Measuring and Managing Soil pH

Summary

Nutrient usage, crop growth, and herbicide activity are all affected by the pH of the soil. For each crop, there is an optimal pH range. To adjust pH, growers apply amendments such as lime and gypsum to raise and lower pH. These rates are typically based on soil sampling and lab analysis. Within a field, there can be a wide range of pH values, with soils that are both below and above the optimal pH. Due to the cost of lime and the possible negative effects of erroneous adjustments to soil pH, many growers use site-specific technology to fine-tune applications. These technologies allow samples to be collected with GPS, and lime to be spread according to a prescription, but the variability within a field poses a challenge for using them effectively. An understanding of the nature of soil variability and the results of averaging and interpolating are needed to manage pH effectively, whether by conventional single rate application or using site-specific management.

Eric D. Lund

Veris Technologies, Inc.
601 N. Broadway
Salina, KS 67401
(lunde@veristech.com)

Soil pH is the measurement of hydrogen ion activity in the soil solution and reflects soil acidity. A pH of 7.0 is neutral, less than 7.0 is acidic, and greater than 7.0 is alkaline. The pH scale is logarithmic and as a result, each whole pH value below seven is ten times more acidic than the next higher value. For example, pH 4 is ten times more acidic than pH 5 and 100 times (10×10) more acidic than pH 6. When fields are not limed regularly, they may become acidic. Erosion, leaching, and the normal growing of crops all contribute to this trend. Nitrogen fertilizer applied to fields is a key contributor to soil acidification. The ideal pH of a soil depends on the crop being grown, but a slightly acid to neutral pH of 6.5–7.0 is considered optimal for many plants (A & L Midwest, 2008) (Table 1).

Table 1. Crop yield by pH level.

Crop	pH 4.7	pH 5.0	pH 5.7	pH 6.8	pH 7.5
Corn	34%	73%	83%	100%	85%
Soybeans	65%	79%	80%	100%	93%
Wheat	68%	76%	89%	100%	85%
Oats	77%	93%	99%	98%	100%
Barley	0%	23%	80%	95%	100%
Sweet clover	0%	2%	49%	89%	100%

As pH drops below 6.0, several primary and secondary nutrients, as well as some of the micronutrients, become less available to the plant (Kelly and Fjell, 1996) (Fig. 1). Growers often overapply fertilizer to prevent nutrient deficiencies, including deficiencies due to pH tie-up, from limiting yields. Accurately managing soil pH could lead to more efficient use of fertilizers.

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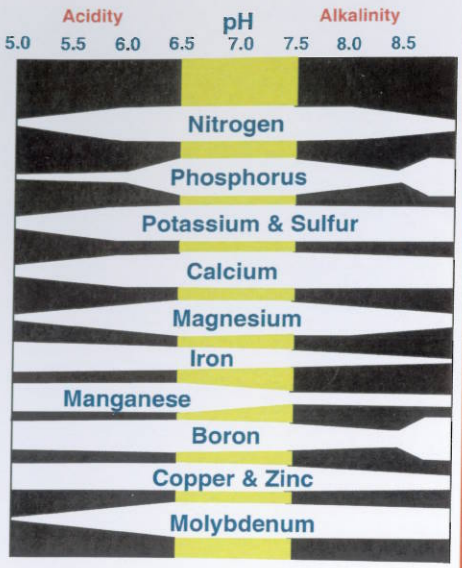
Fig. 1. Nutrient availability at various pH levels.



Herbicide degradation and activity are influenced by soil pH. For example, at low pH atrazine is degraded, further reducing its efficacy. Sulfonylurea compounds are not well broken down when pH is above 8, and may be active on susceptible plants for several years.

Properly balanced pH soils exhibit an increase in microorganism activity. All this leads to a more healthy soil condition, where yields are maximized and the potential of environmental damage is minimized.

Adjusting Soil pH

To correct low pH, growers apply lime to their fields. To reduce pH, elemental sulfur may be applied. Lime application rates depend on soil pH and on a buffer factor, which is largely dependent on soil texture and organic matter. A typical application table is presented in Table 2 (Cornell University, 1996). As is evident from the table, application rates of several tons per acre are commonly recommended.

Table 2. Rate of lime application (tons/acre) required to increase soil pH to 6.8.

