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Stratification of solids, nitrogen and phosphorus in swine manure in deep pits under slatted floors

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Abstract

Manure slurries stored in pits under slatted floors of both finishing and nursery barns were sampled at four different depths to study stratifications of total solids (TS) and nutrients (nitrogen and phosphorus), and to determine the relationship between the stratification of TS and nutrients. The results obtained can be used to improve the management and handling of swine manure in the under-slat storage pits. A management scheme that can be adopted for both the finishing and the nursery barns' pits is the layer-by-layer harvesting of the manure. The thinner manure, which is lower in nutrients, can be spread on land near the production units in larger volumes or it may pumped to land remote from the production units without causing many clogging problems. The thicker manure, higher in nutrients, can be transported to land further away and spread in smaller volumes. The TS content of each stratum can be used to accurately estimate the nitrogen and phosphorus levels in the respective strata so that application rates can easily be adjusted accordingly during the time of land application.

Keywords: Swine manure; Stratification; Management; Nutrients estimations; Storage pits

1. Introduction

Management of any animal manure requires efficient operation of equipment and techniques that minimize the threat to water (surface and ground) and air quality. Concerns expressed by the general public and regulatory bodies at the state and local levels, as well as at national and international levels, dictate that best management practices for manure be implemented. Livestock and poultry producers are continuously seeking management systems that are efficient to operate and are cost-effective (Sutton et al., 1990). Net cost of management can be reduced by maximizing returns from nutrients available in the manure produced in respective operations. Since land application continues to be the most common method for manure recycling, efforts geared towards development of strategies of maximizing utilization of nutrients on the land, without impacting the environment continue to be important.

Land utilization problems associated with swine manure are usually a result of:

1. long distances to the crop fields,
2. the large volumes of wastes on a year-round basis,
3. demand for moisture at certain periods of time,
4. the need for weed control (Oleszkiewicz and Koziarski, 1981).

On the other hand, manure is extremely variable in its composition and it is, therefore, difficult to estimate its fertilizer value at the time of application. The nutrient content of manure is affected by many factors such as diet variation, age of animals, cleaning technique, water spillage, and type of manure storage (Campbell et al., 1997; Piccinini and Bortone, 1991). Application of animal waste on land should be at recommended rates with respect to crop/plant needs in order to minimize its impact on the environment and to maximize its utilization. Guidelines for manure application on land are related to the type of manure, its nutrient concentration, and type of crop, and have usually been based on the nitrogen loading capacity of the available land.

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Chemical analyses of nutrient content of swine manure using standard laboratory methods are accurate, but they are time consuming, complex, and costly, making them impractical for on-farm use. The specific density of swine manure is closely related to total solids (TS), and TS have been found to correlate well with nutrient levels (Scotford et al., 1998; Piccinini and Bortone, 1991; Stevens et al., 1995; Tunney and Bertrand, 1989; Chescheir et al., 1985). The TS versus nutrient relationship has been used to develop a fast, simple field hydrometer based test that can be used by farmers to give adequate estimates of nutrients, so that informed application decisions can be made faster. This approach has both economical and environmental advantages.

This study was based on the hypothesis that, because of inevitable natural settlement during collection and storage in pits, there is stratification of solids resulting from the particle size distribution of manure. This natural stratification could be employed for improving nutrient management and handling of the manure. The specific objectives of the study presented here were:

1. to determine the stratification pattern of TS,
2. to determine the relationship of particle size distribution on TS stratification,
3. to determine the stratification pattern of nutrients (nitrogen and phosphorus),
4. to determine the relationship between TS stratification and nutrient stratification with the aim of providing an effective and simple method of assessing nutrient levels using TS levels in the respective manure layers.

