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Settling Characteristics of Nursery Pig Manure and Nutrient Estimation by the Hydrometer Method

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ABSTRACT

The hydrometer method to measure manure specific gravity and subsequently relate it to manure nutrient contents was examined in this study. It was found that this method might be improved in estimation accuracy if only manure from a single growth stage of pigs was used (e.g., nursery pig manure used here). The total solids (TS) content of the test manure was well correlated with the total nitrogen (TN) and total phosphorus (TP) concentrations in the manure, with highly significant correlation coefficients of 0.9944 and 0.9873, respectively. Also observed were good linear correlations between the TN and TP contents and the manure specific gravity (correlation coefficients: 0.9836 and 0.9843, respectively). These correlations were much better than those reported by past researchers, in which lumped data for pigs at different growing stages were used. It may therefore be inferred that developing different linear equations for pigs at different ages should improve the accuracy in manure nutrient estimation using a hydrometer. Also, the error of using the hydrometer method to estimate manure TN and TP was found to increase, from ±10% to ±50%, with the decrease in TN (from 700 ppm to 100 ppm) and TP (from 130 ppm to 30 ppm) concentrations in the manure. The estimation errors for TN and TP may be larger than 50% if the total solids content is below 0.5%. In addition, the rapid settling of solids has long been considered

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characteristic of swine manure; however, in this study, the solids settling property appeared to be quite poor for nursery pig manure in that no conspicuous settling occurred after the manure was left statically for 5 hours. This information has not been reported elsewhere in the literature and may need further research to verify.

Key Words: Manure settling; Nutrient estimation; Hydrometer; Linear regressions; Nursery pigs.

INTRODUCTION

The present emphasis on maintaining and upgrading our environment has increased the pressure on livestock operators to manage their livestock waste better and to reduce the offensiveness of these by-products. An important part of this management is the estimation of nutrient contents in slurry to determine safe and effective application rates.[1] Due to the settling characteristics of manure solids, it has long been recognized that it is difficult to get good nutrient estimates by simple, rapid on-farm tests of manure samples. As a result, the conceivable on-farm nutrient management plan has hardly been implemented.

There are numerous reports in literature that conclude that the solids in pig manure would settle rapidly in a short period of static detention time, which may by and large be true.[2–5] However, these reports all employed a general term ''pig slurry'' to describe the manure source used in their studies, making no distinction between manures from gestation, nursery, or finishing pigs. The risk of doing so may lead to incorrect information regarding the settling characteristics of manures from pigs at different growing stages due to diet adjustments commonly practiced in commercial operations. It therefore appears necessary to get information on the solids settling properties from manures for each individual pig group such as gestation, nursery, and finishing.

To develop rapid, on-farm tests for manure nutrient determination, understanding of the relationship between the manure solids and nutrient contents is fundamental. Past research has shown that there is a statistically significant correlation between the total solids (TS) and nutrient elements in pig manure and there is also a correlation between TS and specific gravity of manure.[1,6,7] Based on such information, attempts have been made to develop a hydrometer method that can be used by farmers to estimate the nutrient contents in pig manure.[1,6–10] However, the progress in this area has not appeared to be successful.

The problem that impedes the wide use of the hydrometer method to estimate the fertilizer elements in pig manure may result from two primary factors, i.e., the quality of the manure sample and the accuracy of the estimation. Apparently, the first factor is related to the solids settling characteristics, while the second factor is dependent upon the measuring techniques. It thus follows that the estimation accuracy of the hydrometer method for manure nutrient determination may be improved by improved knowledge in these two areas. In particular, for the first factor, since it is commonly recognized that manure properties vary with growing stages of pigs,[11–14] there is a need to closely examine the solids settling properties for manure from pigs at different growth stages. As far as the second factor is concerned, instead of developing a

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universal equation for manure from all pigs, as reported in the past research,[1,6–8] different linear equations may have to be developed accordingly to account for the variability in manure characteristics in relation to animal ages.

The objectives of this study were to 1) examine the solids settling characteristics of nursery pig manure under different agitation schemes; 2) develop the relationships for manure total N and total P with specific gravity measured by a soil hydrometer; and 3) determine the limitations and possible errors in using the hydrometer method to estimate the N and P contents for manure from nursery pigs.

MATERIALS AND METHODS

Experimental Design for Evaluating Manure Solids Settling Characteristics

Fresh manure was collected in a 55-gallon barrel from a swine nursery building located in the vicinity of Waseca, MN. The experiment was carried out immediately after the manure was collected. The pigs were fed on a regular ration.