Initial soil pH	Soil texture			
	Sands	Sandy loams	Loams and silt loams	Silty clay loams
	tons/ha of lime			
5.2–5.3	1.5	4.0	6.5	8.5
5.4–5.5	1.0	3.0	4.0	6.0
5.6–5.7	1.0	2.0	3.0	4.5
5.8–5.9	0.7	1.5	2.5	3.5
6.0–6.1	0.6	1.5	2.0	3.0
6.2–6.3	0.4	1.0	1.5	2.0
6.4–6.5	0.3	0.7	1.0	1.5
6.6–6.7	0.2	0.5	0.7	1.0

Determining actual crop response to lime and calculating the economic returns of correcting soil pH has proven difficult. This is due to the number of years that are required for a response to become evident, as well as the large number of other factors affecting yield during those years. A study of a corn–soybean rotation by the University of Nebraska-Lincoln found that crop response to lime varies by year and by crop (Peterson and Hilgenkamp, 2002). This study found that although in some years there was no return, the cumulative net return over a 12-year period was more than $160/acre. (Table 3).

Table 3. Crop response to lime over 12 years.

Year	Cumulative gross income†	Cumulative net income	Cumulative expense (7 year proration)‡	Soybean yield increase	Corn yield increase
				—— bu/ac ——	
1995		$(6.29)	$6.29		0
1996	$5.50	$(7.08)	$12.58	1	
1997	$13.50	$(5.37)	$18.87		4
1998	$57.50	$32.34	$25.16	8	
1999	$65.50	$34.05	$31.45		4
2000	$98.50	$60.76	$37.74	6	
2001	$102.50	$58.47	$44.03		2
2002	$141.00	$96.97	$44.03	7	
2003	$163.00	$118.97	$44.03		11
2004	$185.00	$140.97	$44.03	4	
2005	$189.00	$144.97	$44.03		2
2006	$211.00	$166.97	$44.03	4	

† Soybean prices $5.50/bu and corn prices $2.00/bu.

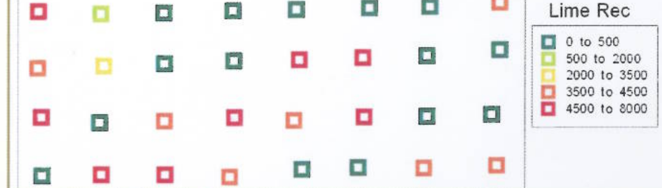
‡ Lime at 2 ton/acre prorated over 7 years.

pH Variability

Within a field, there can be a wide range of pH values, often ranging from soils that call for lime to soils that are already dangerously high in pH. Soil pH above 7.5 can result in reduced nutrient availability, and high pH soils can experience herbicide carryover, causing serious injury to subsequent crops (Martin and Green, 1989).

Figure 2 shows the soil pH and lime map of a field in Illinois where the pH ranges from 5.3 to 7.9. The average pH on this field was 6.3 with an average lime requirement of 2.75 tons/acre. An application of 2.75 tons to the acres where the pH was already high, would be waste of the grower's investment, and could cause significant harm. Yet using a uni-

Fig. 2. pH and lime range on an Illinois field.



form application, the low pH areas of the field would receive several tons less than they actually need.

While this is one example, this magnitude of variability is not uncommon. Data compiled for 1997 from Agvise Laboratories in Benson, MN show that 40% of the fields grid-sampled had soil pH values ranging over 2.0 pH units (Agvise, 2007), and 18% of these fields had pH values ranging over 2.5 pH units (Agvise, 2007).

Many factors can contribute to soil pH variability. The first and foremost of these is parent material. Glaciers, flooding rivers, weathering rocks, and erosion are just a few of the natural forces that are responsible for variability in soil pH. Agricultural management factors, such as drainage, leveling of fields, applying fertilizer, and manure, also contribute to pH variability.

Managing pH Variability

An analysis of pH is typically performed by a soil testing laboratory, but may also be performed by the grower. During lab analysis a pH electrode is inserted into a solution of soil and water (or water and dilute salt) to determine the soil pH. For grower-measured pH, two general approaches are used, qualitative and quantitative. Qualitative approaches involve the use of pH paper strips or low-cost pH sensors purchased in gardening stores. These approaches are typically inexpensive and can provide screening information in the form of a range—low, medium, or high. In quantitative approaches, the sensor reports a pH value, rather than a range. The cost of these handheld sensors ranges from $100 to more than $1000. To ensure data quality, an analysis protocol should be followed. This usually includes air-drying the sample, adding a prescribed amount of water or water containing a dilute salt, and reading the pH over a specified period of time. The protocol for effective on-farm analysis is similar to that used in a soil testing laboratory.