2. Methods

2.1. Sampling from swine manure deep-pit storage systems

To determine the stratification of different sizes of particles and nutrients in deep-pit systems for swine manure storage, a total of four swine establishments were sampled. To determine the effects of the age of the animals and the diet on stratification, the four barns were further categorized into two types, namely: two nursery barns and two finishing barns. General characteristics of the barns used in this study are shown in Table 1. Generally, the main diet in all cases was regular corn–soybean meal with the appropriate mineral and vitamin supplements. The manure was sampled at depths of 0 mm (0 ft), 600 mm (2 ft), 1200 mm (4 ft), and 1800 mm (6 ft). Manure in the pits for the nurseries was not as deep, so the largest depth sampled was 1600 mm (5.25 ft). In all cases the greatest depth was sampled at approximately 120 mm (0.5 ft) from the bottom of each pit. To sample these depths, a giant syringe was constructed using two concentric PVC-pipes. The outer pipe had an inside diameter of 25 mm while the inner tube had an outside diameter of 25 mm so that it fitted perfectly into the outer pipe. Both pipes were cupped at one end but the outside pipe's cup had a 6.5 mm (0.25 in.) hole drilled in the middle to provide liquid entry or exit, when the inner pipe (plunger) was either pulled or pushed, respectively. For each depth, three samples were taken and combined to make a composite sample.

Table 1
Characteristics of the barns in this study

Parameter	Finishing barns	Nursery barns
Size of herd	1000	8000
Period pigs had lived in the barn	4 weeks	4 weeks
Average weight of animals	50 kg	15 kg
Size of barn	64 m × 14 m	100 m × 24 m
Depth of manure in the pit	1800 mm	1600 mm

2.2. Particle size distribution within the sampled depths

A 100 ml composite sample of swine manure collected from each respective depth was diluted with ordinary tap water to 200 ml to make the separation process easier and more effective because the particles were more dispersed. This 200 ml dilute sample was then separated into six different manure fractions with particle size ranges 2.0–1.4, 1.4–1.0, 1.0–0.5, 0.5–0.25, 0.25–0.15, and 0.15–0.075 mm, respectively. The separation was effected by consecutive sieving of the manure through a series of seven ASTM standard wire screen sieves with opening of 2.0, 1.4, 1.0, 0.5, 0.25, 0.15 and 0.075 mm. At each stage of separation and before the next level of separation, the separated sample was thoroughly mixed and a 20 ml sample drawn for further laboratory analysis.

It is more practical to determine the particle size distribution in manure slurries on the basis of mass concentration of particles than to dry and disperse the solids before conducting particle size distribution by the conventional methods. To determine the size distribution based on mass concentration, the total suspended solids (TSS) for each separated sample were measured from a known volume and the TSS concentration retained on each sieve determined by the method of difference. This is equivalent to the determination of size distribution in granular solid materials or soils samples where percentage retained on each sieve is calculated from mass retained in each sieve and the initial mass placed on the top sieve. In the case of manure slurries, the initial volume is comparable to the initial mass of the granular or soil materials.

2.3. Laboratory analyses

The following parameters were determined for each collected sample using standard laboratory methods (APHA, 1998); TS, TSS, total phosphorus (P) and total kjeldahl nitrogen (TKN). For determination of TS, a well-mixed sample was evaporated in a pre-weighed dish and dried to constant weight in an oven at 105 °C. The increase in weight over that of the empty dish represented the TS. Total suspended solids were determined by filtering well-mixed samples through weighed standard glass-fiber filters and drying the residues retained on the filters to constant weights in an oven at 105 °C. Total phosphorus was determined using the Persulfate Digestion Method. This is a method in which all the species of phosphorus in a sample are first converted to orthophosphates. The samples are then filtered and the phosphorus is measured quantitatively using the ascorbic acid method. Nitrogen (N) was determined as TKN in which both organic nitrogen and ammonia nitrogen are converted to ammonium in the presence of concentrated H_2SO_4 and cupric sulfate ($CuSO_4$) catalyst. After addition of base, ammonia is distilled from an alkaline medium and absorbed in boric acid. The distilled ammonia is determined by titration with a standard mineral acid. Total phosphorus and TKN were determined on the raw manure slurry before dilution and/or separation.