Three manure agitation procedures were used in this study to compare manure solids settling characteristics. The experimental apparatus for manure agitation and sampling using procedure 1 was shown in Figure 1. The purpose of this agitation procedure was to create a vertical, outward cycling fashion of mixing in the manure in the barrel using a Drum/Barrel Heavy-Duty mixer with two propellers installed on the shaft (Cole-Parmer Catalog Number: U-04318-15). The mixing speed was controlled at 1000 rpm. After mixing for about 5 minutes, manure samples were taken at 9 locations (Figure 1) with 2.5 cm from the top and bottom ends and 5.0 cm from the barrel wall, with agitation remaining in operation. This sampling plan generated three samples on each level (top, middle, and bottom) to accommodate statistical analysis.

For sampling procedure 2, same barrel with the same manure was used; however, the manure was agitated by a sump pump sitting at the bottom of the barrel with the outgoing stream shooting horizontally. This agitation scheme was to create a horizontal mixing pattern. Also, this method can be easily carried out on site. Similarly, nine samples were collected at the same locations as in the previous procedure.

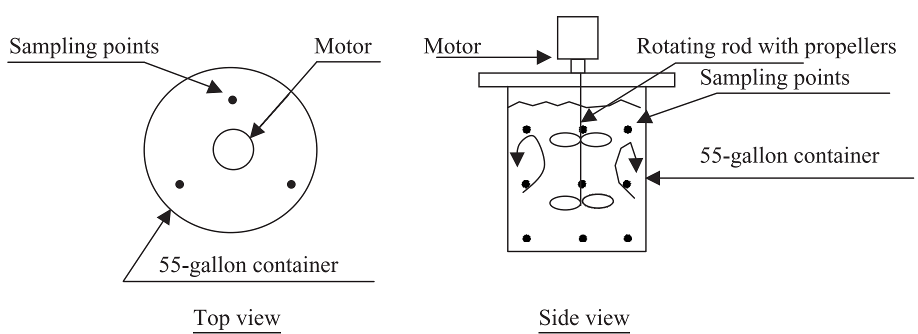

Figure 1. Schematic of manure sampling device and locations (‘‘•’’—sampling point).

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The third procedure was actually a natural settling process without agitation. It was found by past researchers that the solids in swine manure that settle would do so within 15 minutes if undisturbed.[3] Therefore, after the sampling was completed for the first two procedures, the manure in the barrel was allowed to rest for about 5 hours in order to reach relatively thorough sedimentation before taking samples. The sampling locations and the number of manure samples collected were the same as in the previous two methods.

Experimental Design for Developing a Rapid Test Method for TN and TP Using a Hydrometer

In order to obtain manure samples that account for potential variations in livestock management techniques, manure from three nursery farms located in different areas in southern Minnesota was collected for the proposed research. Thick slurries were drawn at a level close to the bottom of the deep pit at each farm and the collected slurries were then diluted in the lab with tap water to generate test manure with 10 different solids levels as shown in Table 1. The pigs on the three farms were all fed on a regular ration.

Each prepared manure sample was poured into a 1 liter cylinder and thoroughly mixed before measuring specific gravity by a soil hydrometer having a scale of 1.000 to 1.070 (Cole Parmer Catalog Number: U-08292-16). The mixing was carried out manually using a brush to rigorously stir the manure in the cylinder to suspend all the solids. And then, the hydrometer was placed in the cylinder to measure specific gravity immediately after stirring.

Sample Analysis

All manure samples were analyzed for total solids (TS), total volatile solids (TVS), total phosphorus (TP), and total nitrogen (TN). Standard methods recommended by the American Public Health Association for wastewater analysis were used in the sample

Table 1. Manure solids levels prepared for the experiment (%).

Farm 1	Farm 2	Farm 3
4.57	5.23	4.44
3.72	3.65	3.65
3.08	3.13	2.98
2.40	2.78	2.31
1.70	1.92	1.78
1.10	1.56	1.08
0.81	1.12	0.77
0.53	0.87	0.46
0.26	0.45	0.21
0.10	0.23	0.08

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analysis.[15] Samples that were not immediately analyzed after collection were stored in a freezer at $-20°C$ and thawed prior to lab analysis.

Statistical Analysis

Statistical *t* test was performed on data collected from the above experiments if these data were used for comparison. A significance level of $\alpha = 0.05$ was applied to all comparisons.

