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Using a Soil Hydrometer to measure the Nitrogen and Phosphorus Contents in Pig Slurries

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The hydrometer method to indirectly measure the nutrient contents, *i.e.* total nitrogen N_t, and total phosphorus P_t of pig slurries was examined against both single and multiple slurry sources. The data indicated that the estimation accuracy of the hydrometer method could be greatly improved if separate linear regressions were developed for slurry sources from pigs at different growing stages such as gestation, nursery, and finishing. In doing so, highly significant correlation coefficients for N_t and P_t with slurry total solids contents S_t were observed (0·9881 and 0·9935 for gestation; 0·9844 and 0·9873 for nursery; 0·9695 and 0·9628 for finishing). The slurry specific gravity G_s was also found to be well correlated with the N_t and P_t contents with correlation coefficients of 0·9909 and 0·9873 for gestation, 0·9836 and 0·9843 for nursery, and 0·9634 and 0·9745 for finishing, respectively. All these coefficients are much better than those reported by past researchers. The concept of using separate linear equations for different pig species was further supported by examining the results from the lumped data in this study. In this case, the correlation coefficients for N_t and P_t with total solids were 0·8878 and 0·6793, respectively, while those for N_t and P_t with slurry G_s were 0·8176 and 0·7022. In addition, the error analysis revealed that use of separate equations to estimate slurry nutrient contents had lower minimum error limits ($\pm$10% for N_t and 11% for P_t — gestation; $\pm$13% for both N_t and P_t — nursery; $\pm$17% for N_t and $\pm$12% for P_t — finishing) than using combined equations ($\pm$40% for N_t and $\pm$64% for P_t).

1. 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 component of this management is estimation of nutrient contents in slurry to determine safe and effective application rates (Chescheir *et al.*, 1985). Past research has shown that using a hydrometer to measure the specific gravity of pig slurry and relate it to the nutrient contents in the slurry is probably one of the simplest methods available and it is the only one that can measure both total nitrogen and total phosphorus (Van Kessel *et al.*, 1999). The basis of operation is that there is a statistically significant correlation between the total solids contents S_t and nutrient elements in pig slurries and there is also a correlation between S_t and specific gravity G_s of slurry (Tunney, 1979, 1985; Chescheir *et al.*, 1985). Specific gravity is a measure of the density of a liquid, and can be easily measured with a simple piece of lab equipment known as a hydrometer. Combining the two previously described relationships gives a linear relationship between both total nitrogen N_t and total phosphorus P_t, and the G_s of slurries as measured with a simple hydrometer. Based on such information, research has been conducted in developing the hydrometer test that can be used at farm level to estimate the nutrient contents in the slurry (Dragun, 1978; Tunney, 1979, 1985; Chescheir *et al.*, 1985; Piccinini & Bortone, 1991; Van Kessel *et al.*, 1999). However, the progress in this area has not appeared to be very successful. As a result, the conceivable on-farm nutrient management plan has hardly been implemented.

Table 1
Slurry total solids levels prepared for the experiment

Slurry total solids, %								
Finishing			*Gestation*			*Nursery*		
Farm 1	*Farm 2*	*Farm 3*	*Farm 1*	*Farm 2*	*Farm 3*	*Farm 1*	*Farm 2*	*Farm 3*
6·35	6·72	5·95	5·64	6·54	5·89	4·57	5·23	4·44
5·40	6·15	5·23	4·83	5·12	4·65	3·72	3·65	3·65
4·52	5·32	4·42	4·11	4·42	3·88	3·08	3·13	2·98
3·81	4·43	3·61	3·20	3·05	3·27	2·40	2·78	2·31
3·08	3·73	2·74	2·44	2·35	2·38	1·70	1·92	1·78
2·36	2·91	1·95	1·76	1·87	1·84	1·10	1·56	1·08
1·70	2·03	1·24	1·12	1·24	1·21	0·81	1·12	0·77
1·09	1·29	0·95	0·83	0·88	0·97	0·53	0·87	0·46
0·53	0·79	0·47	0·53	0·49	0·64	0·26	0·45	0·21
0·26	0·32	0·22	0·26	0·22	0·32	0·10	0·23	0·08