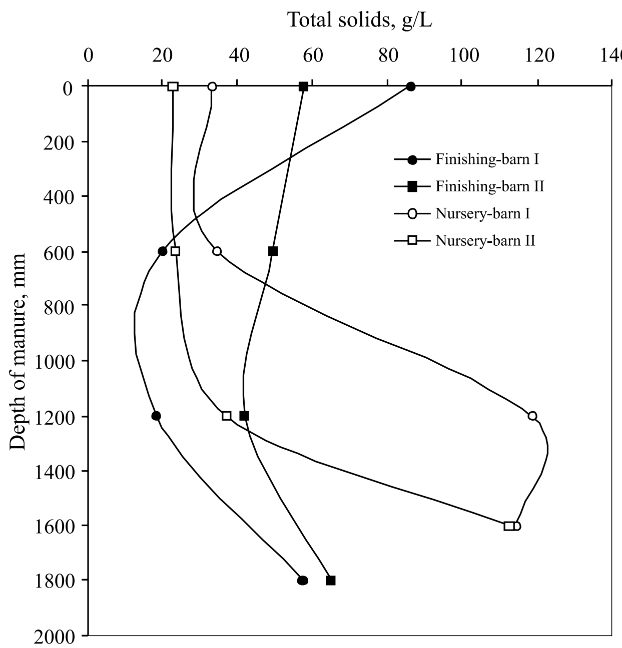

Fig. 1. Variations of total solids (suspended and dissolved solids) with the depth of manure in the finishing and nursery barns.

2.4. Experiment design and analysis

To determine stratification of solids and nutrients; TS, TSS, particle size distribution, total phosphorus and TKN were measured at four depths in each of the four barns studied. Because of the differences in the depths of manure in the finishing and the nursery barns, it was not possible to statistically compare the above parameters with respect to the type of barn. Statistical analysis was therefore only conducted between similar types of barn. Analyses of variances (ANOVA) were done using standard PC-based statistical analysis software (SAS). Regression analyses were performed using Excel® spreadsheet to simplify plotting of the regression results. Plotting the parameters on the same axis and observing the general trends was the only possible method of making comparisons between the two types of barns. Unless otherwise stated statistical significance was implied at the 5% significance level.

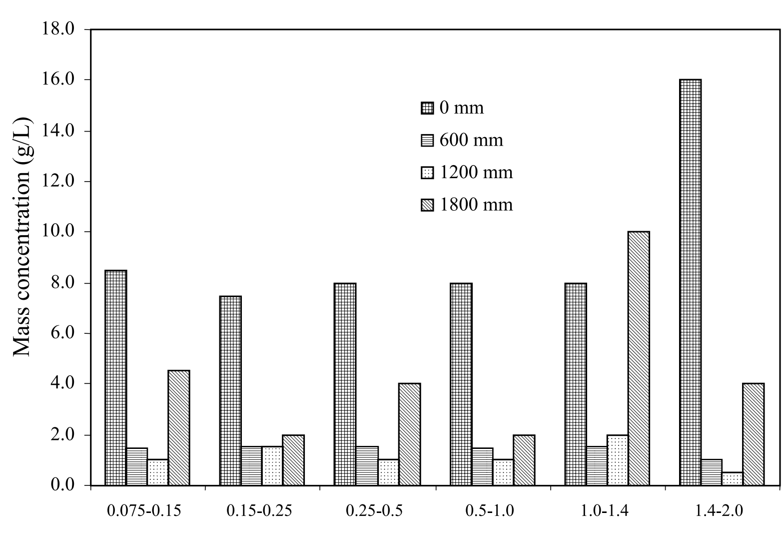

Fig. 2. Mass distribution of solids particles by size and depth of swine manure in finishing barn I.

3. Results and discussion

3.1. Particle size distribution and TS stratification

Variations of TS with depth are presented in Fig. 1 while the particle size distributions for each barn are presented in Figs. 2–5. Tables 2 and 3 summarize the statistics of mass concentration: (i) within barns, (ii) with particles size, and (iii) with depth of manure, for finishing and nursery barns, respectively. Particle size distributions in the respective layers were similar for each type of barn. The more the concentration, and the larger the particle sizes were at each depth, the higher the TS level in that layer. However, the stratification of the TS was found to be different with respect to barn type. For the finishing barns, the TS were highest in the top layer and at the bottom depth. Mean particle mass concentrations were also significantly higher at these two depths than in the middle depths. The observed high TS levels in the top layers of the finishing barns resulted from a thick (10 cm-thick), gummy scum found floating on the rest of manure rather than because of large particles. The intermediate depths (600 and 1200 mm) had similar solid contents. The observed patterns in the finishing barns were in agreement with the earlier work of Campbell et al. (1997), who found that dry matter and nutrients declined with depth, at least above 0.5 m from the bottom of storage. The floating scum made it