Current practices for managing low pH are either to base a whole field lime recommendation on a single soil sample from the field or to develop site-specific recommendations based on data collected from grids, management zones, or on-the-go measurements. The development of site-specific recommendations involves the use of GPS to record soil sample locations. All methods contain a level of uncertainty and error relative to the true pH of each area in the field. Below is a brief description of each practice, along with a few guidelines for its effective use in minimizing pH estimation errors.

Uniform Field Management

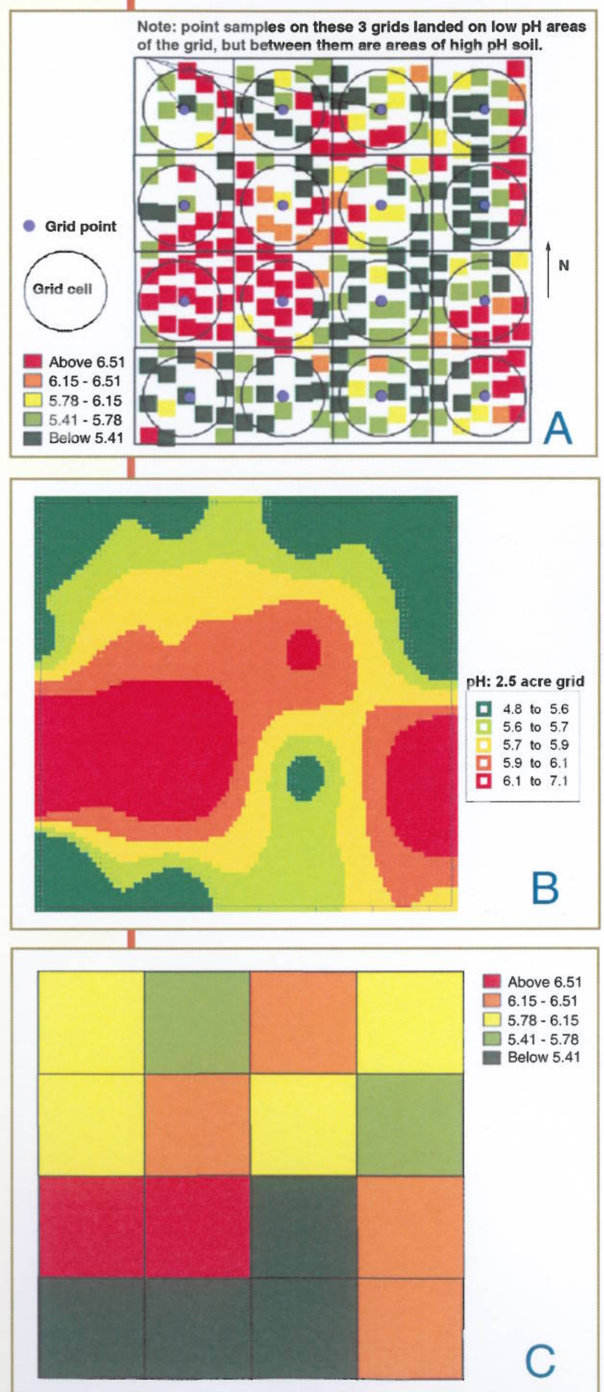
This practice involves collecting soil cores throughout the field, and compositing them into a single sample for lab analysis. A key ingredient for collecting an accurate soil sample is to collect an adequate number of soil cores. For more information, see "Reducing Soil Sampling Errors" (Clay, 2008). While applying a single rate to an entire field has been a common approach in the past, GPS allows growers and consultants to identify and manage the variability within their fields.