The problem that impedes the wide use of the hydrometer method to estimate the fertiliser elements in pig slurries may result partially from the inaccuracy of the estimations. The common practice of past researchers in developing linear regressions is to develop a universal equation for slurries from pigs at all growing stages (gestation, nursery, and finishing). This approach may provide a simple, one-size-fit-all type of equation but at the sacrifice of estimation accuracy due possibly to factors such as animal age, nutrition, and manure management and storage practices (Westerman *et al.*, 1990; Kirchmann & Witter, 1992; Van Horn *et al.*, 1994; Wilkerson *et al.*, 1997). In order to improve estimation accuracy, the objective of this study is to focus on slurries from pigs at different growing stages, based on which corresponding linear equations are developed. These equations are compared with those developed based on the combined data for all pigs to determine if it is possible to improve the estimation accuracy of nutrient contents in the slurry using a hydrometer. The potential error ranges in nutrient estimation using the linear equations developed by data from both single and multiple slurry sources are presented to reveal the difference. Also discussed are the results from previous research as compared to those from this study in terms of the accuracy of nutrient estimation using a hydrometer and the linear regressions.

2. Materials and methods

2.1. *Slurry source*

In order to obtain representative samples to account for potential variations in livestock management techniques, slurries from a total of nine farms (three for each pig species) located in different areas in southern Minnesota were 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 laboratory with tap water to generate liquid slurries with ten different solids contents as shown in Table 1. These samples were primarily used for developing separate linear equations for each individual pig category, and for revealing the consequences if equations were derived using lumped data as well.

In order to verify the equations derived using data from the diluted manure, additional sampling was conducted, in which one slurry sample was randomly collected from the pits of six finishing, six gestation, and five nursery buildings at different depths. These raw samples were then analysed without dilution. The pig buildings for the additional samples were located in the same areas as those in the previous sampling. The pigs from all the sampling sites were fed on a regular corn/soybean based ration (Table 2).

2.2. *The hydrometer method*

Each diluted slurry sample, and each raw sample as well, was poured into a 1 *l* cylinder and thoroughly mixed before measuring specific gravity by a soil hydrometer having a scale of 1·000–1·070 (Cole Parmer Catalog Number: U-08292-16). The mixing was carried out manually using a brush to rigorously stir the slurry in the cylinder to suspend all the solids. And then, the hydrometer was placed in the cylinder to measure specific gravity immediately after stirring. Tunney (1979) observed that the hydrometer readings decreased with time due to the settling of solids and recommended that the hydrometer readings be taken within 1 min of mixing. In a later study by Chescheir *et al.* (1985), it was

Table 2
Feed ration for all the pigs in this study

Ingredient	*Proportion in feed ration, %*		
	Gestation	*Nursery*	*Finishing*
Maize	81·45	35·35	71·65
Soya bean meal	15·0	20·0	25·0
Fish meal	Nil	12·0	Nil
Whey powder	Nil	15·0	Nil
Oat groats	Nil	13·0	Nil
Tallow	1·0	3·0	1·0
Dicalcium phosphate	1·0	0·5	0·8
Vitamin/mineral premix	0·25	0·25	0·25
$CaCO_3$	0·8	0·4	0·8
Salt	0·5	0·5	0·5

found that significant decrease in specific gravity (as great as 0·006) was observed within 1 min, and thus, they suggested that hydrometer readings be taken within 15 s. In this study, the result turned out to be more stringent because it was found that stable hydrometer readings could only be obtained if the hydrometer was read within 10 s after mixing. Therefore, the specific gravity data presented in this paper were based on the hydrometer readings taken at 10 s after mixing in the cylinder.

2.3. *Sample analysis*

All slurry samples were analysed for total solids S_t, total phosphorus P_t, and total nitrogen N_t. Standard methods recommended by the American Public Health Association for wastewater analysis were used in the sample analysis (APHA, 1998). Total nitrogen was determined by the Kjeldahl method. Total phosphorus was measured after digestion with H_2SO_4–H_2O_2 and diluted to 100 ml. Soluble orthophosphate was extracted by filtering ten-fold diluted slurry using a Whatman filter paper. Orthophosphate was determined colorimetrically as the phosphomolybdate complex after reduction with ascorbic acid (APHA, 1998). Samples that were not immediately analysed after collection were stored in a freezer at $-20°C$ and thawed prior to laboratory analysis.

