On-Farm Quick Tests for Estimating Nitrogen in Dairy Manure[1]

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ABSTRACT

Manure nutrient analyses performed rapidly on the farm could be useful for nutrient management programs. The objective of this experiment was to evaluate six quick tests for their accuracy in estimating total manure N or NH_4^+-N. The quick tests included the hydrometer, electrical conductivity meter and pen, reflectometer, Agros N Meter, and Quantofix-N-Volumeter. The hydrometer was used to estimate total N, while the remaining tests were used to estimate NH_4^+-N. Samples (107) were collected from dairy farms in five northeastern states. Samples were analyzed for total N and NH_4^+-N by traditional laboratory methods and using each of the quick tests. Manure compositions ranged from 1.4 to 38.6% dry matter (DM), 0.9 to 9.5 kg/m^3 total N, and 0.3 to 4.7 kg/m^3 NH_4^+-N. The estimated concentration of total N or NH_4^+-N determined by each quick test was regressed against laboratory-determined values. The hydrometer did not estimate total N accurately. The strongest relationship for estimation of NH_4^+-N was with the Quantofix-N-Volumeter followed by the Agros N Meter, the reflectometer, and the electrical conductivity meter and pen. When the samples were split into high (>12%) and low (≤12%) DM groups, in all cases the r^2 for the regression equation was higher for the low DM group than for the high DM group. The Agros N Meter, the reflectometer, and the conductivity meter and pen did not perform well for the high DM group. These data indicate that several quick tests are viable options for measuring NH_4^+-N concentrations in dairy slurries and solids.
(**Key words:** manure, nitrogen, dairy)

INTRODUCTION

In the early part of this century, manure was valued as a nutrient-rich substrate that could be used to improve crop yield. With the advent of mineral fertilizers, manure was treated as a waste product that required disposal. This change arose primarily because mineral fertilizers were much more predictable in their ability to deliver nutrients and were easier to transport. As a result of increasing concern for the possible deleterious effects of excess nutrients on the environment, the nutrients in manure are once again receiving considerable attention.

Manure contains both organic and inorganic N. In cattle, typically 40 to 50% of the total N excreted is via the urine as urea (21, 22, 25), and because ureases are ubiquitous, urea is rapidly degraded to NH_4^+ after excretion (21). Nitrates are only present in trace amounts of freshly excreted manure, and only accumulate in aerobically stored or treated manure (21). Aerobic storage is not a common strategy in the northeast.

Inorganic N is readily available for plant uptake. Therefore, an accurate estimate of the amount of inorganic N being applied to cropland is beneficial for determining the immediate fertilizer value of manure. Organic N must first be mineralized (converted to inorganic N) before plants can utilize it. This microbial process takes a long time, and estimates of both the organic and inorganic N content are needed to determine immediate and residual effects of manure application.

Many producers are (or will be) required to develop nutrient management plans that track the balance of nutrients (primarily N and P) on their farms and to limit nutrient applications that are in excess of crop requirements. An important element of a successful nutrient management program is an accurate, timely estimate of manure nutrients. Nutrient estimates have traditionally been obtained from published book values or by sending manure samples to government or private testing labs for analysis.

Manure nutrient concentrations can vary substantially and are affected by: species, age, nutrition, production and diet of the animal, amount and type of bedding, and manure storage practices (7, 22, 24, 25). Therefore, the use of book values to estimate nutrient concentration can be highly inaccurate. Although the results from standard laboratory analysis are usually accurate, it often takes several weeks before the producer has the results. This may be too late to adjust application location and

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rates, especially if the sample is taken from a mixed slurry storage pit.

Several tests are available that can be used to rapidly estimate the nutrient (primarily N, but also P) content of manures. Most of these 'quick tests' are portable, simple to use, relatively inexpensive, and take 10 min or less to run. Available quick tests include the hydrometer, conductivity meter, conductivity pen, reflectometer, Agros N Meter, and the Quantofix-N-Volumeter.

A detailed description of what each quick test measures, purchase and operation costs, required analysis time, and how each quick test works have been described previously (23). Briefly, the hydrometer is operated on the basis of two established linear relationships between specific gravity and DM, and between total N or total P contents and DM. The combination of these relationships gives a linear relationship between both total N and total P and the specific gravity of slurries, a property that can be measured with a hydrometer (18, 19).