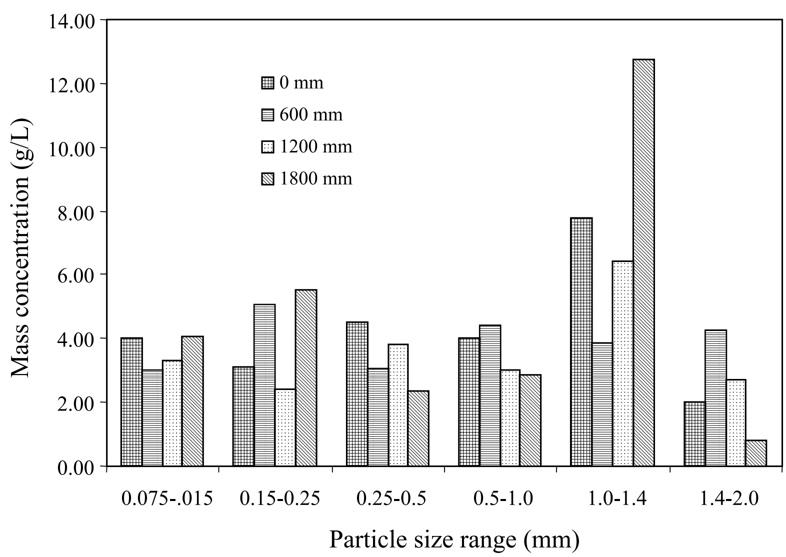

Fig. 3. Mass distribution of solids particles by size and depth of swine manure in finishing barn II.

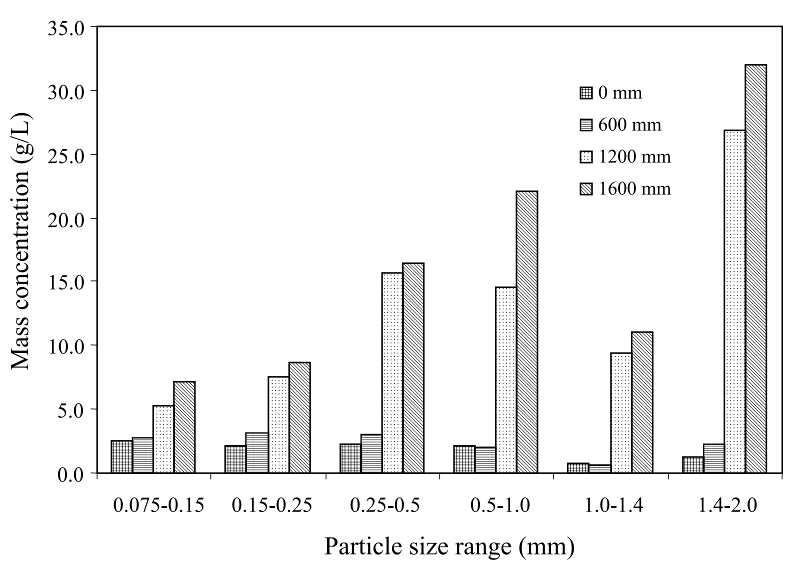

Fig. 4. Mass distribution of solids particles by size and depth of swine manure in nursery barn I.

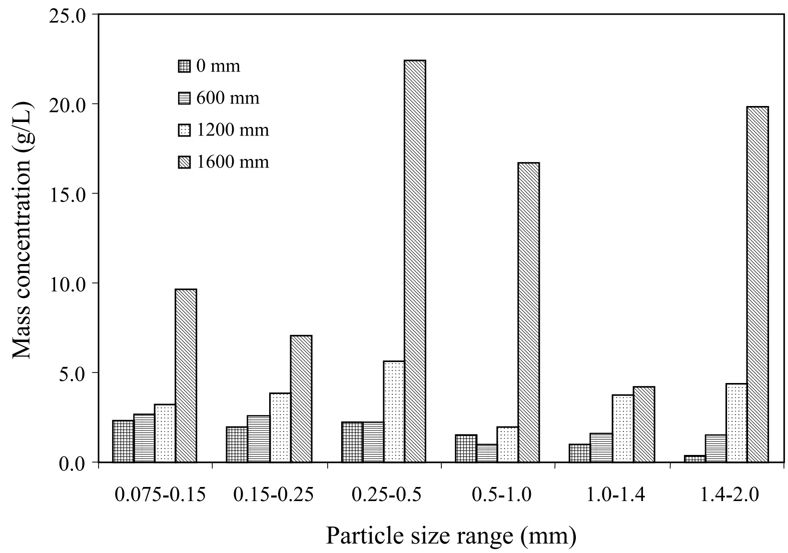

Fig. 5. Mass distribution of solids particles by size and depth of swine manure in nursery barn II.