3. Results

3.1. *Separate results for pigs at different growing stages*

Results describing the relationships for S_t with N_t and P_t based on slurry samples collected from the three different finishing buildings are presented in *Fig. 1*(*a*). Also included are data for additional undiluted slurry samples from the pits of another six finishing buildings. The two linear regression equations (S_t *versus* N_t and P_t) prove highly significant with values for the correlation coefficient R of 0·9695 and 0·9628, respectively. This information appears to indicate that there is no substantial variation in terms of slurry characteristics among the 30 samples, despite that the samples were collected from three farms located in different areas, a case to be perceived as very likely to bring about variation due possibly to feed ration, management, and manure handling. This observation is verified by the extra data points generated by the samples randomly collected from six more finishing buildings, as shown in *Fig. 1*(*a*), in that these additional data points appear to be well positioned in line with the regression equations. Therefore, it may be inferred that, for finishing pigs that are fed on similar materials, the slurry properties may not vary much with the site location. As a result, the slurry nutrient contents (N_t and P_t) can be estimated with good accuracy by using the linear equations in *Fig. 1*(*a*) based on the S_t measurements.

The results of the finishing group for slurry specific gravity G_s *versus* N_t and P_t with linear regression lines fitted are shown in *Fig. 1*(*b*) and (*c*). The regressions are highly significant with values for the correlation coefficient R of 0·9634 and 0·9745, respectively, indicating that true values of slurry N_t and P_t contents can be approached accurately by a linear relationship with G_s. For the undiluted data, despite some variation, they generally follow the trend of the two linear regression lines.

In the same fashion, the relationships for N_t and P_t with slurry S_t and G_s for the other two groups of pigs (gestation and nursery) are presented in *Figs 2* and *3*, together with data from the undiluted slurry samples. Apparently, the observations are not different from those of finishing pigs in terms of highly significant linear correlations. The linear equations as well as their