Electrical conductivity is a measure of the flow of electrons due to the cations and anions of a solution (10) and has been used to estimate the NH_4^+ concentration of animal slurries (2, 4, 6, 14, 26). Traditional conductivity meters are similar in structure to pH meters in that they have a base structure (meter) and an attached probe. Conductivity 'pens' are also available that house the probe and electronics in a single, small unit that is very portable.

Ammonium can be quantified colorimetrically (27), and test strips are available that can be used to estimate NH_4^+ concentrations by the colorimetric reactions between Nessler's reagent and NH_4^+. The color intensity on the exposed test strip is quantified by a small, handheld, reflectometer. The reflectometer is internally calibrated to convert the color intensity to NH_4^+-N concentration. Reflectometers have previously been used to measure NH_4^+ concentrations in animal slurries (2, 26).

When NH_4^+ is mixed with hypochlorite, the NH_4^+ is oxidized, and N_2 gas is produced. The Agros N Meter (also called the Nova Meter) and the Quantofix-N-Volumeter both operate on this principle. The Agros N Meter has been tested and used in the United States (3, 16), as well as in Europe (2, 8, 11, 26), whereas the Quantofix-N-Volumeter has been used mostly in Europe (2, 9, 20, 26).

In the case of the Agros N Meter, slurry is mixed with a powdered reagent containing $Ca(ClO)_2$, $CaCl_2$, and $Ca(OH)_2$ in a sealed chamber and the resulting N_2 gas produced is measured with a pressure gauge that is calibrated to read in kilograms of available N per cubic meter of slurry. The reagent used with the Quantofix-N-Volumeter is a liquid mixture of NaClO and NaOH. The meter is made of a reaction chamber that is attached to a water-filled base. The N_2 gas generated from the reaction of the reagent and the manure displaces water in a cylinder that is calibrated to read in kilograms of NH_4^+-N per cubic meter.

Each of these quick tests has been evaluated with manure from several farm species (dairy, beef, swine, and poultry); however, there are no comparisons of all the tests on dairy manures typical of the Northeastern United States. The objective of this study was to evaluate six quick tests for their ability to accurately estimate the N content of a wide variety of dairy manures.

MATERIALS AND METHODS

Samples

Manure samples (N = 107) were collected from dairy farms in five states (Maryland, Pennsylvania, Virginia, New York, and Connecticut) over a 2 mo period in the fall of 1998. Samples were obtained from manure storage facilities. When possible, samples were representative. For example, in some instances producers were in the process of emptying their storage pit or tank and the manure was well mixed prior to sampling. However, in many cases, the manure had not been mixed for several months, and a representative sample could not be obtained. Approximately 9 to 10 L of manure was collected for each sample, and samples were kept as cool as possible after collection. Upon arrival at the lab, samples were mixed, subsampled into smaller containers, and stored at 4°C.

Laboratory Analysis

An aliquot of each sample was sent to the University of Maryland Soil Testing Laboratory (College Park) for a standard manure nutrient analysis. Dry matter content was determined at 70°C to a constant weight, and NH_4^+-N was analyzed by distillation of a fresh sample (1). Samples from the DM analysis were used to determine organic N (assumes NH_4^+ volatilized during drying) by combustion using a Leco CHN 600 analyzer (Leco Corporation, St. Joseph, MI). Analyses of P and K were done by perchloric/nitric acid digestion (13). Total N was determined by summing NH_4^+-N and organic N.

Quick Test Analysis

Quick test analyses were conducted in triplicate on groups of samples as soon as possible after collection (typically within 1 wk). Manufacturer directions were followed closely, and for consistency, each quick test was run by the same person throughout the experiment.

The hydrometer was purchased from the Whatcom County Manure Management Committee (Lynden, WA). It was precalibrated to read in units of lbs/1000 gal and

Table 1. Nutrient composition and pH of collected dairy manure samples.