RESULTS AND DISCUSSIONS

Total Solids and Total Volatile Solids

The means and standard deviations of total solids (TS) concentrations for samples collected from the three barrels are presented in Table 2. Apparently, there is no statistical difference in TS concentrations between different sampling depths in all agitation procedures. A striking phenomenon is seen for nursery pig manure in terms of natural settling characteristics (column 3 in Table 2), which implies that nursery manure is poor in natural settling due possibly to the feed ration that contains high protein content. The observation may also imply that the size of solids in nursery manure could be relatively small, which means that the settling process could only proceed at an extremely slow rate. According to data from this study, after the manure was stored without disturbance for 5 hours, there was still no noticeable solid settling occurred. Therefore, at least it can be concluded that a representative manure sample for TS concentration analysis from nursery pigs can be obtained if the sampling is conducted within 5 hours after agitation, regardless of sampling locations. To the best of authors' knowledge, this information hasn't been reported in the literature. The finding from this study appears to prod the need for more research to determine the settling characteristics of manure from nursery pigs over storage time. Similar results are also observed for total volatile solids (TVS) concentrations (Table 3). Since it has been reported by many past researchers that there is a good correlation between TS and TVS for swine manure,[16–18] it is not surprising to see that the TVS concentrations behave in the same fashion as those of TS.

Table 2. Total solids measurements by the three agitation and sampling procedures (g/L).†

Sampling locations	Procedure 1	Procedure 2	Procedure 3
Top	$71.06 \pm 0.72^{a,x}$	$70.78 \pm 1.42^{a,x}$	$67.22 \pm 1.84^{a,x}$
Middle	$69.80 \pm 1.86^{a,x}$	$70.30 \pm 0.89^{a,x}$	$68.99 \pm 0.66^{a,x}$
Bottom	$69.81 \pm 1.89^{a,x}$	$69.61 \pm 1.22^{a,x}$	$67.23 \pm 1.47^{a,x}$

†Different letters indicate there is significant difference between numbers in different columns (a) and different rows (x).

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Table 3. Total volatile solids data by the three agitation and sampling procedures (g/L).†

Sampling locations	Procedure 1	Procedure 2	Procedure 3
Top	$53.98 \pm 0.76^{a,x}$	$55.11 \pm 0.92^{a,x}$	$52.80 \pm 2.16^{a,x}$
Middle	$53.27 \pm 1.52^{a,x}$	$54.39 \pm 0.94^{a,x}$	$53.09 \pm 1.27^{a,x}$
Bottom	$53.09 \pm 1.67^{a,x}$	$52.81 \pm 0.15^{a,x}$	$52.15 \pm 0.74^{a,x}$

†Different letters indicate there is significant difference between numbers in different columns (a) and different rows (x).

Total Nitrogen and Total Phosphorus and Their Relationships with Total Solids

Comparisons of the means and standard deviations for total nitrogen (TN) and total phosphorus (TP) among the three agitation procedures are presented in Figures 2 and 3. Although there are some variations as indicated by the error bars, there is no statistical difference in TN measurements between samples collected from the three barrels at all depths. Similar observation is present for TP data (Figure 3). These data thus indicate that in all three cases, a reliable manure sample for TN and TP analysis can be obtained, regardless of sampling locations in the barrels.

Figure 4 presents results describing the relationships for TS with TN and TP based on manure samples collected from the three different nursery buildings. The two linear regression equations (TS vs. TN and TS vs. TP) prove highly significant with correlation coefficients (R) of 0.9944 and 0.9873, respectively. This information appears to indicate that there is no substantial variation in terms of manure characteristics among the 30 samples, despite that the manure for this study was collected from three farms located in different areas, a case to be perceived as very likely to bring about variation

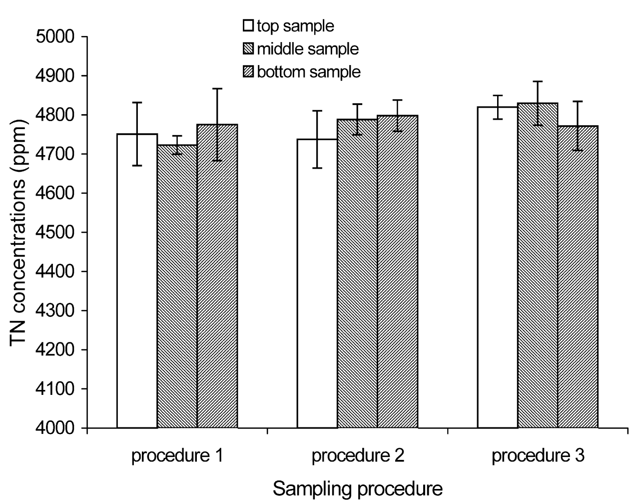

Figure 2. Comparisons among the three sampling procedures in TN concentrations.

