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Original Research

Evaluation of Specific Gravity and Electrical Conductivity for Determining Nutrient Concentrations in Suspensions of Poultry Manure

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Abstract

With increasing concern for the pollution potential of farm wastes, there is a corresponding need for rapid and robust methods of analysis for animal manures. In order to study the rapid testing methods based on the relationship between nutrient concentrations and physicochemical properties, diverse samples (n=105) were used in this study. The results indicated strong linear relations between specific gravity (SG) and total phosphorous (TP), total nitrogen (TN), volatile solids (VS), copper (Cu), iron (Fe), zinc (Zn), and magnesium (Mg) concentrations (R^2=0.80, 0.90, 0.91, 0.68, 0.71, 0.66, 0.77, respectively). Relationships between electrical conductivity (EC) and Sodium (Na), ammonium nitrogen (AN), and total potassium (TK) were significant with R^2 values of 0.62, 0.85 and 0.68. Therefore, the hydrometer and conductivity meter can estimate rapidly nutrient concentrations of layer manure.

Keywords: layer manure, specific gravity, electrical conductivity

Introduction

Animal manure used as a crop fertilizer can be economically sound, solving both a waste management problem and reducing the cost of chemical fertilizer. With increasing concern about the pollution potential of farm wastes, there is a corresponding need for rapid and robust methods of analysis for animal manure.

At present time, most manure analysis is finished by conventional chemical procedures. However, these procedures, while accurate, can be time consuming, expensive and generate chemical wastes. Compared to traditional chemical analysis, the rapid tests are cost efficient and generate no waste.

Currently, a number of rapid tests for determining ammonium nitrogen (AN) and total nitrogen (TN) are available which can be used for on-farm testing of manure. These include Agros Nitrogen Meter [1-5] and Quantofix-N-Volumeter [6, 7] which estimate AN concentration by the reaction of hypochlorite (CLO^-) with NH_4^+, electrical conductivity pens and meters [3, 4, 8, 9] that measure AN through estimating the NH_4^+ concentration, and hydrometers [10-12] which can estimate TN concentration.

Although the rapid testing methods were feasible, the wide use of the rapid techniques has been challenged by some factors. One primary factor was the presentation of the sample. Due to the setting characteristics of manure sol-

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id, it has been long been recognized that it is difficult to get representative samples. A few works had been conducted on the effect of manure sampling procedures on the representation of TN and TP [12-14]. Other concentrations (VS, AN, TK, Cu, Fe, Zn, Mg, Na) have not been evaluated.

Another limitation was that they only focused on the rapid testing models between the nutrient concentrations (TN, TP, TK, AN) and physicochemical properties in swine, cattle and dairy manure. There was little report about layer manure. Due to the differences in the diets and physiology of livestock species, the manure produced by each has different chemical and physical properties. For example, many dairy manures are slurries with a high moisture (80-95%) concentration but which may also contain large amounts of straw or other bedding materials [15]. Layer manures, on the other hand, are generally much drier but contain minerals such as Zn and Cu. Thus, further work is needed to determine the feasibility and limitations for using rapid testing method to analyze layer manures.

The objective of this study was to

1) evaluate the effect of three sampling procedures on obtaining a representative sample for layer manure composition analysis;
2) develop some rapid testing models based on the relationships between physicochemical properties (EC, SG) and layer manure compositions (TN, TP, AN, TK, VS, Cu, Fe, Zn, Mg, Na).

Materials and Methods

Collection and Preparation of Manure Samples

A total of 105 layer manure samples including different growing stages were collected from 70 layer farms in Shunyi, Pinggu and Yanqing of Beijing in China during 2 months in the spring of 2005. Approximately 5kg of manure was collected for each sample. Samples were frozen at -20°C from the time of arrival at the laboratory.

EC and SG must be measured in liquid samples. Therefore, the solid samples should be diluted. The dilution ratios from 2-fold to 10-fold (the result has not been presented in the paper) have been studied. According to the result of the studies, it is found that when the poultry manure is diluted with clean water by 2-fold, 3-fold, 4-fold, the sample is still viscous, the hydrometer cannot float freely. However, when the dilution ratio exceeds 5-fold, the measured value of SG for most samples nears 1 and it is difficult to reflect the original physicochemical property of the sample. Therefore, in this study, the manures were diluted with clean water by 5-fold [16].