Nutrient	All manures[1]				Low DM (≤ 12%) manures[2]				High DM (> 12%) manures[3]			
	Mean	SD	Min	Max	Mean	SD	Min	Max	Mean	SD	Min	Max
DM (%)	11.4	5.6	1.4	38.6	8.0	3.0	1.4	12.0	16.4	4.7	12.3	38.6
Total N (kg/m^3)	4.5	1.6	0.9	9.5	3.6	1.2	0.9	6.4	5.8	1.2	3.0	9.5
NH_4^+-N (kg/m^3)	1.8	0.8	0.3	4.7	1.5	0.7	0.3	3.6	2.2	0.9	0.4	4.7
P (kg/m^3)	0.9	0.5	0.2	3.8	0.8	0.5	0.2	3.8	1.1	0.3	0.5	2.1
K (kg/m^3)	2.9	1.1	0.5	5.3	2.4	0.8	0.5	5.2	3.7	0.9	1.7	5.3
pH	7.1	0.4	6.1	8.0	7.1	0.4	6.1	8.0	7.1	0.4	6.3	7.7

[1]n = 107.

[2]n = 64.

[3]n = 43.

converted to kg/m^3. This hydrometer was calibrated for use with slurries from liquid manure handling systems, but it would not float freely (a requirement for proper function) in most of the samples studied here. Therefore, each sample was diluted with adequate tap water for the hydrometer to float freely in the mixture. Dilutions (0 to 7-fold) were carried out in a graduated cylinder, and samples were mixed by inverting the cylinder 10 times. The hydrometer was placed in the manure and water mixture immediately following mixing, and a reading was taken within 30 s.

The conductivity meter (Fisher Scientific Pittsburgh, PA) and pen (Cole-Parmer Instrument Co. Vernon Hills, IL) were both purchased from general laboratory supply companies. The instruments were calibrated daily with standard solutions of known electrical conductivities. All samples required dilution (5- to 45-fold) to bring them within the operating ranges of the meter and pen (approximately 0 to 2000 μS cm^{-1}). After dilution, the pen or probe was inserted directly into the sample, and mixed gently. The conductivity was recorded as soon as the reading was stable (typically less than 30 s).

The reflectometer and test strips used in this study were manufactured by Merck (Darmstadt, Germany) and purchased from EM Science (Gibbstown, NJ). The reflectometer can be used to analyze several compounds, but for this study it was calibrated for NH_4^+-N analysis with a barcode calibration strip (supplied with the test strips). The samples required dilution (5 to 45-fold) to bring them within the operating range of the instrument and test strips (20 to 180 mg NH_4^+-N/L).

The Agros N Meter was purchased from Farm Home Offices (Vinton, IA). This company has since been purchased by The Sylvette Corporation (Edina, MN). The meter consists of a black polyvinyl chloride tube that is sealed at one end, has a screw cap on the other end, and an attached pressure gauge. To operate this meter, manure and water were added to the chamber, a cup containing reagent was placed in the chamber, the chamber was sealed and mixed, and NH_4^+-N concentration was read from the pressure gauge. Preliminary work demonstrated that the reaction was complete after 5 min; therefore, the chamber was mixed for 5 min and the reading was recorded.

The Quantofix-N-Volumeter was developed by German researchers (9) for measurement of NH_4^+-N in sewage sludge and manure. The meter used in this study was purchased from BMS Marketing (Letterson, Pembrokeshire, United Kingdom). The reagent was prepared as directed, by mixing 30% NaOH and NaClO (33.3:66.7). To initiate the reaction, reagent (150 ml) was mixed with a 2 to 1 mixture of water and manure. The mixture was allowed to stand for 1 min, mixed again, allowed to stand for 2 min, and a reading of NH_4^+-N was taken from the water cylinder. Care was taken that a tight seal was obtained and that the water level never descended. If this occurred, the test was repeated.

Statistical Analysis

Quick test estimations of N or NH_4^+-N were regressed against laboratory-determined estimates using SigmaPlot. Based on residual plots and thorough examination of the individual quick test data sets, several outliers were removed (see Tables 2, 3, and 4 below) from the analysis. Typically, outliers had residuals that were more than twice as far from zero as the remaining points in the data set. In several cases, it was clear that samples were outliers due to inaccurate laboratory analyses (e.g., residuals were high for all quick tests).