Table 2
Summary statistics of the mass concentration of particles of sizes 0.075–2.00 mm in the swine manure slurries from the finishing barns

Barn	Mean mass concentration (g/l)	Range of particle sizes (mm)	Mean mass concentration (g/l)	Depth of manure (mm)	Mean mass concentration(g/l)
Finishing I	4.08[a]	1.4–2.0	3.91[a,b]	0	6.78[a]
Finishing II	4.12[a]	1.0–1.4	6.54[a]	600	2.68[b]
		0.5–1.0	3.45[b]	1200	2.39[b]
		0.25–0.5	3.53[b]	1800	4.57[a]
		0.15–0.25	3.57[b]		
		0.075–0.15	3.73[b]		

Means with the same letter in the same column are not significantly different at $\alpha = 0.05$.

Table 3
Summary statistics of the mass concentration of particles of sizes 0.075 to 2.00 mm in the swine manure slurries from the nursery barns

Barn	Mean mass concentration (g/l)	Range of particle sizes (mm)	Mean mass concentration (g/l)	Depth of manure (mm)	Mean mass concentration (g/l)
Nursery I	8.40[a]	1.4–2.0	11.05[a]	0	1.72[a]
Nursery II	5.15[b]	1.0–1.4	4.04[b]	600	2.10[a]
		0.5–1.0	7.75[a,b]	1200	8.51[b]
		0.25–0.5	8.74[a,b]	1600	14.76[c]
		0.15–0.25	4.63[b]		
		0.075–0.15	4.45[b]		

Means with the same letter in the same column are not significantly different at $\alpha = 0.05$.

extremely difficult to effect separation at the laboratory scale, meaning this would probably create even more problems at the field/practical level. If this scum were skimmed off prior to solids–liquid separation, the separation process perhaps could be improved in terms of energy consumption and efficiency of separation. The stratification of manure in the under-slat pit of nursery-barns was completely different from that of the finishing barns. Although the mean mass concentrations of particles (i.e., the number) were significantly different in the two nurseries studied, both particle sizes and TS generally increased with the depth of the storage pit in each case.

3.2. Nutrient stratification and relationship between TS and nutrients

Concentrations of the nutrients P and TKN with depth of manure in each of the four barns are presented in Figs. 6 and 7, respectively. Nutrient stratification trends were similar to those observed for TS in all four cases studied (Fig. 1). Regression analyses of TKN

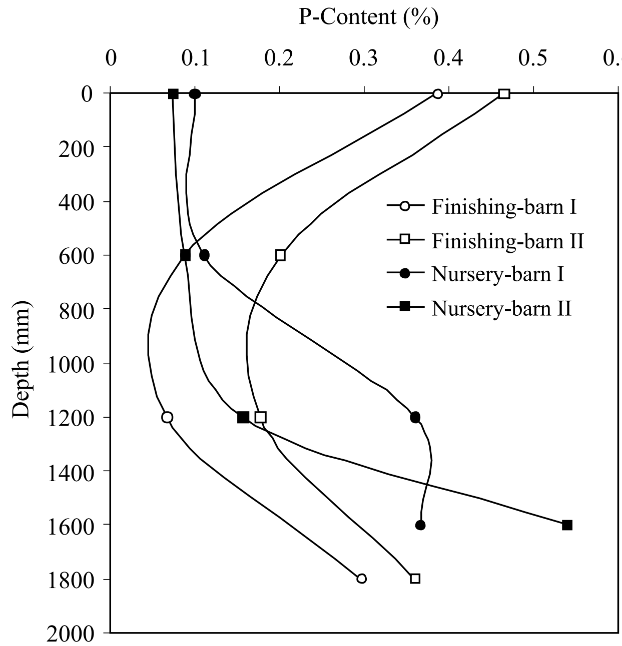

Fig. 6. Variations of phosphorus (P) with depth of manure in the storage pit of finishing and nursery barns.

versus TS, and phosphorus versus TS by type of barn are presented in Figs. 8 and 9, respectively. For TKN versus TS, linear relationships in both cases were consistent with a correlation coefficient (R) of 0.96 for finishing and nursery barns. Similarly, P versus TS linear relationships were strong with correlation coefficients of 0.87 and 0.94 in the finishing and nursery barns, respectively.