Experimental Design for the Effect of Setting on Concentrations

In order to evaluate the effect of setting on concentrations, one of the 105 original manures (about 4kg) was selected at random. The manure was diluted with clean water by 5-fold to generate a liquid sample of about 10L.

This experiment included three sampling procedures: vertical agitation, horizontal mixing and no agitation. The liquid sample was poured into a 12L barrel. The experiment generated 3 levels in the barrel. The first and third level was with 2.5cm from the top and the bottom ends, the second level was the middle layer of the solution. There were 3 points in every level with 5.0cm from the barrel wall [12]).

For sampling procedure 1 the manure was agitated with a beater with two propellers installed on the shaft (Model: JJ-1, Ronghua Instrument Corp., Jiangsu). The agitation speed was controlled at 1,200rpm. After mixing 15min, manure samples of 100mL each were taken at nine points. The agitation remained during sampling. This agitation scheme was to create a vertical mixing pattern.

For sampling procedure 2, after about 5h of resting the second procedure was performed in the same barrel. The manure was agitated by a stirring machine (Model: 81-2, Sile Instrument Corp., Shanghai) with a magnetic stirring bar at the bottom of the barrel. The mixing speed was controlled at 1,200rpm. After mixing 15min, nine samples were collected at the same locations as in the first procedure. This agitation scheme was to create a horizontal mixing pattern.

Sampling procedure 3 was to simulate the sampling situation for manure without agitation. After the second sampling procedure was finished, the third procedure was not performed until the manure in the barrel deposited thoroughly. The sampling points and the number of samples collected were the same as in the first procedure.

Laboratory Analysis

Measurement of EC and SG

EC was measured using a digital conductivity meter with automatic temperature compensation (Model: SC8221, Yokogawa Electric Corp., Japan). The conductivity meter was calibrated with calibration solutions. SG were measured by a hydrometer having a scale of 1.000~1.100 (Model 09000123, Qing city, Yanhe Glass Corp.).

Before measuring EC and SG, the sample of about 1.5L should be mixed completely, then poured into a 2L cylinder. First, EC was measured. The measuring was not finished until the EC reading was stable. Mixing subsequently was executed again before the hydrometer was placed in the cylinder. Due to the setting of the solids with time, the hydrometer reading was taken within 15s after mixing [10, 17].

Chemical Analysis

Each of the 105 samples was analyzed for VS by oven drying at 525±10°C, TP, TN, AN, TK, Cu, Fe, Zn, Mg and Na using conventional laboratory analysis as detailed in Table 1 [18, 19].

Table 1. Laboratory analysis methods used.

Measured variable	Laboratory method
Dry matter, DM (%)	Dry at 105±5°C for 6 h
Total phosphorus, TP (g kg^{-1})	Microwave digestion in nitric acid followed by spectrometric method
Total nitrogen, TN (g kg^{-1})	Digestion in sulfuric acid followed by steam distillation
Ammonium nitrogen, AN (g kg^{-1})	Steam distillation
Total potassium, TK (g kg^{-1})	Microwave digestion in nitric acid followed by atomic absorption spectrophotometry
Volatile Solids, VS (g kg^{-1})	Oven drying at 525±10°C for 6 h
Copper, Cu (g kg^{-1})	Microwave digestion in nitric acid followed by atomic absorption spectrophotometry
Iron, Fe (g kg^{-1})	Microwave digestion in nitric acid followed by atomic absorption spectrophotometry
Zinc, Zn (g kg^{-1})	Microwave digestion in nitric acid followed by atomic absorption spectrophotometry
Magnesium, Mg (g kg^{-1})	Microwave digestion in nitric acid followed by atomic absorption spectrophotometry
Sodium, Na (g kg^{-1})	Microwave digestion in nitric acid followed by atomic absorption spectrophotometry

Statistical Analysis

Physicochemical properties such as SG and EC were compared with TP, TN, AN, TK, VS, Cu, Fe, Zn, Mg and Na derived from laboratory analysis. Then the simple linear regressions were applied. All of these statistical analyses were carried out using SPSS (Statistical Package for the Social Science) [20] and statistical significance was detected at the 0.05 level of probability.

Results and Discussion

Chemical Analysis

The nutrient concentration of the 105 samples was diverse. TP, TN, AN, TK, VS, Cu, Fe, Zn, Mg and Na concentrations varied by 2.87-, 2.16-, 11.92-, 8.05-, 2.07-, 8.33-, 5.84-, 6.70-, 3.83- and 5.95-fold, respectively, and the range of dry matter concentration was from 14.99 to 57.40% (Table 2).