All quick tests, other than the conductivity meter and pen, were pre-calibrated in units of measurement for either total N or NH_4^+-N. In the case of the conductivity meter and pen, measurements were made in units of conductivity (μS cm^{-1}). The jackknife regression procedure of SAS (12) was used to determine one-out NH_4^+-N estimation equations from the conductivity measurements and laboratory measurements. For each observation, NH_4^+-N was estimated using these equations. This estimated NH_4^+-N was then regressed on laboratory

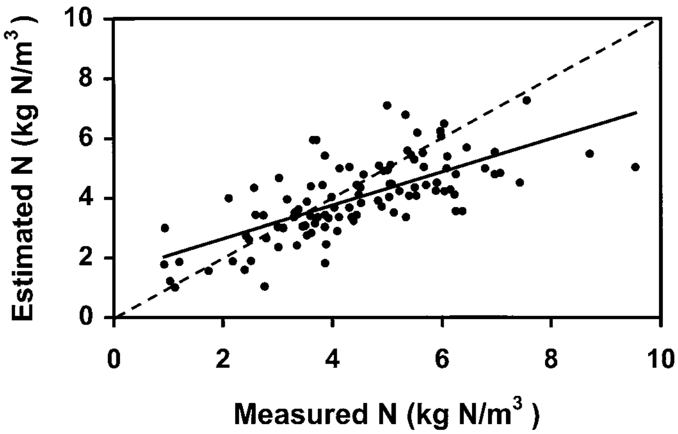

Figure 1. Total N concentrations in dairy manure samples estimated with a hydrometer versus standard laboratory methods (n = 105). The dashed line represents a line with slope = 1 and intercept = 0. The solid line represents the regression equation ($\hat{y} = 1.52 + 0.56x$).

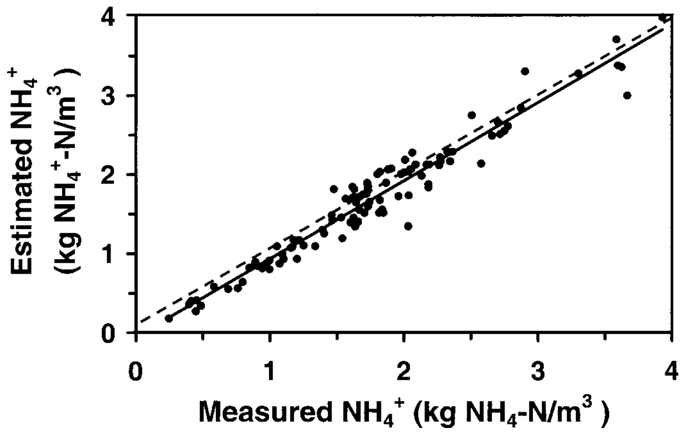

Figure 2. Ammonium N concentrations in dairy manure samples estimated with the Quantofix-N-Volumeter versus standard laboratory methods (n = 104). The dashed line represents a line with slope = 1 and intercept = 0. The solid line represents the regression equation ($\hat{y} = -0.05 + 0.98x$).

NH_4^+-N using PROC GLM of SAS to determine the comprehensive estimation equation for NH_4^+-N.

Some of the quick tests were clearly designed for slurries rather than solids. Therefore, the samples were divided into two groups based on DM to determine whether the accuracy of the quick tests was different for slurries and solids. The samples were split into two groups with 12% DM as the cut-off.

RESULTS AND DISCUSSION

The collected manure samples represented a wide range of nutrient concentrations (Table 1). This further demonstrates the need to test individual samples rather than using book values to determine the nutrient contents. The manure samples were also very different in consistency and content. For example, some were relatively homogeneous, while others contained straw, sand, sawdust, or chunks of feed material such as corncobs and stalks. This variation in the manures provided a very suitable sample set with which to challenge and evaluate the quick tests.

Total N with the hydrometer method gave a linear relationship with total N by standard laboratory procedures (Figure 1). However, the coefficient of determination (r^2) of the equation describing this relationship was only 0.48 (Table 2). Total N was underestimated at values higher than approximately 3.5 kg/m^3, and overestimated at lower N concentrations. The relationship between the hydrometer readings and the organic N in the manures was similarly weak ($r^2 = 0.44$; data not shown).