Grid Sampling—Grid Point and Grid Cell

A widely practiced alternative to uniform application is to sample fields on a grid pattern, typically a 2.5-acre grid. Grid sampling approaches fall into two categories: point and cell. **Grid point sampling** involves sampling at a single location within the grid, typically in a small radius (10–20 feet). To predict pH values for areas between the grid sample points, various interpolation methods are used. The predicted pH values for unsampled areas are valid only if there is a degree of spatial dependence between the sample sites. Interpolation of unrelated values can lead to erroneous assumptions. For example, if one were to estimate the elevation between Denver and Salt Lake City using interpolated elevation data from those cities, the results of flying over the Rocky Mountains would be disastrous. On a 2.5-acre grid, each sample site is located 330 feet from the next site. With a 5-acre grid spacing, the distance between samples is 466 feet. Numerous studies have shown that the range of spatial dependence for pH can be significantly shorter than these distances (McBratney and Pringle,1997), as short as 70 feet (Wollenhaupt et al., 1997). In **grid cell sampling**, soil cores are collected from throughout the entire cell, and the lab result represents the average for the cell. Figure 3a shows a 40-acre Iowa field, with 2.5-acre gridlines overlaid and 156 pH samples, along with radii representing typical grid point and grid cell sampling. As is evident from this map, many of the 2.5-acre grids have a wide range of pH variability within them. Interpolating the pH values from the samples collected at grid points would make a large error in the lime estimated for the areas between the grid points, especially in the north end of the field. The larger radius of the grid cell sampling results in a different type of error—it averages the high and low pH parts of the grid into one sample.

When maps of grid samples are generated, all gaps are filled in (Fig. 3b and 3c). For grid point sampling, the values are based on a computer algorithm that estimates a value for unsampled areas (Fig. 3b). For grid cell sampling, the map shows the

Fig. 3. (a) pH variability within 2.5-acre grids on a 40-acre Iowa field. (b) Interpolated grid point samples from map shown in Part a. (c) Composited cores from grid cell samples from map shown in Part a.



sample value from the cores collected throughout the grid cell (Fig. 3c).

This example represents a unique opportunity—most fields aren't sampled intensively enough to establish the underlying variability and verify the grid sampling results. Yet, short-range variability has been reported in several studies. An Iowa study found that pH varied as much as two pH units over a 40-foot distance (Bianchini and Mallarino, 2002). A study in Ontario concluded that a grid spacing of 96 feet or less would be required to adequately assess the spatial variation of soil pH (Lauzon et al., 2005). An Indiana study found that data from 2.5-acre grids were too far apart to provide much information about the nature of pH or lime requirement change between adjacent sampling locations (Brouder et al., 2005).

Armed with an understanding of the likely possibility of short-range variability within a field, here are some effective strategies to consider:

Strategies to Consider »

1. Determine the purpose of the sampling. For example, if the goal is to manage areas with pH < 6.0, intensify sampling in areas that are expected to have pH tests in that range.
2. Sample on a grid that is less than 2.5 acres.
3. At selected points collect additional samples halfway between the grid points.

Regardless of the approach used, recognize that grid point sampling provides helpful information on the pH values present within a field, but be cautious of interpolating the grid point data unless the underlying spatial variability is understood.

Zone Sampling

Areas within a field that appear similar, or respond to management practices in a similar way, can be termed **management zones**. Common methods of defining zones include soil surveys, soil electrical conductivity (EC) maps, topography, and crop image or yield data (Franzen and Kitchen, 1999). The theory underlying soil sampling based on management zones contains the assumption that the property of interest is relatively consistent within each zone. The concept of management zones sampling is not new. Many extension bulletins have advised sampling areas of a field based on visible differences.

With the availability of yield and soil sensor data, and GPS technology that measures elevation precisely, zones can be delineated from factors not readily apparent. Here are some issues to consider when using management zones to sample for soil pH:

1. The layer(s) used to define the zones should have a scientific rationale for having a different pH. For example, aerial imagery showing patches of yellow soybean plants could represent areas of high pH. Soil acidification is affected by soil texture, so soil EC maps and high-resolution soil surveys are logical layers (Fig. 4). Historical aerial photographs may show areas that should be sampled separately, such as old livestock pens and sub-fields with different management history.
2. While soil texture affects acidification, there is not a direct relationship between the two. In unlimed soils, the coarser textures typically exhibit lower pH, due to their weaker buffering against acidification. Yet, after blanket applications of lime, the coarser textured soils may have a higher pH, as their weaker buffering results in a more rapid pH increase from lime.
3. Be aware that management practices can change the relationship between the soil physical and chemical properties. For example, eroded clay knobs may typically have higher pH than nearby depositional loams, but if a portion of the field has been limed more frequently, that relationship may no longer hold true on that portion. In general, the longer a field has been in production, the less likely the chemical and physical properties are related. When using management zones on large fields with a long and unknown history, care should be taken in identifying the zone boundaries. Note the range of pH values within each soil type in Fig. 5.
4. Once identified, each zone should be thoroughly sampled. While it is assumed that within a zone a uniform management strategy is appropriate, it should also be recognized that there is likely a degree of pH variability within zones. Also, noncontiguous zones should be sampled separately.