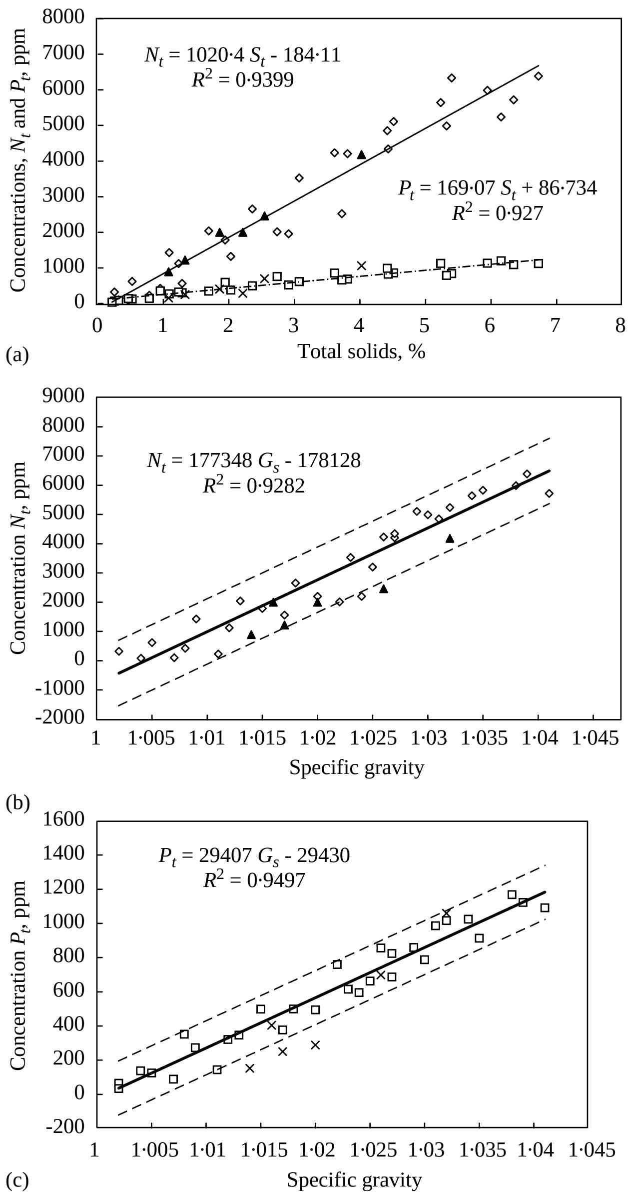

Fig. 1. The linear relationships for total solids, S_t, and specific gravity, G_s, with total nitrogen, N_t, and phosphorus, P_t, contents in slurry from finishing pigs; R^2, coefficient of determination; ▲ and ×, N_t and P_t from samples randomly collected from the pits of six additional finishing barns without dilution: (a) N_t and P_t versus S_t; (b) N_t versus G_s; and (c) P_t versus G_s; ◇, N_t; □, P_t; dotted lines in (b) and (c) indicate a 95% confidence limits for the regression lines

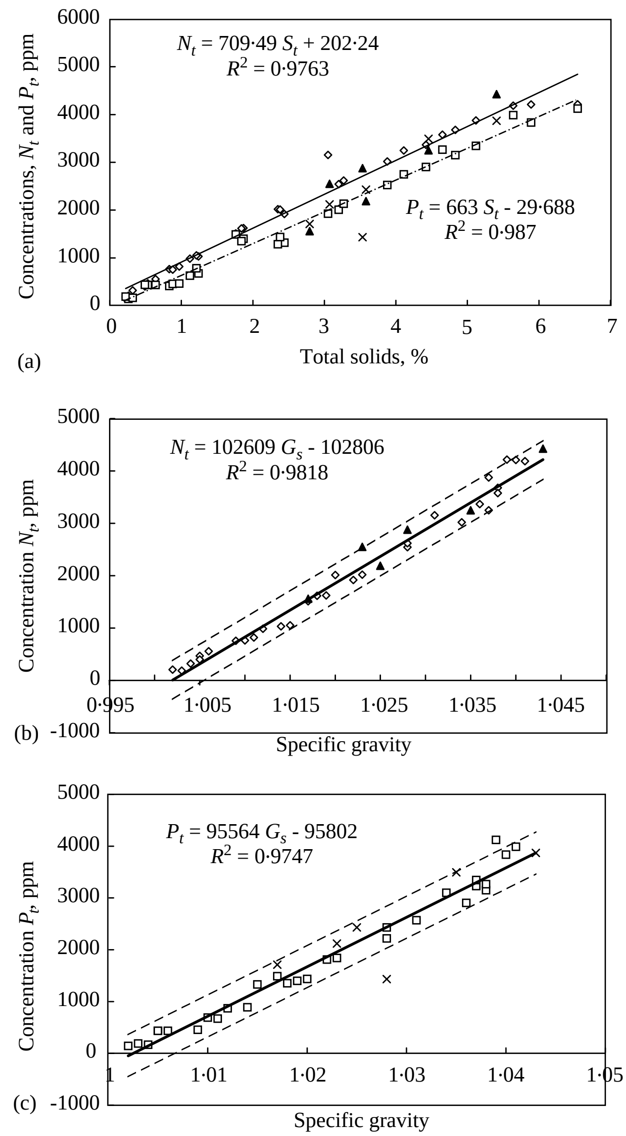

Fig. 2. The linear relationships for total solids, S_t, and specific gravity, G_s, with total nitrogen, N_t, and phosphorus, P_t, contents in slurry from gestation pigs; R^2, coefficient of determination; ▲ and ×, N_t and P_t from samples randomly collected from the pits of six additional gestation barns without dilution: (a) N_t and P_t versus S_t; (b) N_t versus G_s; and (c) P_t versus G_s; ◇, N_t; □, P_t; dotted lines in (b) and (c) indicate a 95% confidence limits for the regression lines

coefficients of determination for all pig species are listed in Table 3. It is clearly seen that if each individual equation is used for a particular pig group based on which this equation is developed, a good estimate of slurry nutrients (N_t and P_t) can be achieved. Evidently, this conclusion appears to be supported by the additional data, although limited, generated from the undiluted samples within each individual pig group (*Figs 1–3*).