The combined data for TKN, P and TS from all the four barns are presented in Fig. 10. Consolidating all the data from the four barns together similarly resulted in strong linear relationships with a correlation coefficient of 0.95 for TKN versus TS, and a linear relationship with R of 0.85 for phosphorus versus TS. The correlation coefficients for the consolidated data from all four barns were slightly lower than for the merged data from each type of barn. This variation was probably caused by differences in the contents of P and TKN in the manures because of different ages of pigs. However, these two R-values were both within the 99% confidence interval for the sample size considered in this study. This observation seems to suggest that the contents of P and TKN in the manures of finishers and the piglets were not significantly different.

Regression analyses of TS on TKN and P obtained in this study as well as other comparable regression equations of TS on N and P from literature have been summarized in Table 4. Apart from the regression equations compiled by Chescheir et al. (1985) from various literature sources, most of these studies indicate acceptable correlations of both TKN and P with the concentration of TS in the pig slurries (Dragun, 1978; Tunney, 1979; Chescheir et al., 1985; Scotford et al., 1998; Piccinini and Bortone, 1991; Campbell et al.,

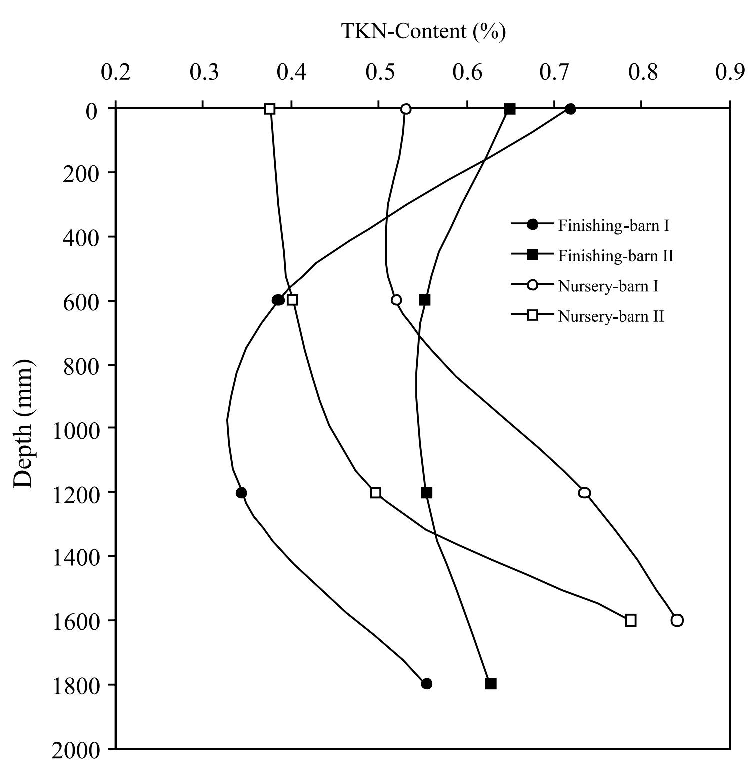

Fig. 7. Variations of total kjeldahl nitrogen (TKN) with depth of manure in the storage pit of finishing and nursery.