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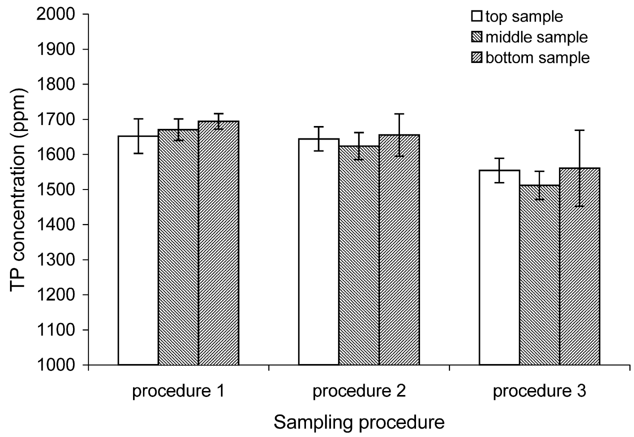

Figure 3. Comparisons among the three sampling procedures in TP concentrations.

due possibly to feed ration, management, and manure handling. Therefore, it may be inferred that, for nursery pigs that are fed on similar materials, the manure properties may not vary much with the site location. As a result, the manure nutrient contents (N, P) can be estimated with good accuracy by using the linear equations in Figure 4 based on the TS measurements.

It is interesting to note that the linear regressions obtained in this study are probably the best among those reported by a number of other researchers. A comparison between regression equations from this study and the others is presented in Table 4. Apparently, none of the past researchers have achieved R^2s as high as the ones reported here. One possibility could be the large variations present in their data, as commented by Chescheir et al.[1] in which they stated that variability was likely due to differences in such factors as rations, management, animal breeds, and climate. However, this postulate could not be verified because no ration information was

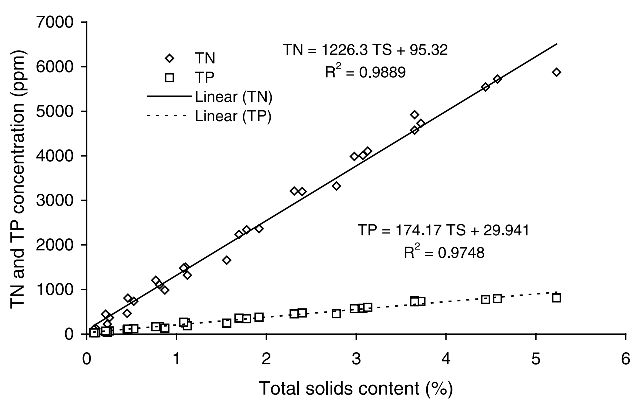

Figure 4. The relationships between manure total solids (TS) and total nitrogen (TN), total phosphorus (TP) concentrations.

Table 4. Regression equations for TS and SG versus N and P from literature data and this study.

Related parameters†	Regression equation	R^2	Reference
TN vs. TS	TN = 1194 + 424 (TS)	0.84	[6]
	TN = 362 + 598 (TS)	0.91	[8]
	TN = 2433 + 396 (TS)	0.77	[1]
	TKN = 109.5 + 600 (TS)	0.81	[9]
	TN = 95.32 + 1226.3 (TS)	0.99	In this study
TP vs. TS	TP = − 117 + 232 (TS)	0.85	[6]
	TP = 112 + 239 (TS)	0.89	[8]
	TP = 32 + 312 (TS)	0.77	[9]
	TP = 29.941 + 174.17 (TS)	0.97	In this study
TN vs. SG	TN = − 103580 + 105591 (SG)	0.86	[1]
	TN(g/kg) = − 67.4 + 69.19 (SG)	0.56	[9]
	TN = − 192739 + 192510 (SG)	0.97	In this study
TP vs. SG	TP = − 79958 + 79795 (SG)	0.60	[1]
	TP (g/kg) = − 46.61 + 46.88 (SG)	0.56	[1]
	TP = − 26558 + 26544 (SG)	0.97	In this study

†Units: TS (%), TN and TP (ppm, unless otherwise indicated).