Hydrometers can only be used with liquids, and most of the manure samples required dilution before a measurement could be made. When the samples were split

Table 2. Parameters and statistics for the regression equations that describe the relationships between quick test analysis of manures and standard laboratory analysis.[1]

Quick test	Nutrient	n^2	Intercept[3]	$SE_{intercept}$	Slope[4]	SE_{slope}	r^2
Hydrometer	Total N	105	1.52***	0.27	0.56***	0.06	0.48
Quantofix-N-volumeter	NH_4^+-N	104	−0.05	0.05	0.98	0.02	0.95
Agros N meter	NH^{4+}-N	104	0.23*	0.09	0.99	0.05	0.81
Reflectometer	NH_4^+-N	104	0.34***	0.05	0.84***	0.03	0.91
Conductivity meter	NH_4^+-N	103	0.20*	0.06	0.89***	0.03	0.89
Conductivity pen	NH_4^+-N	103	0.22**	0.06	0.87***	0.03	0.87

[1]All regressions were significant ($P < 0.001$).

[2]The initial sample set contained 107 samples. Outliers were removed based on residual plots.

[3]Superscripts indicate if intercepts were different from 0.

[4]Superscripts indicate if slopes were different from 1.

*$P < 0.05$.

**$P < 0.01$.

***$P < 0.001$.

Table 3. Parameters and statistics for the regression equations that describe the relationships between quick test analysis of the low DM (≤ 12%) manures and standard laboratory analysis.[1]

Quick test	Nutrient	n[2]	Intercept[3]	$SE_{intercept}$	Slope[4]	SE_{slope}	r^2
Hydrometer	Total N	64	1.28***	0.34	0.58***	0.09	0.39
Quantofix-N-volumeter	NH_4^+-N	62	–0.16***	0.04	1.08**	0.03	0.97
Agros N meter	NH_4^+-N	60	0.07	0.06	1.02	0.04	0.92
Reflectometer	NH_4^+-N	61	0.18**	0.05	0.93†	0.03	0.92
Conductivity meter	NH_4^+-N	61	0.16*	0.07	0.89*	0.04	0.89
Conductivity pen	NH_4^+-N	61	0.17*	0.07	0.89***	0.04	0.88

[1]All regressions were significant ($P < 0.001$).

[2]The initial sample set contained 64 samples. Outliers were removed based on residual plots.

[3]Superscripts indicate if intercepts were different from 0.

[4]Superscripts indicate if slopes were different from 1.

†$P < 0.10$.

*$P < 0.05$.

**$P < 0.01$.

***$P < 0.001$.

into high (>12%) and low (≤12%) DM groups, the hydrometer estimated the total N concentration in both groups with less accuracy than when the sample sets were combined (Tables 3 and 4). In fact, the relationship between total N as determined by conventional laboratory methods and the hydrometer for the high DM group was not significant ($P = 0.96$) (Table 4).

Previous results for using the hydrometer to estimate total N in cattle and pig manure were mixed, but generally positive (3, 8, 11, 15). Chescheir et al. (3) reported a relatively strong ($r^2 = 0.69$) relationship between specific gravity (as determined by a hydrometer) and total N in dairy slurries. Sullivan et al. (15) demonstrated similar results for the relationship between percent total solids (as determined by a hydrometer) and total N in 37 dairy lagoon slurries ($r^2 = 0.72$). This latter study used slurries that ranged from 0.5 to 10% total solids, a sample set that was more uniform than the samples used in this study. Typically a stronger prediction equation can be developed from a less diverse sample set, but that type of equation is only useful when the samples being tested are similar to those used for calibration development.

The remaining five quick tests were all designed for estimating NH_4^+-N concentrations. The relationship between NH_4^+-N determined with the Quantofix-N-Volumeter and laboratory distillation was strong ($r^2 = 0.95$; Figure 2, Table 2), and the intercept was not significantly different ($P > 0.05$) from 0. When the samples were split into high and low DM groups (Tables 3 and 4), the slope and coefficient of determination of the estimation equation increased slightly for the low DM group (1.08 and 0.97, respectively) and decreased slightly for the high DM group (0.96 and 0.92, respectively).

Based on these results, the NH_4^+-N concentration of both solid and liquid dairy manures can be accurately estimated with the Quantofix-N-Volumeter. Previous work demonstrated similar results for dairy slurries (2, 26) as well as slurries from other species (2, 20, 26).