3.2. *Combined results for pigs at all growing stages*

When the linear regressions are derived with lumped data including all pig species under study, the goodness

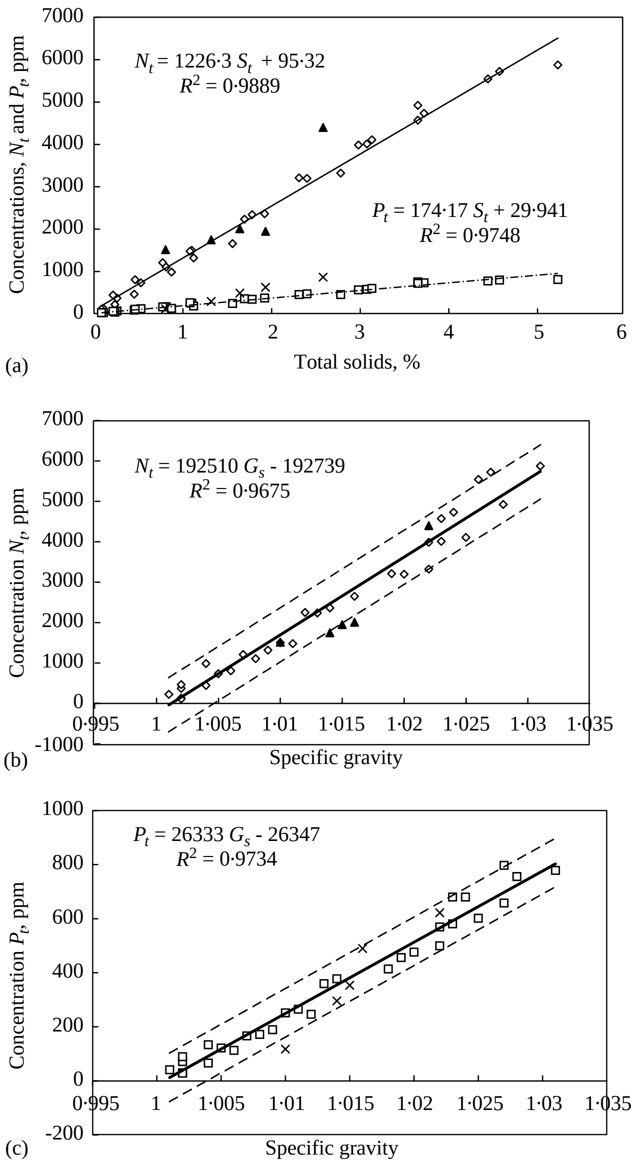

Fig. 3. The linear relationships for total solids, S_t, and specific gravity, G_s, with total nitrogen, N_t, and phosphorus, P_t, contents in slurry from nursery pigs; R^2, coefficient of determination; ▲ and ×, N_t and P_t from samples randomly collected from the pits of five additional nursery barns without dilution: (a) N_t and P_t versus S_t; (b) N_t versus G_s; and (c) P_t versus G_s; ◇, N_t; □, P_t; dotted lines in (b) and (c) indicate a 95% confidence limits for the regression lines

of correlation is noticeably reduced as shown in *Figs 4–7*, in which data points are scattered in broader areas than those in *Figs 1–3*. In particular, the correlation coefficients for N_t and P_t with S_t are observed to be 0·8878 and 0·6793, respectively, which are much lower than those obtained for each individual pig species, *i.e.*, 0·9695 and 0·9628 for finishing, 0·9881 and 0·9934 for gestation, and 0·9944 and 0·9873 for nursery. Similarly, the value of the correlation coefficient for N_t with G_s declines from a range of 0·9634–0·9909 to 0·8176 and that for P_t with G_s drops from a range of 0·9745–0·9873 to 0·7022. The observation appears to suggest that use of combined data to construct linear regressions will deteriorate the goodness of fit, leading to inaccurate estimation of slurry nutrient contents. The undiluted data from additional samples, also included in these figures, have confirmed the above findings.

