commercial fertilizer was assumed to be $1.62/ha.

Manure would be transported using a semi tractor with a 22712 L liquid tank used for the urine liquids or slurry, and a 25 ton trailer for solids (6000 gallons of liquid = 25 tons). This vehicle was assumed to travel at 72 km/h, operated for 8 h per day with a driver labor cost of $10.00 per hour. Vehicle rental was based upon a $126 daily charge with an additional $0.27/km charge. Fuel price was assumed to be $3.22/L with a fuel consumption rate of 1.66 km/L. The charges for loading equipment was on the basis of $20.00/hour and 0.33 hours of operation per load.

The manure production quantities used were based upon the measured manure production rates from trial 1 of this project and extrapolated to 1000 growing-finishing pigs with an average weight of 73 kg and produced over a 180 d period.

Composting Feasibility Analysis

To determine if separating solids from liquids is an advantage for composting. A computer program called COMPOST (Person and Shayya, 1993) was used to compare the system requirements for composting the solids versus composting the slurry mixture of solids and liquids. Mean manure production data and characteristic data collected from trial 1 as a 1000 hd operation was used as input into the COMPOST model. Table 2 summarizes the inputs for COMPOST.

Table 2. Inputs for Solid and Slurry Mixture for the Compost Process Design Model COMPOST. (Person and Shayya, 1993)

Input	Fecal Solids	Mixture
MANURE CHARACTERISTICS		
Daily Residue Addition (kg/day)	2313	8618
COD[a]/Total Solids (%)	113	113
Moisture Content (% wet basis)	64	87
Volatile Solids (% Total Solids)	84	84
Biodegradable Volatile Solids(%)	68	68
Nitrogen (% Total Solids)	3.31	4.50
AMENDMENT CHARACTERISTICS		
Moisture Content (% wet basis)	15.5	15.5
Volatile Solids (% Total Solids)	92	92
Biodegradable Volatile Solids(%)	58	58
Nitrogen (% Total Solids)	1	1
COMPOSTING PROCESS PARAMETERS		
Recycled Compost Moisture Content (%)		
Minimum Acceptable Mixture Moisture Content (%)	40	40
Compost Mixture Initial Bulk Density Factor	60	60
Post-Active Compost Moisture Content (%)	.3	.3
Bulk Density Factor for Post Active Compost	35	35
Minimum Solids Retention Time (days)	0.35	0.35
Hydraulic Retention Time for Active Composting	90	90
Outside Air Temperature (degrees C)	5.6	5.6
Outside Relative Humidity (%)	80	80
Compost Temperature (degrees C)	27	27

[a] Chemical Oxygen Demand

CHAPTER 4

RESULTS AND DISCUSSION

Trials

Trial 1 resulted in a mean daily wet manure production of 3.18 kg/pig for liquids and 1.16 kg/pig for the solids. The separated solids made up only 27% of the total manure mass produced with an average moisture content of 63.8% (Table 3). The mean total P_2O_5 produced daily was 22.80 g/pig (Table 4). The separated solids contained 94% of the total P_2O_5 produced, while liquids contained only 6% (Table 6). Daily nitrogen production per pig was 25.14 grams (Table 5), 55% of which was held by the solids and 45% in the liquids (Table 6). Phosphorus concentration, TKN and moisture content in the solids and liquids did not differ ($P>.01$) between slope and orientation treatments.

The changes in daily production of liquids per pig, which range from 2.53 kg to 4.05 kg, could have been affected by a variety of variables including pig age, environmental temperature, weather, and room temperature which were not recorded. Trials were conducted from June to October. In summer, pigs may have not eaten as much feed, been less active, and drank more causing the liquid production to increase from urination, and wasted water.

Table 3. Wet Manure Production and Characteristics Results for Trials 1, 2, and 3.