Table 4. Parameters and statistics for the regression equations that describe the relationships between quick test analysis of the high DM (> 12%) manures and standard laboratory analysis.[1]

Quick test	Nutrient	n[2]	Intercept[3]	$SE_{intercept}$	Slope[4]	SE_{slope}	r^2
Hydrometer	Total N	43	. . .	. . .	. . .	. . .	. . .
Quantofix-N-volume	NH_4^+-N	42	–0.06	0.10	0.96	0.04	0.92
Agros N meter	NH_4^+-N	41	0.86***	0.19	0.80*	0.08	0.69
Reflectometer	NH_4^+-N	42	0.60***	0.10	0.73***	0.04	0.87
Conductivity meter	NH_4^+-N	42	0.29*	0.13	0.87*	0.06	0.86
Conductivity pen	NH_4^+-N	42	0.35*	0.14	0.84**	0.06	0.83

[1]The regression for the hydrometer was not significant ($P = 0.96$). All other regressions were significant ($P < 0.001$).

[2]The initial sample set contained 43 samples. Outliers were removed based on residual plots.

[3]Superscripts indicate if intercepts were different from 0.

[4]Superscripts indicate if slopes were different from 1.

*$P < 0.05$.

**$P < 0.01$.

***$P < 0.001$.

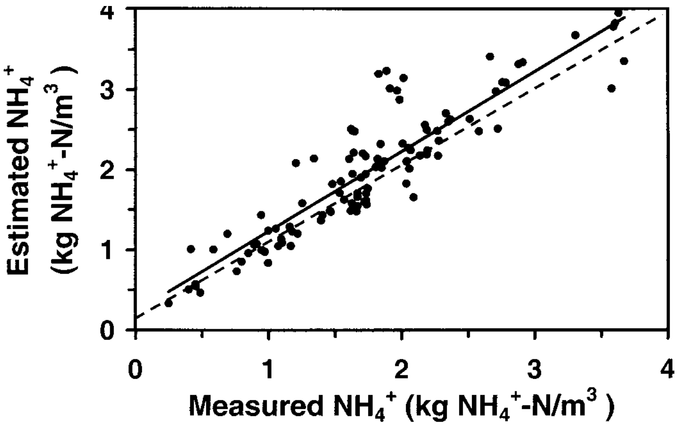

Figure 3. Ammonium N concentrations in dairy manure samples estimated with the Agros N Meter versus standard laboratory methods (n = 104). The dashed line represents a line with slope = 1 and intercept = 0. The solid line represents the regression equation ($\hat{y}$ = 0.23 + 0.99x).

However, studies with solid dairy, beef, swine, and poultry manures from farms across England and Wales showed little or no relationship between NH_4^+-N determined with the Quantofix-N-Volumeter and standard laboratory methods (2, 26).

The basis for operation of the Agros N Meter is similar to that of the Quantofix-N-Volumeter, and there was also a strong relationship (r^2 = 0.81) between laboratory NH_4^+-N results and the Agros N Meter results (Figure 3, Table 2). The slope was not significantly different (P > 0.05) from unity (0.99); however, there was a consistent overestimation (negative bias) of 0.23 kg NH_4^+-N/m^3. Evidence indicates that the reagents of the Quantofix-N-Volumeter and the Agros N Meter also react with some readily available organic forms of N, which can explain the overestimation of NH_4^+-N (3, 17, 23). The inclusion of this organic N would have some added, although unquantified, benefit when using the data to estimate the amount of N that is readily available for plants. If desired, the bias is easily corrected by subtracting the value from any estimated value.

When the samples were split with respect to DM, the regression equation for the low DM group (Table 3) had a higher coefficient of determination (0.92) and a similar slope (1.02; P > 0.05) as the combined sample set, and an intercept that was not significantly different (P > 0.05) from 0 (0.07). However, the regression for the high DM group (Table 4) had a smaller coefficient of determination (r^2 = 0.69), more bias (–0.86; intercept ≤ 0; P < 0.001), and a smaller slope (0.80; slope ≤ 1; P < 0.05) than the combined sample set. Based on the bias and the slope for the high DM group, it would be difficult to develop correction factors that would improve this estimation, and it appears that the Agros N Meter is more suited for slurries than for solid manures. Results from studies in Canada (5, 6), Great Britain (2, 26), and Italy (11) similarly demonstrated strong regressions for dairy, beef, poultry, and swine slurries, and essentially found no relationship for solid manures.