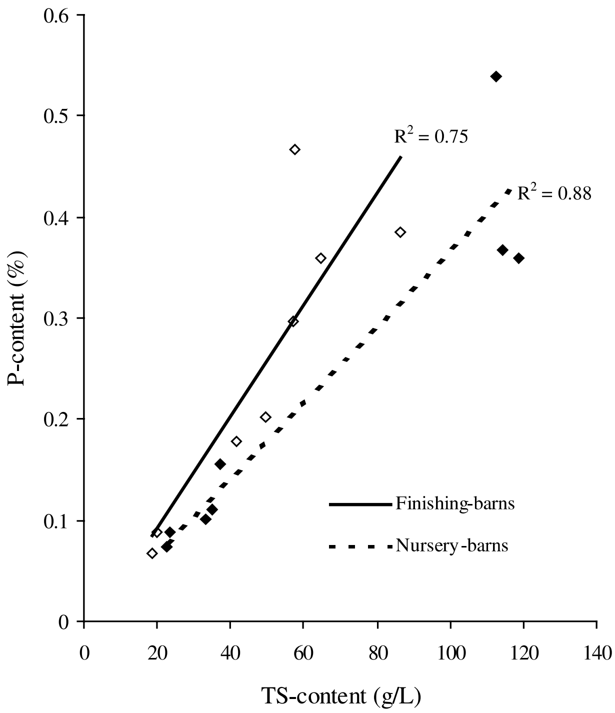

Fig. 8. Linear regressions between total solids (TS) and phosphorus (P) for finishing and nursery barns.

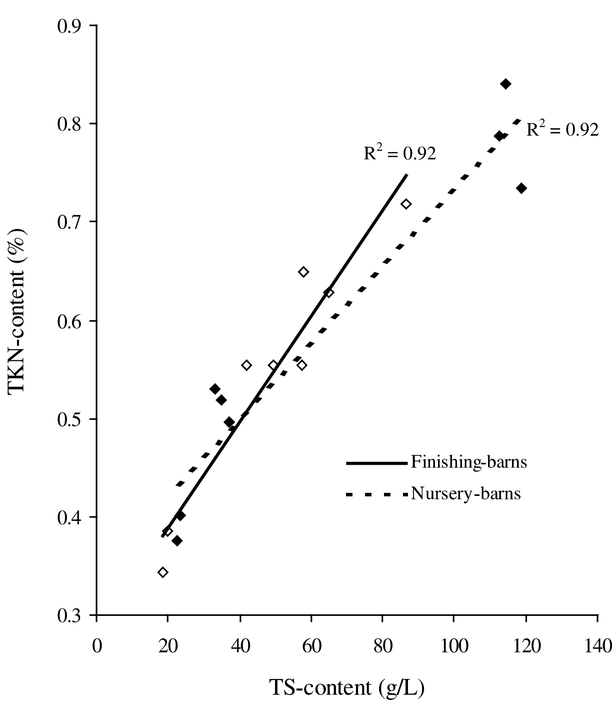

Fig. 9. Linear regressions between total solids (TS) and total kjeldahl nitrogen (TKN) for finishing and nursery barns.

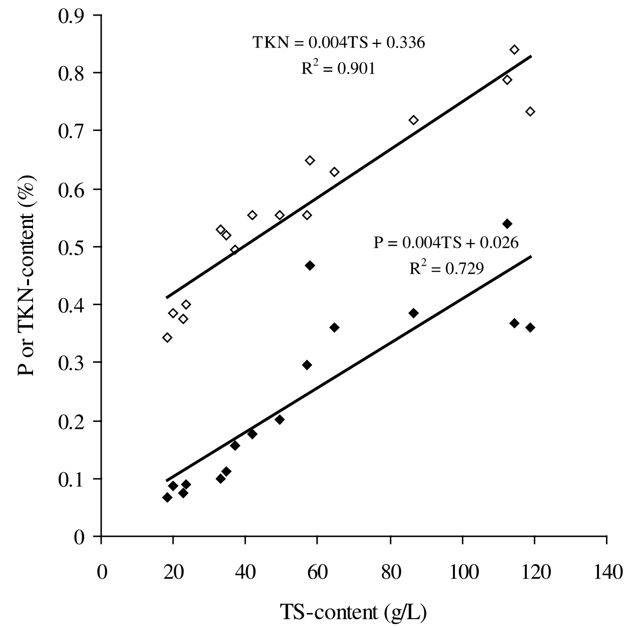

Fig. 10. Linear regressions between total solids (TS) and both phosphorus (P) and total kjeldahl nitrogen (TKN) using consolidated data from all four barns.