Slope %	Wet Manure Production		Liquids % of Total	Solids % of Total	Solids Moisture Content %
	Liquids kg/pig/d	Solids kg/pig/d			
T1: 1 m V-shaped Slope Parallel with Slot Length					
31.5	2.53	0.88	74.2	25.8	63.5
11.8	2.57	1.25	67.2	32.7	61.5
8.0	4.05	1.16	77.8	22.2	65.2
2.0	3.56	1.34	72.7	27.3	64.8
Mean	**3.18**	**1.16**	**73.0**	**27.0**	**63.8**
T2: 2 m Slope Parallel with Slot Length					
8.0	1.40	0.94	60	40	63
11.8	1.13	0.68	63	37	62
T3: 2 m Slope Perpendicular with Slot Length					
11.8	0.48	1.07	31	69	68
16.7	3.45	1.43	71	29	70

P_2O_5 concentration in liquids in treatment 2.0 was about three times the concentrations of the other treatments. This difference could have been caused by the variables addressed earlier. The results show that there may have been a dilution effect in the liquids P_2O_5 concentrations for slope treatments of 31.5, 11.8, and 8.0%.

Table 4. Dry Matter and Phosphorous Results for Trials 1, 2, and 3.

Slope %	Dry Matter Production		P_2O_5 Production		P_2O_5 Concentrations	
	Liquids kg/pig/d	Solids kg/pig/d	Liquids g/pig/d	Solids g/pig/d	Liquids % wet basis	Solids % wet basis
T1: 1 m V-shaped Slope Parallel with Slot Length						
31.5	0.108	0.321	1.08	15.58	0.044	1.77
11.8	0.116	0.481	0.87	22.38	0.034	1.79
8.0	0.162	0.401	1.75	22.02	0.043	1.91
2.0	0.142	0.472	1.76	25.75	0.112	1.92
Mean	**0.132**	**0.419**	**1.37**	**21.43**	**0.058**	**1.85**
T2: 2 m Slope Parallel with Slot Length						
8.0	0.077	0.348	0.85	13.22	0.061	1.41
11.8	0.062	0.256	1.06	10.67	0.094	1.58
T3: 2 m Slope Perpendicular with Slot Length						
11.8	0.035	0.342	0.43	16.16	0.112	1.51
16.7	0.138	0.429	2.04	17.38	0.060	1.21

There is noticeable variation in nitrogen production which was collected which can be expected. Many variables which were not accounted for could have affected the total nitrogen collection. Feed consumption, pig age, temperature, and dilution all could have caused the variability.

Table 5. Nitrogen Production and Concentration Results for Trials 1, 2, and 3.

Slope %	Nitrogen Production		Nitrogen Concentrations	
	Liquids g/pig/d	Solids g/pig/d	Liquids % wet basis	Solids % wet basis
T1: 1 m V-shaped Slope Parallel with Slot Length				
31.5	8.26	10.56	0.330	1.20
11.8	9.36	15.80	0.360	1.26
8.0	12.90	13.34	0.320	1.15
2.0	14.74	15.60	0.415	1.16
Mean	**11.32**	**13.82**	**0.356**	**1.19**
T2: 2 m Slope Parallel with Slot Length				
8.0	8.00	12.87	0.572	1.37
11.8	9.52	9.22	0.840	1.36
T3: 2 m Slope Perpendicular with Slot Length				
11.8	4.22	11.22	0.880	1.05
16.7	11.36	16.00	0.329	1.11

Trial 2 resulted in a mean daily wet manure production of 1.40 and 1.13 kg/pig for liquids along with 0.940 and 0.675 kg/pig solids for the respective slope treatments. Therefore, the solids made up an average of 38.8% of the total manure mass, with an average moisture content of 62.5% (Table 3). The total mean P_2O_5 produced daily was 12.88 g/pig (Table 4). The solids concentrated a 93% average of the total P_2O_5, while liquids contained an average of only 7% (Table 6). Mean daily nitrogen production was 19.81 g/pig (Table 5), 55% of which was held by the solids and 45% in the liquids (Table 6).