The Agros reagent is a dry powder and, even though extra water is added to the mixture for drier samples, complete mixing may not be achieved between the reagent and the sample. The reagent used with the Quantofix-N-Volumeter is liquid and, therefore, would not pose this problem. This difference may account for some of the difficulties in measuring the NH_4^+-N content of dry samples with the Agros N Meter. Chambers (2) determined that a reasonable calibration equation (r^2 = 0.82) may be obtained by extracting the NH_4^+ from solid manures with water, and subsequently determining the NH_4^+-N concentration with the Quantofix or Agros meters. Based on the data from this study, extraction is not necessary for dairy manures from the Northeastern United States if the Quantofix meter is used, but may be necessary for the Agros meter. This would reduce the ease of use for this test.

Regression analysis showed that a strong linear relationship existed (r^2 = 0.91) between the laboratory NH_4^+-N results and the estimations made with the reflectometer; however, the slope of this line (0.84) was significantly different (P < 0.001) from 1 (Figure 4, Table 2). Therefore, the reflectometer tended to underestimate NH_4^+-N at concentrations higher than approximately 2.1 kg of NH_4^+-N/m^3 and overestimate NH_4^+-N at concentrations below this value. The slope of the regression equation was closer to unity (0.93 vs. 0.84) for the group of low DM samples, but there appeared to be little difference

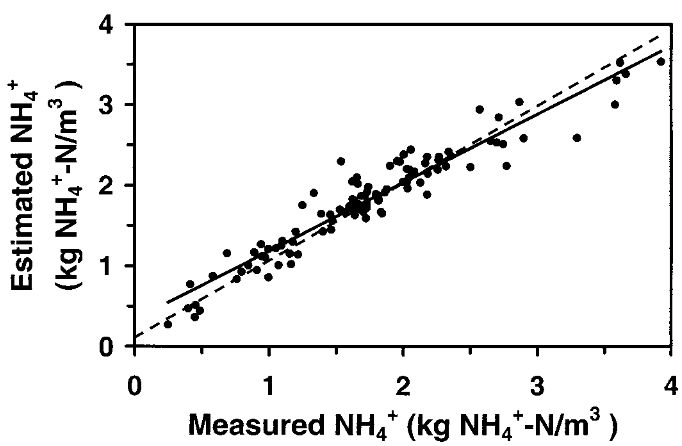

Figure 4. Ammonium N concentrations in dairy manure samples estimated with the reflectometer versus standard laboratory methods (n = 104). The dashed line represents a line with slope = 1 and intercept = 0. The solid line represents the regression equation ($\hat{y}$ = 0.34 + 0.84x).

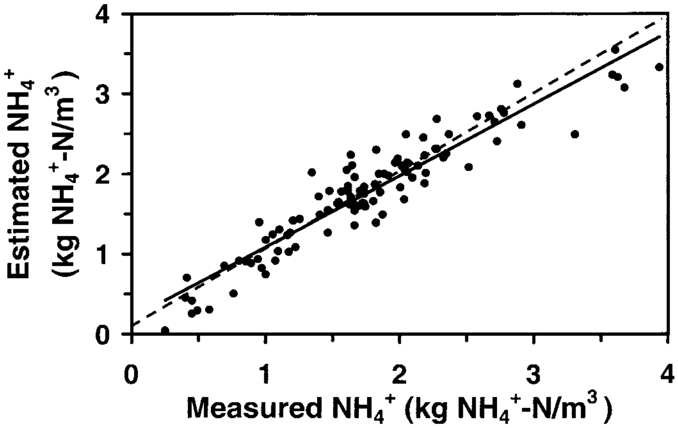

Figure 5. Ammonium N concentrations in dairy manure samples estimated with the conductivity meter versus standard laboratory methods (n = 103). The dashed line represents a line with slope = 1 and intercept = 0. The solid line represents the regression equation ($\hat{y}$ = 0.20 + 0.89x).

between the coefficient of determinations (Table 3). The reflectometer did not perform well in estimating the NH_4^+-N concentrations in solid samples (Table 4). Although the coefficient of determination was relatively high (0.87), the slope (0.73) was significantly less ($P <$ 0.001) than unity and the intercept was large (0.60 kg N/m^3).