Table 2. Descriptive statistics for nutrient concentrations in layer manure samples.

	Min	Max	Mean ± SD
DM (%)	14.99	57.40	29.17±10.01
TP (g kg^{-1})	7.27	20.88	14.47±2.94
TN(g kg^{-1})	34.79	75.16	53.35±8.47
AN(g kg^{-1})	0.82	12.11	4.75±2.83
TK(g kg^{-1})	2.01	10.90	4.54±1.97
VS(g kg^{-1})	9.47	37.96	19.54±6.79
Cu(g kg^{-1})	0.97	20.35	7.95±3.98
Fe(g kg^{-1})	0.09	1.15	0.43±0.26
Zn (g kg^{-1})	10.27	154.28	57.47±31.46
Mg(g kg^{-1})	1.21	7.48	3.45±1.57
Na(g kg^{-1})	0.11	1.14	0.52±0.19
SG(kg.m^{-3})	1.001	1.036	1.013±0.01
EC(ms.cm^{-1})	3.42	16.53	7.04±2.57

SD: standard deviation; the concentrations are on a fresh weight basis.

The Effects of Different Sampling Procedures on Concentrations

The means and standard deviation of TP, TN, VS, AN, Cu, Fe, Zn, Mg, TK and Na concentrations for samples from the three procedures are presented in Table 3.

Total Phosphorus, Total Nitrogen, Volatile Solid and Ammonium Nitrogen

Apparently, there was no statistical difference in the TP and TN concentrations between samples collected at different depths in procedures 1 and 2, respectively. This result was similar to the report of Zhu et al. [12], which showed that agitation was an important step for obtaining a representative sample in TP and TN. Similar observation is present for AN and VS. It was also observed that there was no statistically significant difference between procedures 1 and 2 in obtaining a representative sample for TP, TN, AN, and VS. Therefore, it can be concluded with procedure 1 or procedure 2, a representative manure sample for TP, TN, AN and VS analysis can be obtained from anywhere without respect to the sampling location (top, middle, or bottom).

Table 3. Concentration data by three sampling procedures.

Contents	Sampling locations	Procedure 1	Procedure 2	Procedure 3		Procedure 1	Procedure 2	Procedure 3
TP (mg L^{-1})	Top	969.38ax	905.77ax	119.38ay	Fe (mg L^{-1})	76.03ax	79.44ax	3.24ay
	Middle	1015.46ax	996.14ax	937.05bx		86.00ax	84.21ax	113.39by
	Bottom	975.22ax	1020.7ax	1677.09cy		90.92ax	75.87ax	165.12cy
TN (mg L^{-1})	Top	2484.43ax	2465.19ax	947.95ay	Zn (mg L^{-1})	10.92ax	11.01ax	1.75ay
	Middle	2543.25axy	2759.56ax	2101.40by		11.26ax	10.62ax	13.20bx
	Bottom	2623.69ax	2743.09ax	4069.32cy		12.12ax	11.50ax	18.42cy
VS (g L^{-1})	Top	39.66ax	38.59ax	8.97ay	Mg(mg L^{-1})	575.40ax	634.92ax	119.64ay
	Middle	39.99ax	38.65ax	37.90bx		682.54ax	651.59ax	989.29by
	Bottom	40.01ax	39.86ax	90.88cy		667.46ax	609.52ax	1123.81cy
AN (mg L^{-1})	Top	524.42ax	504.22ax	420.95ay	TK(mg L^{-1})	785.90ax	837.40ax	785.90ax
	Middle	517.86ax	528.67ax	625.05by		781.20ax	771.75ax	761.57ax
	Bottom	526.37ax	519.63ax	701.32cy		819.40ax	827.60ax	795.39ax
Cu (mg L^{-1})	Top	2.21ax	1.98ax	0.95ay	Na (mg L^{-1})	78.69ax	88.71ax	78.12ax
	Middle	2.50ax	2.34ax	2.32abx		89.23ax	124.27ax	99.42ax
	Bottom	2.34ax	2.46ax	3.71cy		87.86ax	109.33ax	94.04ax

Note: Different letters indicate there is significant difference between numbers on different rows (a, b, c) and different columns (x, y). Sample number is 3 for all entries.