Trial 3 resulted in mean daily wet manure production for the respective slope (11.8% and 16.7%) treatments of 0.48 and 3.45 kg/pig for liquids along with 1.070 and 1.430 kg/pig for solids. The solids made up 69% and 29% of the total manure mass, with an average MC of 69% (Table 3). The mean total P_2O_5 produced daily was 18.01 g/pig (Table 4). The solids concentrated averages of 97% and 89% of the total P_2O_5, while liquids contained only 3% and 11%, respectively (Table 6).

Table 6. Solids and Liquids Nutrient Concentrations as Percentages of the Total Production for Trial 1 (T1), Trial 2 (T2), and Trial 3 (T3).

Trial and Treatment	Solids % of P	Liquids % of P	Solids % of N	Liquids % of N	% TS removal
T1: 1 m V-shaped Slope Parallel with Slot Length					
31.5%	93	7	56	44	74
11.8%	96	4	63	37	81
8%	93	7	51	49	71
2%	94	6	51	49	76
Mean	**94**	**6**	**55**	**45**	**76**
T2: 2 m Slope Parallel with Slot Length					
8%	94	6	62	38	83
11.8%	92	8	49	51	78
Mean	**93**	**7**	**55**	**45**	**81**
T3: 2 m Slope Perpendicular with Slot Length					
11.8%	97	3	73	27	91
16.7%	89	11	58	42	76
Mean	**93**	**7**	**65**	**35**	**84**

Mean daily nitrogen production in trial 3 was 15.44 and 27.36 g/pig, for the 11.8 and 16.7 percent slopes, respectively (Table 5). The 11.8% treatment allowed solids to contain 73% of the total nitrogen and liquids held 27%. Slope treatment 16.7% solids contained 58% of the nitrogen and liquids held 42% (Table 6).

Trial 2 solids made up 38.8% of the wet manure mass which differs from the 27% in trial 1, due to the pigs being younger, therefore consuming less feed and excreting less feces. Pigs on trial 2 may also have been less active, so ended up wasting less water. Shown in Table 7, the percent mass measurements differ because it may be the case that more liquids evaporated in the process. First of all, the slope length is longer than what was used in trial 1. Secondly, the liquids from the lower 8.0% slope flowed slower to the PVC pipe allowing more time for evaporation.

The differences between the two slope treatments in trial 3 can be based on the change in pig groups. The body weights were not exactly the same and the healthy group would obviously be more productive and active accounting for the liquid production during the 16.7% slope being seven times greater than the 11.8% slope. For further discussion treatment 16.7% will be assumed to be normal production to compare all trials.

To compare the separation performance of all trials, moisture content is an important measurement. As the MC of the separated solids decreases, the lighter weight and easier it is to handle the solids. Solids moisture content was the highest for trial 3 which could be explained by the liquids having to flow through the solids on the pit floor.

The short (1 m) slope of trial 1 is of benefit requiring less time for the liquids to be in contact with the solids. Nutrients initially present in each fraction would be more likely to stay attached, using short gravitational flow, because of less mixing and opportunity to exchange nutrients.

The 11.8% slope in trial 1 gave the best performance values, but for the longer (2 m) parallel sub-floor the values were slightly favoring the 8% slope rather than 11.8%. This could possibly be explained be the length of slope allowing the liquids more time to contact the solids and the liquid picked up more phosphorus dense solids caused also by the steeper (11.8%) slope, by comparing the liquid dry matter percentages of the two slopes finding more solids in the 11.8% slope liquids.

Perpendicular slope of 16.7% proved to be the least desirable, as solids not only concentrated the least amount of phosphorus but also had the highest moisture content. The increase of phosphorus in liquids and decrease in solids as a percent (Table 6) is likely a result of the liquids having to pass through solids because of the orientation of accumulated solids on the pit floor. Solids moisture content was higher for the same reason.