reported in the past publications. Another possibility may be inferred by reviewing the published work of past researchers. The equations presented by them were developed based on data from manure samples taken from all kinds of pig units including gestation and farrowing, nursery, and finishing. The intention of lumping all the data together is to develop a universal equation that can be applied to all pig manures without regard to pig's age. Such operation has obviously increased variability in data because of the differentia in manure properties between gestation and farrowing, nursery, and finishing pigs. It may therefore be inferred that the concept of using a universal equation for all pig species needs to be revisited. The results from this study apparently suggest that different equations should be developed to calculate manure nutrients (N, P) for manure from pigs at different growing stages to potentially improve the correlation of linear regressions. In this way, the TS method, as well as the hydrometer method to be discussed in the next section, may be significantly improved, and relatively accurate estimates of manure N and P contents can be made, as demonstrated by the data from this study. This postulate, nevertheless, is waiting for verification by data for manure produced by pigs at other growing stages (gestation and finishing).

The Hydrometer Method

Tunney[6] observed that the hydrometer readings decreased with time due to the settling of the solids and recommended that the hydrometer readings be taken within one minute of mixing (no mention of the manure source used in his study). In a later study by Chescheir et al.,[1] it was found that significant decrease in specific gravity (as great as 0.006) was observed within one minute, and thus, they suggested that hydrometer readings be taken within 15 seconds (again, no specification of the manure

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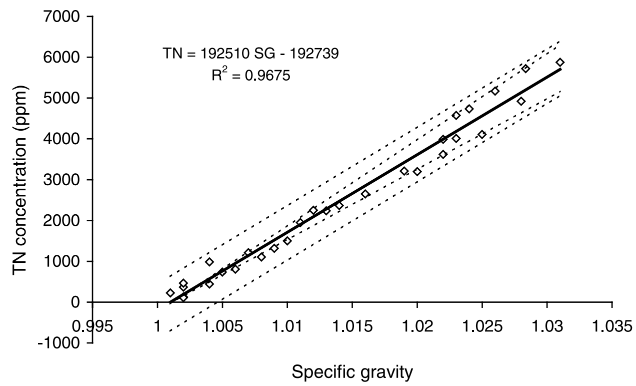

Figure 5. The relationship between manure specific gravity (SG) and TN concentration.

used). In this study, due to the observed poor settling characteristics of nursery pig manure, such concern appears to be unnecessary. However, the hydrometer readings were still taken at 10 seconds after mixing in the cylinder.

The results for manure specific gravity versus TN and TP with linear regression lines fitted are shown in Figures 5 and 6. The two regression equations are listed below for the convenience of discussion.

$$TN = 192510\ SG - 192739 \quad (1)$$

$$TP = 26544\ SG - 26558 \quad (2)$$

where TN = total nitrogen (ppm); TP = total phosphorus (ppm); SG = specific gravity.

The regressions are highly significant with correlation coefficient $R = 0.9836$ and 0.9843, respectively. These correlations are found to be much higher than those reported by past researchers (Table 4), indicating that true values of manure TN and TP contents can be approached accurately by a linear relationship with specific gravity.

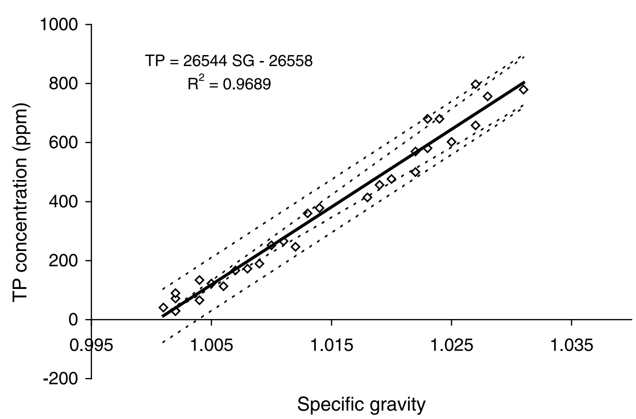

Figure 6. The relationship between manure specific gravity (SG) and TP concentration.

The information obtained from this study apparently provides better evidence than that of past studies in supporting this concept.

However, these linear regression equations (as well as all other linear equations) cannot be used without limitations, regardless of the goodness of the correlation coefficients. Piccinini and Bortone[9] first used error evaluation to examine the goodness of these equations in terms of the precision in calculating the nutrient contents (N and P) in pig slurries. Precision in this case refers to the repeatability of the measurement calculated on the basis of the ratio between the standard deviation of the estimated variable (TN) and its average value. This means that when the equation of the straight line regression is used to estimate the TN (or TP) content in the pig slurry, it is based on only one determination of specific gravity. Based on this concept, the data calculated using the linear equations derived by Piccinini and Bortone[9] were liable to a minimum error of ±25% for TN and ±46% for TP. Errors at such levels appear to cause concerns in using those linear equations.