1997). Although correlation coefficients obtained in those studies compare well with each other and with correlation coefficient values determined in the present study, it is obvious that the absolute terms in all the regression equations are as varied as the authors, thus making it difficult to compare them. These differences are not surprising given the dynamic changes in pig diets over the years, different diets in different countries, different diets for different ages of pigs, and finally the different management systems of both the pigs and the slurries. For these kinds of data to be useful, a complete description of the slurries with regard to all the aforementioned parameters needs to be given each time so that data from similar sources can be compared or consolidated to provide more accurate regression equations for specific situations.

The data presented here show that, although the general trends in stratification of both the TS and the nutrients (TKN and P) are similar for the same type of operation (finishing or nurseries), the absolute amounts are different at any given stratum. This suggests that the differences were not simply due to the age of animals or the feed rations but probably because of different management schemes. Therefore, when planning for proper TS and nutrient management, individual pits require sampling. From the observed patterns of TS and nutrient stratification, feasible management strategies emerge. For the nurseries, overflow pipes with sluice gates can be used to remove the supernatant liquid and lighter elements from the storage pits of the nurseries at various intervals along the depth of manure. This part of the manure can be pumped to land remote from the swine production units without clogging the pumping and conveying systems. Alternatively it may be spread in

Table 4
Regression equations for total solids (TS) versus total kjeldahl nitrogen (TKN) and total phosphorus (P) from literature

Related parameter[a]	Regression equation	Correlation coefficient, R	Source
TS versus N	TKN = 1194 + 424 (TS)	0.92	Tunney (1979)
	TKN = 3753 + 186 (TS)	0.28	Literature[b]
	TKN = 362 + 598 (TS)	0.95	Dragun (1978)
	TKN = 2433 + 396 (TS)	0.88	Chescheir et al. (1985)
	TKN = 1095 + 600 (TS)	0.90	Piccinini and Bortone (1991)[c]
	TKN = 3365 + 415 (TS)	0.95	Current study
TS versus P	P = −117 + 232 (TS)	0.92	Tunney (1979)
	P = 305 + 186 (TS)	0.75	Literature[b]
	P = 112 + 239 (TS)	0.94	Dragun (1978)
	P = −112 + 334 (TS)	0.77	Chescheir et al. (1985)
	P = 26 + 269 (TS)	0.84	Scotford et al. (1998)
	P = 320 + 312 (TS)	0.88	Piccinini and Bortone (1991)[c]
	P = 264 + 383 (TS)	0.85	Current study

[a] Units: TS (%), TKN (ppm), and P (ppm).
[b] Compiled by Chescheir et al. (1985) from other literature sources.
[c] Converted from different units by the authors.

large volumes on land near production units by regular tank wagons without posing any threat to nutrient over-application while reducing the cost because of reduced hauling distances. The settled solids can then be scraped or vacuum-loaded into conventional tank wagons once in a while for further treatment or for application onto lands further from the production units. This also saves on transportation cost because this fraction is much richer in nutrients but much smaller in volume. An added advantage of this method of collecting the liquid is that the pits need not to be large since the liquid can periodically be removed. A similar approach could be adopted for manure management in the swine finishing barns if the scummy layer, which was approximately 10 cm, was skimmed off from the top prior to harvesting.

4. Conclusions

The data presented here show that, although the general trends in stratification of both the TS and the nutrients (TKN and P) are similar for the same type of operation (finishing or nurseries), the absolute amounts are different at any given stratum. This suggests that, the differences were not simply due to the age of animals or the feed rations but probably because of different management schemes. Therefore, when planning for proper TS and nutrient management, individual pits require sampling to provide accurate profiles of TS and nutrient levels.

The strong correlations found between TS and both P and TKN suggests that the TS levels in the different strata may be used for practical and accurate estimation of nutrient levels of the various strata in under-slat storage pits. This information can then be used for making proper manure management decisions. Owing to the large variations of both the TS and the nutrients in different storage pits, this relationship is an important component of the management of manure. However, data from more storage pits may be needed to further validate the relationship between stratification of TS and that of the nutrients, before widespread adoption of the above suggested nutrient estimation technique.

It is apparent that regression equations found in the literature between TS and nutrients TKN and P are diverse probably because of variation in diets in different places at different times, different ages of pigs, and different management strategies for pigs and slurries. It is therefore important to completely categorize the slurries in question whenever such regression equations are developed so that data from similar sources can be consolidated to provide more accurate regression equations for specific situations.

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