Fig. 4. Soil pH overlaid on soil electrical conductivity (EC) map. Note high pH and high EC zone in center.

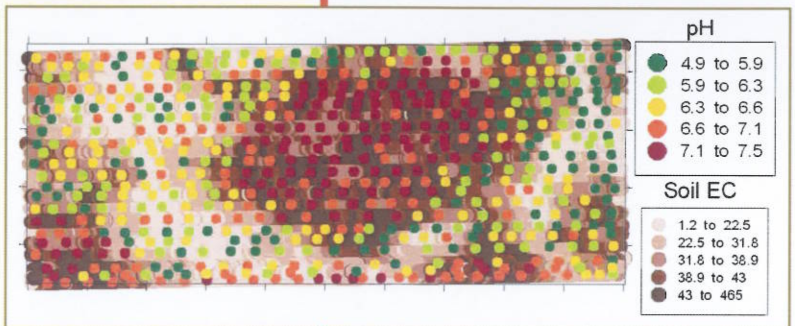


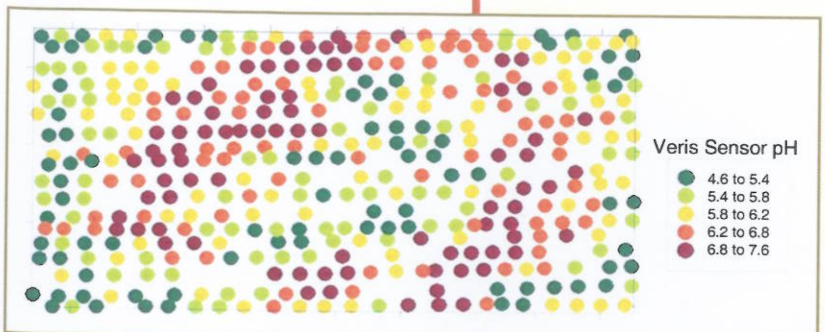
Fig. 5. Soil pH variability within USDA-NRCS soil survey map units.

Fig. 6. Veris Mobile Sensor Platform with on-the-go pH measuring.

On-the-Go pH Mapping

The recent introduction of on-the-go mapping of soil pH makes it possible to collect pH values at a much greater density than is feasible with traditional soil sampling and lab analysis. For example, the Veris Mobile Sensor Platform (MSP) shown in Fig. 6 collects a soil pH measurement approximately every 10 seconds.[1] When operated on 60-foot transects at speeds of 6 mph, eight samples per acre are measured (Fig. 7).

Fig. 7. Map of pH sensor data from an 80-acre Illinois field.



[1] Trade names are included for the benefit of the reader and do not imply endorsement of or preference for the product listed by the author or SSSA.

This system uses ion-selective pH electrodes, similar to those that analyze soil solution in a laboratory, to measure pH directly on soil extracted by the machine as it moves through the field. Field testing, including validation with more than 1000 lab-analyzed samples, was conducted on 40 fields in six states (Fig. 8). Independent research on this system has also been reported (Staggenborg et al., 2007; Adamchuk et al., 2007).

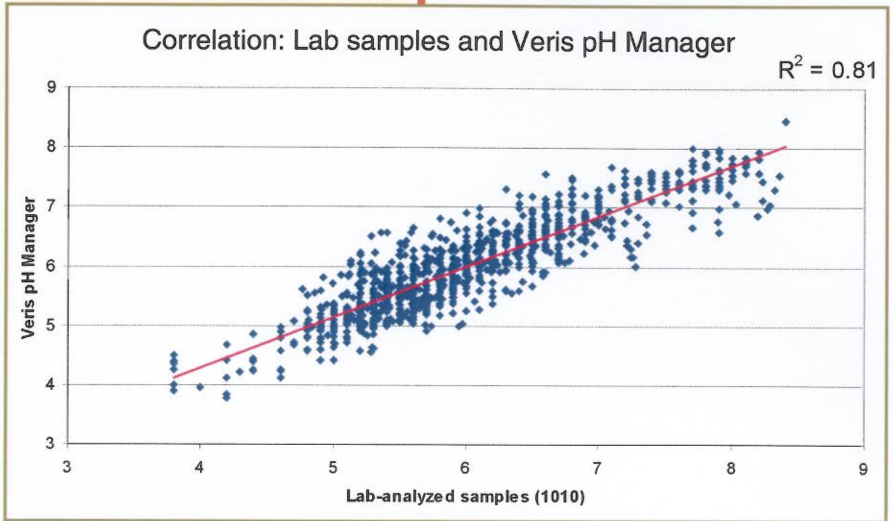


Fig. 8. Results from validation sampling for the on-the-go Veris pH Manager.