Overall average performance of all trials are shown in Figures 6, 7, 8, and 9. Phosphorus retention by every trial was consistent showing that there was little of no slope effect (Figure 6). The nitrogen retention is variable due to the environment, ammonia voitlization, variation in pig age and feed intake, and urine dilution (Figure 7). The moisture content shown in Figure 8 was found to be the highest in the perpendicular orientation from more liquids being captured by the solids. Figure 9 illustrates the total solids removed by every treatment which is highest for the perpendicular slope, possible due to a straining affect on the liquids.

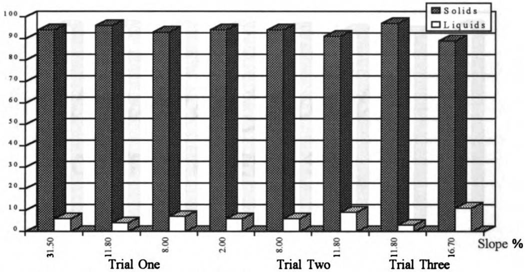

Figure 6. Percent of Total Phosphorus in Liquids and Solids

Figure 7. Percent of Total Nitrogen in Liquids and Solids

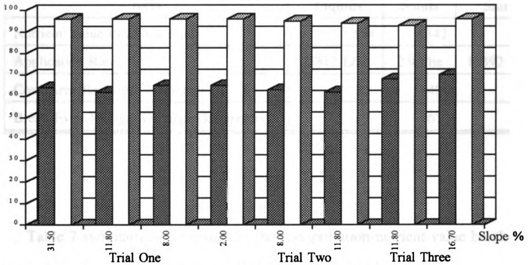

Figure 8. Percent Moisture Content of Liquids and Solids

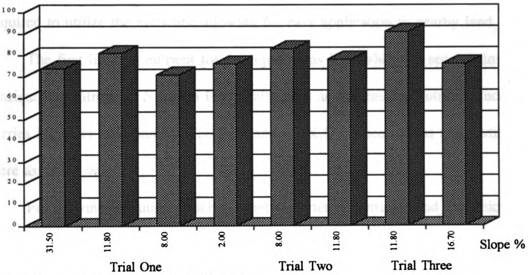

Figure 9. Percent Total Solids Removal

Transportation Break-even Analysis Results

Table 7. Summary of Transportation and Nutrient Value Break-even Analysis.

Item	Liquids	Solids	Slurry
Nutrient Value ($/25 ton load)	$54	$342	$131
Application Rate	25817 L/ha	2.9 t/ha	10392 L/ha
Corn Area Required (hectares)	23	140	150
Break Even Hauling Distance (kilometers)	19	167	63

Table 7 summarizes the results of the transportation-nutrient value break-even analysis for the liquids, solids, and the mixture of the two. All loads were 25 tons of wet manure. The nutrient value of one load of solids was 2.6 times that for the slurry. The break even hauling distance for the solids was 167 km compared to 63 km for the slurry. The liquids are not very nutrient dense which resulted in a break even distance of only 19 km. However, there is a compensating advantage in that only 23 ha is required to utilize the nutrients, allowing for easy application to nearby land.

The first limiting nutrient for the liquids was K_2O while the second limiting nutrient was nitrogen. Nitrogen is typically used as the limiting nutrient since it carries a greater environmental concern and the K_2O concentrations and partitioning were assumed values.

For a swine operation which is a net importer of nutrients and for which land area for nutrient utilization is limited, use of the liquids locally would have a higher probability of being feasible compared to the slurry or the solids. The nutrient dense solids can be cost effectively transported further from the production site to land that can utilize the nutrients.

One of the issues that Table 7 shows relative to application rates is that the rate for solids is 2.9 t/ha on soil requiring 45 kg/ha P_2O_5. This is a relatively low application rate and one that is difficult to achieve with current solid manure application equipment. One solution is to apply 2 years worth of manure at one time and skip a years worth of phosphorous application. This increases the application rate to 5.8 t/ha which is more easily achieved with current technology.