The conductivity meter and pen behaved similarly in their ability to estimate NH_4^+-N concentrations in dairy manures (Figures 5 and 6; Tables 2, 3, and 4). Although not as strong as the Quantofix and Agros meters, there was generally good agreement between the laboratory NH_4^+-N determinations and the estimates made with the conductivity meter (r^2 = 0.89) and pen (r^2 = 0.87). Both methods tended to slightly underestimate NH_4^+-N at high concentrations (>1.8 kg NH_4^+-N/m^3) and overestimated NH_4^+-N at low concentrations (<1.8 kg NH_4^+-N/m^3). There was little difference in the performance of the conductivity meter and pen when comparing the low DM group (Table 3) with the high DM group (Table 4), although there was a tendency for less bias in the low DM group.

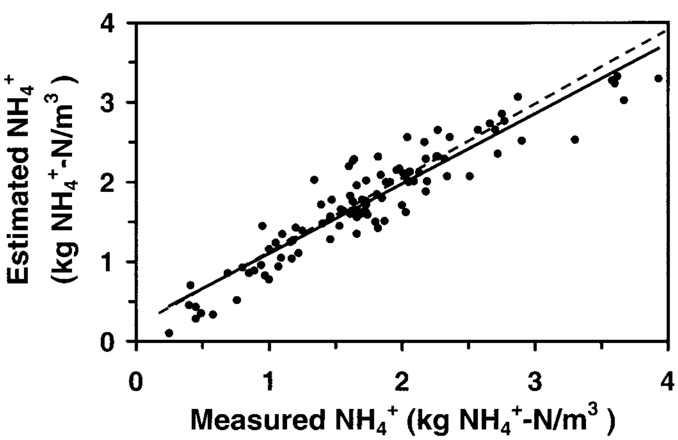

Figure 6. Ammonium N concentrations in dairy manure samples estimated with the conductivity pen versus standard laboratory methods (n = 103). The dashed line represents a line with slope = 1 and intercept = 0. The solid line represents the regression equation ($\hat{y}$ = 0.22 + 0.87x).

Based on these results, both the conductivity pen and meter are suitable for estimating NH_4^+-N concentrations in manures. Because the pen is less expensive and less cumbersome than the meter, it would be the preferred method. Conductivity is an indirect measurement of NH_4^+ concentration and measures the flow of electrons due to all cations and anions in the solution. Therefore, large shifts in ions other than NH_4^+ (e.g., K^+, Na^+) could alter the conductivity and give a false indication of a change in NH_4^+ concentration.

Based on this experiment, several quick tests can be used to estimate NH_4^+-N concentrations in manures. For this sample set, the Quantofix-N-Volumeter was the most accurate estimator of NH_4^+-N in both liquid and solid samples; however, other tests also performed well for liquids (Agros N Meter, reflectometer, conductivity meter, and pen) and solids (conductivity meter and pen). All of the samples required dilution with water (5 to 45-fold) prior to measurement with the reflectometer or the conductivity meter and pen. This increases the complexity of analysis in an on-farm situation.

Although most liquid manure storage facilities are mixed before being emptied, mixing is rarely complete. Considerable fluctuations in nutrient concentration are possible throughout the emptying process. Similar problems exist in getting representative samples from solid manure packs. Quick tests provide a fast and accurate way to monitor these fluctuations and allow appropriate application rate adjustments. Quick tests are also useful for monitoring changes in nutrient concentrations in daily spread operations. Quick tests should not be considered as a replacement for standard laboratory analysis, but rather as a complementary tool. Quick test calibrations should initially be checked against laboratory analysis to be sure that the calibration is valid for the type of sample being used. Once the calibration is validated, the results of periodic laboratory analyses should be compared to estimates from quick test analyses.

The hydrometer is the only quick test available for measuring total N, and, although it is not extremely accurate, it may be beneficial for some applications with liquid manures. Calibration with a less variable data set may improve the ability of the hydrometer to estimate total N as indicated by the results of Sullivan et al. (15). Use of this type of calibration should be limited to samples similar to the calibration data set. Further work is needed to develop quick tests that will accurately estimate either the total N or the organic N components of manures, particularly with solids, so that medium and long term availability of manure N can be estimated.

CONCLUSIONS

An improved method for rapidly measuring total N is needed, although a hydrometer can be used for making rough estimates in slurries. Several quick tests are available for accurate estimations of NH_4^+-N concentrations in manure from dairy operations typical of the Northeastern United States. The accuracy of estimation is generally greater for slurries (DM ≤ 12%) than for solid (DM > 12%) manures. Although these tests should not completely replace standard laboratory analyses, they can be a valuable addition to a successful nutrient management program.

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