4. Discussion

The data from this study indicate that use of a hydrometer to indirectly measure slurry nutrient contents (N_t and P_t) can be a feasible way and its accuracy can be greatly improved if used properly. A comparison between regression equations from this study and the others is presented in Table 3, which clearly shows that the linear regressions obtained in this project are the best because none of the past researchers have achieved values for the coefficient of determination, R^2, as high as the ones reported here. The possibility for low values of R^2 could be the large variations present in their data, as commented by Chescheir *et al.* (1985) in which they stated that variability was likely due to differences in such factors as rations, management, animal breeds, and climate. The equations presented by them appeared to be developed based on data from slurry samples taken from all kinds of pig units including gestation, nursery, and finishing (same as the combined results in this study). However, this postulate could not be verified because no ration and other information were reported in past publications. The intention of lumping all the data together is to develop a universal equation that can be applied to all pig slurries without regard to pig age. Such operation obviously tends to increase variability in data because of the differentia in slurry properties between gestation, nursery, and finishing pigs. In order to discuss the effect of lumping data on the goodness of fit for the linear regression, the universal equations developed by the combined data in this study are also included in Table 3. As can be seen, the values for the coefficient of determination R^2 for the linear regressions significantly decline from a range of 0·94 to 0·98 (separate data) to 0·79 (combined data) for N_t *versus* S_t, from a range of 0·93 to 0·99 (separate data) to 0·46 (combined data) for P_t *versus* S_t, from a range of 0·93–0·98 (separate data) to 0·67 (combined data) for N_t *versus* G_s, and from a range of 0·95–0·97 (separate data) to 0·49 (combined data) for P_t *versus* G_s. It is interesting to note that when the lumped data in this study are used, the R^2 values obtained from the linear regressions are somewhat comparable to many of those

Table 3
Regression equations for total solids S_t in % and specific gravity G_s, *versus* total nitrogen N_t in ppm, Kjeldahl nitrogen N_{tk} in ppm, and total phosphorus P_t in ppm, from literature data and this study

Related parameters	*Regression equation*	R^2	*Source*
N_t *versus* S_t	$N_t = 1194 + 424\ S_t$	0·84	Tunney (1979)
	$N_t = 362 + 598\ S_t$	0·91	Dragun (1978)
	$N_t = 2433 + 396\ S_t$	0·77	Chescheir *et al.* (1985)
	$N_{tk} = 109{\cdot}5 + 600\ S_t$	0·81	Piccinini and Bortone (1991)
	$N_t = -184{\cdot}1 + 1020{\cdot}4\ S_t$	0·94	In this study (finishing)
	$N_t = 202{\cdot}2 + 709{\cdot}5\ S_t$	0·98	In this study (gestation)
	$N_t = 95{\cdot}32 + 1226{\cdot}3\ S_t$	0·99	In this study (nursery)
	$N_t = 293{\cdot}24 + 853{\cdot}02\ S_t$	0·79	In this study (combined)
P_t *versus* S_t	$P_t = -117 + 232\ S_t$	0·85	Tunney (1979)
	$P_t = 112 + 239\ S_t$	0·89	Dragun (1978)
	$P_t = 32 + 312\ S_t$	0·77	Piccinini and Bortone (1991)
	$P_t = 86{\cdot}7 + 169{\cdot}1\ S_t$	0·93	In this study (finishing)
	$P_t = -29{\cdot}7 + 663\ S_t$	0·99	In this study (gestation)
	$P_t = 29{\cdot}941 + 174{\cdot}17\ S_t$	0·97	In this study (nursery)
	$P_t = 12{\cdot}14 + 345{\cdot}56\ S_t$	0·46	In this study (combined)
N_t *versus* G_s	$N_t = -103580 + 105591\ G_s$	0·86	Chescheir *et al.* (1985)
	$N_{tk} = -67400 + 69190\ G_s$	0·56	Piccinini and Bortone (1991)
	$N_t = -178128 + 177348\ G_s$	0·93	In this study (finishing)
	$N_t = -102806 + 102609\ G_s$	0·98	In this study (gestation)
	$N_t = -192739 + 192510\ G_s$	0·97	In this study (nursery)
	$N_t = -123396 + 123489\ G_s$	0·67	In this study (combined)
P_t *versus* G_s	$P_t = -79958 + 79795\ G_s$	0·60	Chescheir *et al.* (1985)
	$P_t = -46610 + 46880\ G_s$	0·56	Piccinini and Bortone (1991)
	$P_t = -29430 + 29407\ G_s$	0·95	In this study (finishing)
	$P_t = -95802 + 95564\ G_s$	0·97	In this study (gestation)
	$P_t = -26347 + 26333\ G_s$	0·97	In this study (nursery)
	$P_t = -56245 + 56063\ G_s$	0·49	In this study (combined)