Solids were applied to meet the P_2O_5 needs for 122 m^3/ha corn under an assumed soil test. Commercial fertilizer application of 112 kg/ha of nitrogen and 71 kg/ha of K_2O would be required in this situation following fertilizer recommendations. The total land area required for the liquids plus the solids was 163 ha where as the land area required for the mixture was only 150 ha. The reason is that more nitrogen could have been applied with the phosphorous in the solids.

Composting Feasibility

The results of the compost process design analysis in Table 8 shows that composting the solids instead of the slurry mixture, only 27% of the mass of the manure produced will need to be handled in the composting process.

Since the moisture content of the solids (64%) is near that required for composting, the wet weight of amendment required to supply the energy to complete the composting process was 120 kg/d compared to 1860 kg/d for the mixture. The solids required only 6% of the amendment required for the mixture. In both cases, additional amendment was needed to adjust the C:N ratio to 24:1 to minimize the risk of odor production and to facilitate temperature control, also done by turning the windrows at reasonable frequencies. The total amendment required for the solids was 40% of that required for the mixture.

Eleven hundred and thirty six (1136) liters of water was required for the solids to adjust the initial moisture content when corn stover with a 15.5% MC was used.

Table 8. Compost process design results.

Item	Fecal Solids	Mixture
Daily Residue Addition (kg/day)	2313	8618
Wet Weight of Amendment to Supply Required Energy (kg/day)	120	1860
Total Amendment Required (kg/day)	1207	2994
Initial Water Addition (liters/day)	1136	0
Recycled Compost Addition for Moisture Control (kg/day)	45	4990
Total Weight of Compost Mixture (kg/day)	4717	16511
Mixture C:N Ratio	24:1	24:1
Actual Solids Retention Time (days)	43	124
Active Composting Volume (cu m)	185	657
Curing Volume (cu m)	107	0
Total Processing Volume (cu m)	292	657

Recycled compost, assumed to be at 40% MC was used to adjust the compost mixture to 60% for both materials. For the slurry 4990 kg/day of recycled compost was required compared to 45 kg/day for the solids. Actual solids retention time in the active composting phase was less for solids composting (124 vs 43 d). This results in a total volume requirement in the active composting windrows of 657 cubic meters for the slurry compared to 185 cubic meters for the solids. With the long residence time in the active composting phase, no curing was required. The curing volume requirement for the solids was 107 cubic meters. The total volume requirement for the entire composting process (active composting and curing) for the solids was 44%

of that required for the slurry.

The composted solids are in a form that can be conveniently stored and handled without creating a public nuisance. Storage that could be used for composting is flexible to different operations outside or inside of an existing facility, and can be very low cost. The material is weed free, does not contain animal or plant pathogens and is light weight and granular. This allows the compost to be cost effectively transported over a greater distance to consumers who are more likely to view the material as a valuable soil amendment for lawn and garden, removing P from the farm. The composted material could be altered with commercial fertilizer ingredients to custom blend a product that fits the needs of a specific customer. This whole process opens up several viable beneficial uses for manure nutrients and reduces the risk of environmental degradation from inappropriate use of animal manures.

CHAPTER 5

IMPLICATIONS

The mechanics need to perform the scraping of solids and flow of liquids to storage is acknowledged here. Some type of scraper system on chains or cable would be required to move solids out of the building to spreading equipment or temporary storage which would be easily accessible to work equipment.

Liquids could be stored in a pit below the sub-floor or could flow outside the facility to lagoon storage as it collects in a trough, like the PVC pipe used in this study. The trough would have a slope to allow liquid flow. Solids contained in the liquids would flow well from observation. If problems would arise with liquid solids in the trough, three options could be considered: drag clean, liquid recirculation to wash, or periodic flow (plug and unplug) to the liquid outlet.With solids phosphorus retention ranging from 89% to 97% in this study and only a speculated 20% to 40% retention in using modern separation technology, this gravitational separation system definitely allows for higher concentration of phosphorus in a smaller mass than what can be made with any other separation device.