In order to examine regression Eqs. 1 and 2, similar error analysis to those used by Piccinini and Bortone[9] is applied to the data obtained from this study. The results show that using the two equations to estimate TN and TP may lead to a minimum error of ±13% in both cases (the two external dotted lines in Figures 5 and 6 representing the 95% confidence limits), which are much better than the minimum error ranges derived by Piccinini and Bortone[9] for TN and TP. This improvement is most likely attributed to the single manure source used in this study, which again signals the importance of developing separate equations for manure from pigs at different growing stages. In spite of the improvement, Eqs. 1 and 2 still show a precision no better than ±13% for TN and TP. If the error of estimation is desired to be limited within ±10% for all estimates by using the regression equations, an error range needs to be established so that the actual data points obtained can be checked against the average value to see if these data fall within the error range. Such operation produces two internal dotted lines in Figures 5 and 6 which indicate the error ranges of ±10% when using these equations to estimate manure TN and TP content. As can be seen in Figures 5 and 6, under low TN and TP conditions, the estimating errors of using these equations will be larger than ±10% because the likelihood for the observed data points to fall outside the two internal dotted lines becomes quite obvious. Specific to the linear regression equations in this study, when the TN and TP concentrations in manure fall below about 700 ppm (0.7 g/L) and 130 ppm (0.13 g/L), the chance to control the measurement error within ±10% appears to be reduced.

The above discussion implies that even if a linear regression equation is characteristic of a good correlation coefficient, significant errors in estimation can still occur. This, however, does not mean that this equation is defective and cannot be used.

Table 5. The lowest levels of TN and TP for different error ranges.

Error ranges	TN (ppm)	TP (ppm)
±10%	700	130
±20%	500	80
±30%	300	60
±50%	100	30

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The critical guideline is to understand that there is an error range associated with the equation. Table 5 gives the error ranges for the lowest concentrations of TN and TP of nursery pig slurry in this study when Eqs. 1 and 2 are used. Obviously, the accuracy of using these two equations to estimate TN and TP contents in nursery pig manure is contingent upon the existing concentrations of these two nutrient elements in that the error in estimation will increase with the decrease in nutrient concentrations. Practically in most cases, nursery pig manure contains TN and TP at higher concentrations than 700 ppm and 130 ppm, respectively (corresponding to a TS content of 0.5%, Figure 4). Unless the manure is extremely diluted, the precision of using Eqs. 1 and 2 to calculate the TN and TP contents in the manure can thus be guaranteed within ±10%. For diluted manure with TN and TP contents less than 100 ppm and 30 ppm, respectively, the estimation error by using the above equations can be larger than 50% (Table 5).

CONCLUSION

It was observed from the data in this study that the solids in nursery pig slurry did not settle well even if the slurry was undisturbed for 5 hours. This phenomenon may be attributed to the solids characteristics such as particle size (very small) and composition (high protein content). Further research is needed to determine the cause for the observation.

The total solids content of manure has demonstrated better correlations with TN and TP (correlation coefficients: 0.9944 for TN and 0.9873 for TP, respectively) than those reported in past research. The improvement could be due to the single manure source used in this study (from nursery pigs only). It may thus be inferred that developing different linear equations for pigs at different growing stages may improve the reliability in estimating manure nutrient contents (TN and TP) by these equations.

Also highly significant are the linear regressions between manure specific gravity and TN, TP contents with correlation coefficients of 0.9836 and 0.9843, respectively, which are better than all that were developed by past researchers. It may therefore be concluded that, for a single manure source, the hydrometer method can be improved to produce relatively accurate information about manure TN and TP contents, when used with these linear regression equations.

The precision of the hydrometer method to estimate manure nutrients may be compromised by the low concentrations of TN and TP in liquid manure. According to the data from this study, the error in estimation will increase, from ±10% to ±50%, with the decrease in TN (from 700 ppm to 100 ppm) and TP (from 130 ppm to 30 ppm) concentrations. Therefore, for diluted manure (TS $<$ 0.5%), using regression equations generated from this study may not be appropriate to estimate the TN and TP contents in the manure.

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