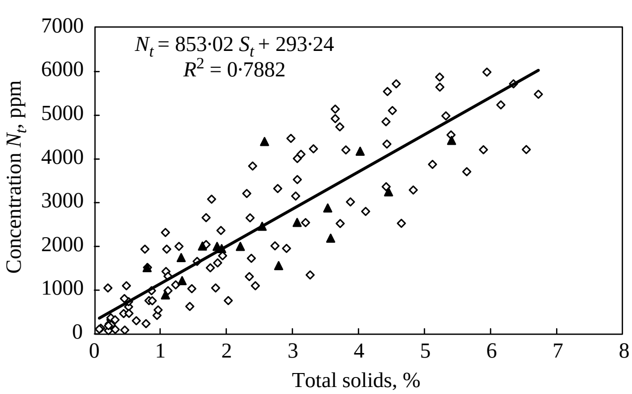

Fig. 4. The relationship between total nitrogen, N_t, and total solids content, S_t, for slurry from all pigs: ◇, N_t; ▲, N_t from samples randomly collected from the pits of all additional barns without dilution

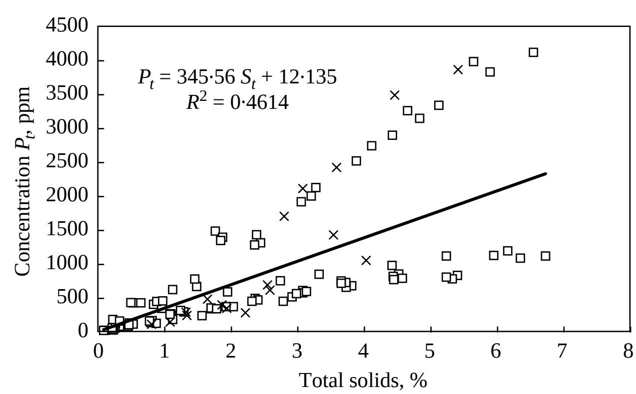

Fig. 5. The relationship between total phosphorus, P_t, and total solids content, S_t, for slurry from all pigs: □, P_t; ×, P_t from samples randomly collected from the pits of all additional barns without dilution

in the early reports (Table 3). It is also interesting to note that the undiluted data from this study behave in the same manner as the rest of data as shown in *Figs 4–7*.

The picture depicted by the combined data delivers a clear message 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

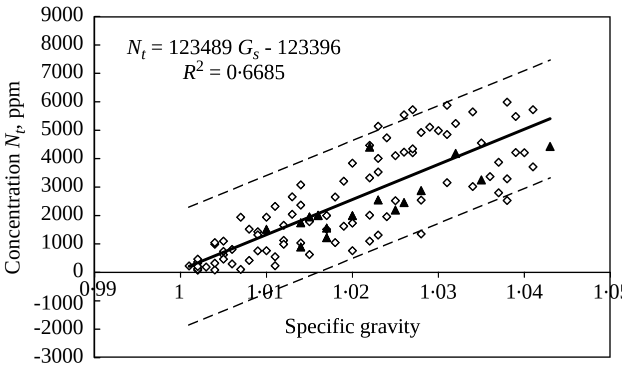

Fig. 6. The relationship between total nitrogen, N_t, and specific gravity, G_s, for manure from all pigs (dotted lines indicate a 95% confidence limits for the linear regression line):◇, N_t; ▲, N_t from samples randomly collected from the pits of all additional barns without dilution