Use of gravitational separation successfully separated swine manure liquids and solids and concentrates the phosphorus in solids, even in extreme treatments without the use of additional water for dilution. Pollution of surface water is an important issue that is addressed by gravitational separation of liquids and solids. Most separation technology requires water for increased performance, polluting clean water, which is not necessary with this technology.

Phosphorus concerns have not yet reached across the country, but here in Michigan the knowledge is that phosphorus can migrate depending greatly on soil type, Bray P1 soil phosphorus levels, and crop management. Phosphorus can cause pollution problems affecting surface water. Current separation technology being used, may soon have to face the phosphorus challenge and create a greater advantage for the producer through nutrient concentration, allowing for possible nutrient balance in regards to phosphorus. This concept of gravitational separation provides alternatives for manure handling to swine producers.

In speculating on the performance, many variables could affect the results, which is why the various treatments were tested. It would be expected that a shorter length floor parallel with slats would perform the best in the long run. Varying designs could be used depending on whether the facility was new or being remodeled and depending upon what type of manure management scheme best fit the operation. For example, more than one sloping sub-floor could be used as described in trial 1 with the V-shaped sub-floor. Collection of liquids could be in a pit beneath the sub-flooring or could flow out to other storage as would the solids. Using a shorter slope could provide the best results allowing less distance for solids phosphorus loss would occur and a shorter time for liquid velocity to increase picking up more solids. Most importantly, the results from this study showed that all slopes performed well and can be of benefit to manure management systems.

This new technology shows promise with the possibility of more strict regulation. This could allow pork producers to better manage the nutrient balance on the farm in an economical, agronomical, and environmentally conscious manner.

With resulting fertilizers of different nutrient content, this process makes the manure a more valuable resource, in a way a value added product, for farms with excessive phosphorus soil loads. This can help solve nutrient balance problems on nutrient deficient and excessive operations. The nutrient deficient operation can benefit their crops and their economics by the use of an inexpensive readily available fertilizer. The operation with excess nutrients benefits from their already high yields, and the opportunity to put a monetary value on nutrients produced on their farm which can not be efficiently utilized, on their own land. They would be protecting their operations sustainability through assuring the protection of the environment by good manure management practices.

CHAPTER 6

CONCLUSIONS

1 Under slat gravitational liquid-solid separation has potential to be used successfully in swine production.

2 Separated fecal solids made up 27% to 69% of the total manure production where phosphorus concentrations ranged from 89% to 97% of the total P_2O_5 produced while using a variety of slope treatments.

3 The feasibility of hauling the separated, phosphorus dense solids off the farm increases as the break-even distance increases by a factor of 2.

4 The feasibility of composting the fecal solids increased requiring only 28% of the total active composting volume, 40% of the amendment requirement, and 1% of the recycled compost for moisture control.

SUGGESTIONS FOR FURTHER RESEARCH

1 To assess the total benefits to a production operation it is necessary to further engineer the design and equipment to a full scale production model. The design variations for this type of separation are numerous making this technology very applicable in different situations.

2 A full scale testing of this technology would be very beneficial in the process of industry implementation for the design of the system and to form an understanding of its operational alternatives. The design of the operation can take a variety of forms with different scrapers, collection processes, storage options, sub-floor surface texture, scraping frequency, and feeder and waterer types.

3 Odor emissions of a full scale model should be taken with every design variation. Emissions can vary due to design factors which could allow for mare evaporation and volitlization.

4 Nutritional studies to optimize the performance of the separation system using variations of pig weight, age, and stage in production. Possibly changing the consistency of the solids making phosphorus concentrations higher and lowering the moisture holding capacity.

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