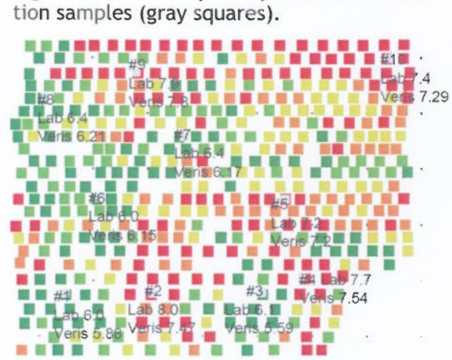
While the density of data from this system is advantageous, and thus solves many of the spatial variability issues, several constraints need to be considered:

Initial Costs. The retail price on this system is more than \$16,000. An annual coverage of at least 3000 acres is needed to justify the initial cost. Economic returns will vary with crop value, pH impact on crop production, lime costs, and other factors.

Field Operations. The attention of the operator can significantly affect the quality of the pH data. While there are several data-quality monitoring functions designed into the system, an attentive operator can help ensure data quality.

Calibration/Validation Soil Sampling. The Veris system produces a pH variability map, which shows the spatial pattern of the field pH. Follow-up sampling is required to field-calibrate the sensor pH to the lab pH. Typically, these are 5–10 samples per field, and are often part of the normal sampling for other nutrients (Fig. 9).

Fig. 9. Veris sensor pH map with lab calibration samples (gray squares).



Lime Estimation

To use pH information, it must be interpreted. For lime application, the buffering characteristics of soil must be considered. Typically, a soil-testing lab runs a pH buffer test, which functions like an extremely fast-acting lime. An equal amount of buffering solution is applied to each soil sample, and the resulting buffer pH is used to determine a lime recommendation. Soils with the same pH value may have different buffer pH results, and need different lime rates. Clay mineralogy and higher organic matter contents increase buffering capacity of soil. Since there is no commercially available on-the-go buffer test, the lime requirement for on-the-go pH data must be derived in another manner. The method recommended by Veris Technologies is to perform a regression analysis using the sensor pH, along with the lab pH and buffer pH data from the five to ten calibration samples. A program called Veris LimeCalc is available which automates this process and includes the capability of performing multivariate regression, adding soil EC as a surrogate for buffer capacity. Results of performing this analysis show that it performs well compared with 2.5-acre grid sampling and uniform lime management strategies, with an error reduction of approximately 50% (Table 4).

Table 4. Error comparison at independent sites (Lund et al., 2005)

Field ID	Number of validation samples	Root mean squared error (RMSE)			
		Uniform liming	Grid sampling	On-the-go mapping	
				pH only	pH and EC
		kg/ha			
Kansas 1	10	3550	3085	1117	797
Kansas 2	10	1930	1745	1470	1450
Nebraska 2	10	2527	2088	2701	1120
Wisconsin	10	2900	2781	1400	1444
Overall	40	2857	2506	1354	1259

Keep in mind that one of the main objectives in improving pH maps is the clear and accurate delineation of high pH areas that should not receive any lime. For this objective, the lime calibration issue is not a factor. If the pH information is intended to assist in herbicide applications, the soil pH values should be classified according to herbicide label recommendations. For example, Glean (DuPont Crop Protection, Wilmington, DE) should not be applied to areas with pH value higher than 8.

Conclusions

While site-specific pH mapping and lime applications have the potential to increase lime precision, the nature of pH and buffer pH variability within the field makes it challenging to actually achieve the expected results. Whether the management unit is a field, a grid cell, or a zone, it is essential to do a thorough job of soil sampling to minimize errors. On-the-go sampling, properly deployed, has the potential to produce pH maps at the density needed for accurately mapping pH variability. This information can be used for a variety of purposes.

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