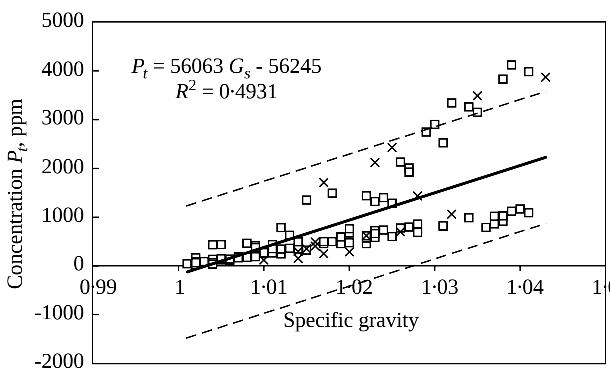

Fig. 7. The relationship between total phosphorus, P_t, and specific gravity, G_s, for manure from all pigs (dotted lines indicate a 95% confidence limits for the linear regression line): □, P_t; ×, P_t from samples randomly collected from the pits of all additional barns without dilution

equations should be developed to calculate the nutrients (N_t and P_t) for slurries from pigs at different growing stages to greatly improve the correlation of linear regressions. In this way, the hydrometer method may become an effective tool in getting relatively accurate estimates of slurry nitrogen and phosphorus contents.

The difference in estimation accuracy between linear equations generated from single and combined slurry sources can also be revealed by error analysis. Piccinini and Bortone (1991) first used error evaluation to examine the goodness of linear equations in terms of the precision in calculating the nutrient contents (N_t and P_t) 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 (N_t) and its average value. This means that when the equation of the straight line regression is used to estimate the N_t (or P_t) content in 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 (1991) were liable to a minimum error of $\pm 25\%$ for N_t and $\pm 46\%$ for P_t.

The error analysis used by Piccinini and Bortone (1991) is also applied to the data obtained from this study. The confidence intervals (95%) for Nt and Pt *versus* G_s are constructed and shown in *Figs 1*(*b*), *1*(*c*), *2*(*b*), *2*(*c*), *3*(*b*), *3*(*c*), *6*, and *7* (the two dotted lines in these graphs). The results show that using separate equations to estimate N_t and P_t based on G_s measurements may lead to a minimum error of ± 17 and $\pm 12\%$ for finishing pigs, $\pm 10\%$ and $\pm 11\%$ for gestation pigs, and $\pm 13\%$ and $\pm 13\%$ for nursery pigs. However, if the equations for the combined data are used (*Figs 6* and *7*), the minimum error ranges will be increased to $\pm 40\%$ for N_t and $\pm 64\%$ for P_t, respectively. Errors at such levels will certainly cause concerns in using these equations. The above analysis further concludes that separate equations should be developed and used in preference to combined ones in order to obtain relatively accurate estimations of pig slurry nutrient contents (N_t and P_t) by the hydrometer method.

5. Conclusion

Data from this study indicate that to use the hydrometer method, it is necessary to develop separate linear regression equations for slurry from pigs at different growing stages in order to obtain good estimates of slurry nutrient contents (total nitrogen and total phosphorus). The values of the correlation coefficients for total nitrogen N_t and total phosphorus P_t with total solids S_t are found to be ranging from 0·9695 to 0·9944 and 0·9628 to 0·9935, respectively, for separate equations. In contrast, the values of the correlation coefficients for the combined data (including slurries from all the pig species) are 0·8878 for N_t and 0·6793 for P_t in relation to the S_t measurements.

The reduction in goodness of fit for linear correlation is also observed for the regressions for N_t and P_t with slurry specific gravity G_s, with the correlation coefficients declining from a range of 0·9634–0·9909 to 0·8176 for N_t *versus* G_s and from a range of 0·9745–0·9873 to 0·7022 for P_t *versus* G_s.

The error analysis reveals that if the combined equation is used, the minimum estimation error will be $\pm 40\%$ for N_t and $\pm 64\%$ for P_t. These error limits are significantly higher than those in using separate linear regressions in which error limits fall into a range between ± 10 and $\pm 17\%$, including both N_t and P_t situations. Based on the above discussions, it may therefore be concluded that the hydrometer method can be greatly improved in estimation accuracy by using separate linear regressions. In doing so, good estimates of the nutrient contents (N_t and P_t) in pig slurries can be achieved.

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