Compared with procedures 1 and 2, the problem with procedure 3 in getting a uniform manure sample for TP, TN, AN and VS analysis was clearly shown in Table 3. There were significant differences between the data collected from the three depths in procedure 3. It was shown that the lower location sample had significantly higher average TP, TN, AN and VS than the higher sample. The results for TP and TN were similar with previous study [12]. However, the result for AN does not agree with previous research [21], which showed that sedimentation had no impact on AN. This needs further studied.

Copper, Iron, Zinc and Magnesium

The effect of settlement on Cu, Fe, Zn and Mg has not been studied in the past. In this study, it was clear there were no statistical differences in Cu, Fe, Zn and Mg concentrations between samples collected at different depths in procedure1 and 2. There was also no statistically significant difference between procedures 1 and 2 in obtaining a representative sample for Cu, Fe, Zn and Mg. These data showed that a reliable sample for Cu, Fe, Zn and Mg can be obtained with procedure 1 or 2, regardless of the sampling location.

The natural settlement also had effective impact on Cu, Fe, Zn and Mg concentrations for samples collected at different depths in procedure 3. The lower sample contained significantly higher concentrations of Cu, Fe, Zn and Mg than the higher sample. The result indicated that some Cu, Fe, Zn and Mg may not exist in ionic form in the solution and adhere to granule of manure.

Total Potassium and Sodium

For TK and Na, there was no statistical difference for samples collected at different depths using procedures 1, 2 and 3. There was also no statistically significant difference between procedures 1, 2 and 3. The result indicated that TK and Na in manure samples exist mainly in ionic form.

According to the discussion above, it can be concluded that the sedimentation characteristic has an important impact on most concentrations in layer manure, such as TP, TN, AN, VS, Cu, Fe, Zn and Mg. Therefore, in order to obtain a representative sample, procedure 1 or procedure 2 were suitable for manure sampling.

The Relationships between Physicochemical Properties and Nutrient Concentrations

The simple linear regressions were performed according to the previous section "Statistical Analysis." However, the finally selective models for concentration estimation in layer manure ought to be those which can provide the best fit to the data, i.e. high value of determinate coefficient and low value of the root mean squared error (RMSE). All linear regression results are presented in Table 4.

Total Phosphorus, Total Nitrogen, Ammonium Nitrogen and Total Potassium Correlations

Total Phosphorus

Total phosphorus in most animal manures was largely insoluble. It was expected that phosphorus would relate to properties reflecting total solid concentration of manures. The best regression is with SG with R^2 value of 0.80. This indicated that TP of layer manure is related only to SG. This result is similar with previous studies which showed that a good correlation existed between SG and TP in pig and cattle slurries [22].

Total Nitrogen

The best simple regression for TN is SG with R^2 value of 0.90. Therefore, the TN of layer manure may be estimated by SG. This result is consistent with previous studies for pig manure [12, 14].

Ammonium Nitrogen

The simple linear regressions show that the regressions between AN and SG, EC were significant (p<0.001) with R^2 values of 0.27 and 0.86. Therefore the simple linear regression between AN and EC is chosen.

Total Potassium

The simple linear regressions show that the regressions between TK and SG and EC are significant (p<0.001). The best regression is EC with R^2 value of 0.68. Therefore the simple linear regression between TK and EC is chosen.

Volatile Solid, Copper, Iron, Zinc, Magnesium and Sodium Correlations

There were no reports of rapid testing methods based on the relationships between physicochemical properties (SG and EC) and VS, Cu, Fe, Zn, Mg and Na in the animal manure at present time. In this study we performed the initial explorations of rapid testing models for these compositions.

Volatile Solid

The simple linear regressions showed that the regressions between VS and SG, EC were significant (p<0.001) with R^2 values of 0.91 and 0.34. Therefore, VS of layer manure may be related with SG. It was also expected because VS was mainly composed of total solid and therefore should relate to SG reflecting the total solids concentrations.

Table 4. Linear regressions between physicochemical properties and nutrient concentrations in layer manure.

Compositions	Measured properties	Regression equation	Adjusted R^2	p value	RMSE
TP ($g\ kg^{-1}$)	SG	TP=176.15SG-174.20	0.80	<0.001	0.75
	EC	TP=0.35EC+1.72	0.29	<0.001	1.40
TN ($g\ kg^{-1}$)	SG	TN=627.27SG-619.85	0.90	<0.001	1.78
	EC	TN=1.30EC+6.34	0.35	<0.001	4.52
AN ($g\ kg^{-1}$)	SG	AN=172.44SG-169.91	0.26	<0.001	2.44
	EC	AN=1.02EC-2.42	0.85	<0.001	1.08
TK ($g\ kg^{-1}$)	SG	TK=126.38 SG-123.46	0.28	<0.001	1.66
	EC	TK=0.63EC+0.08	0.68	<0.001	1.14
VS ($g\ kg^{-1}$)	SG	VS=0.20SG+8.83	0.91	<0.001	2.02
	EC	VS=1.55EC+8.65	0.34	<0.001	5.53
Cu ($g\ kg^{-1}$)	SG	Cu=383.14SG-380.11	0.68	<0.001	2.31
	EC	Cu=0.79EC+2.38	0.26	<0.001	3.44
Fe ($g\ kg^{-1}$)	SG	Fe=25.65SG-25.55	0.71	<0.001	0.14
	EC	Fe=0.06EC+0.02	0.33	<0.001	0.21
Zn ($g\ kg^{-1}$)	SG	Zn=3026.00SG-3007.50	0.66	<0.001	18.33
	EC	Zn=5.14EC+21.34	0.17	<0.001	28.70
Mg ($g\ kg^{-1}$)	SG	Mg=163.09SG-161.74	0.77	<0.001	0.75
	EC	Mg=0.35EC+1.01	0.31	<0.001	1.30
Na ($g\ kg^{-1}$)	SG	Na=9.58SG-9.17	0.16	<0.001	0.18
	EC	Na=0.06EC+0.11	0.62	<0.001	0.12

Note: RMSE is root mean squared error. The concentrations are on a fresh weight basis.

Copper, Iron, Zinc and Magnesium

Simple linear regressions all show that their best regressions are with SG, with R^2 values of 0.68, 0.71, 0.66 and 0.77 respectively.

From the studies of different sampling procedures, it had been shown that the natural settlement also had effective impact on Cu, Fe, Zn and Mg concentrations. This may indicate that the majority of Cu, Fe, Zn and Mg in layer manure do not exist in ionic form. Thus the high density values of these non-mobile metals concentrations may significantly contribute to SG property of manure. Therefore, it seemed reasonable that Cu, Fe, Zn and Mg concentrations are related to SG.

Sodium Correlations

The simple linear regressions show that the regressions between Na and SG, EC are all significant (p<0.001). The best regression is with EC, with R^2 value of 0.62. The second best regression is with SG with R^2 value of 0.16. Therefore, the simple linear regression between Na and EC is chosen.

The result is consistent with the studies of different sampling procedures where it is shown that the natural settlement has no effective impact on Na concentration. It indicates that the main existent form of Na is ionic. Therefore, it is expected that Na concentration is related to EC.

At the present, there are limited studies on the mechanism of the rapid prediction method of the nutrient value of animal slurry by EC and SG. Japenga & Harmsen [23] have studied the element composition of animal slurry. The result indicated that the cations of the manure liquid fraction were composed of Na^+, NH_4^+ and K^+. The element compositions of the manure solid fraction were composed of Cu, Fe, Zn, Mg, P and N. The ionic composition of the slurry sample determined the EC of the sample. The manure solid fraction determined the SG of the sample. Therefore, EC has a good relationship with TK, AN and Na. SG has good relationship with Cu, Fe, Zn, Mg, TP and TN.

Summary and Conclusions

Data in this study show that representative manure samples for TP, TN, VS, Cu, Fe, Zn, Mg and AN could be obtained with procedure 1 (vertically stirred) and procedure 2 (bottom stirred). There are no significant differences for TK and Na between the three procedures utilized in this study. Therefore, representative samples for TK and Na can be obtained using each of the three procedures.

SG is well correlated with TP and TN in layer manure (R^2=0.80, 0.90). Linear correlations also are observed between SG and VS, Cu, Fe, Zn, Mg concentrations (R^2=0.91, 0.68, 0.71, 0.66, 0.77, respectively). Relationships between EC and Na, AN, TK are significant with R^2 values of 0.62, 0.85 and 0.68.

Hydrometer and conductivity meter are simple, robust and easy to use for the farmers. Although this technology should not completely replace standard laboratory analyses and is only part of the solution to increase nutrient utilization efficiency, these methods can assist farmers in making application adjustments and thus minimize concentration losses to the environment.

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