Site-Specific Nutrient Management

For Nutrient Management Planning To Improve Crop Production, Environmental Quality, and Economic Return

Soil Sampling: Chapter 9 of 10

Written By:

Agustin Pagani, Post-Doctoral Fellow
John E. Sawyer, Professor
Antonio P. Mallarino, Professor
Department of Agronomy, Iowa State University

Developed in cooperation with:
Lara Moody, The Fertilizer Institute (TFI)
John Davis, Natural Resources Conservation Service (USDA-NRCS)
Steve Phillips, International Plant Nutrition Institute (IPNI)

Chapter 9:
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Agustin Pagani, John E. Sawyer, and Antonio P. Mallarino / Department of Agronomy, Iowa State University
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Introduction

Soil testing is one of the most useful and commonly used tools to estimate the crop availability of many nutrients. Therefore, the accuracy of a nutrient recommendation depends on how well soil samples represent a field or areas within a field. The amount of plant available nutrients can vary considerably across and within fields due to natural variation of physical and chemical characteristics of the soils and also due to variation in crop management practices that over time influence the amount of available nutrients. Natural variation arises from different soil-forming processes (such as parent material and weathering) or losses/deposition (erosion) that lead to accumulation or loss of nutrients or processes that differently affect nutrient availability. Management factors that often influence nutrient availability include tillage, crops grown, harvest system, fertilization and liming and irrigation among others. It is typically necessary to collect multiple samples from a field to accurately assess the fertility status. Recommended soil sampling procedures can vary significantly between geographic regions, for specific nutrients and specific purposes. The information provided here relates to routine testing for soil pH and immobile nutrients such as phosphorus (P) and potassium (K), but also is relevant for mobile nutrients such as nitrate nitrogen (N). Specific sampling recommendations should be followed for each nutrient and region. Sampling procedures have been published by most Land Grant universities and some regional research and extension soil testing committees. Useful considerations relevant to soil sampling for P to assess the risk of water quality impairment were prepared by the Organization to Minimize Phosphorus Losses from Agriculture (SERA-17) and published in "Soil sampling methods for phosphorus" by Mallarino, Beegle, and Joern (2007, www.sera17.ext.vt.edu) and "The importance of sampling depth when testing soils for their potential to supply phosphorus to surface runoff" by Vadas, Mallarino, and McFarland (2005, www.sera17.ext.vt.edu).

Soil Sampling Strategies

Five main factors generally should be considered when taking soil samples:

1. Sampling depth.

2. Time of year when samples are collected.

3. Number of soil cores per composite sample.

4. Number and distribution of samples across a field.

5. Sampling frequency.

The nutrient of interest, the soils present and the crop rotation can influence the specific sampling practice and importance of each of these factors. Proper consideration of each factor for each specific field or region is needed to best estimate the nutrient availability in the soil and to develop reliable nutrient application recommendations.

1. Sampling Depth

A major misconception among nutrient management planners and producers is that a soil sample should be collected from the depth where the nutrient level is higher. For example, such a criterion would result in very shallow sampling for P and K with no-till management since both nutrients are relatively immobile in the soil and tend to accumulate near the soil surface. Instead, the most important criterion to decide the appropriate sampling depth is the depth that best estimates plant sufficiency and best predicts crop response to nutrient additions or best determines the risk that nutrients are transported offsite. Sometimes the best sampling depth is the one where the nutrient accumulates, such as for nitrate, but for other less mobile nutrients that often is not the case. This is one of the main reasons the soil sampling depth is an important issue and that is specified in the calibration of soil test methods. Therefore, it is very important that soil samples used for nutrient recommendations should be taken at the same depth that is used in the research for soil-test calibration and interpretations to generate the nutrient recommendations.

For tests like pH, P, K, and many secondary and micronutrients, the depth is typically the surface 6 to 8 inches of soil. For nitrate, the sample depth may be the surface 12 inches (for tests like the Pre-Sidedress Nitrate Test, PSNT) or the rooting zone depth for profile nitrate (3 to 5 feet). For soil pH, an exception involves sampling in no-till or systems with very shallow tillage. For estimating lime requirements for no-till management or pastures, a shallower surface sample (0-2 or 0-3 inches) often is recommended because, except in sandy soils, it is too costly or impractical to apply lime to change pH of subsurface soil layers. Use of a deeper sampling depth may result in lime application rates that cause excessively high pH

of the surface soil layers which could affect, for example, herbicide activity and/or carry-over, the availability of various macro- and micro-nutrients and crop disease or pests incidence. While not typically cost effective for crop production, one could sample by depth increments (like every 2 to 3 inches) to assess the degree of nutrient stratification and better assess nutrient availability. Due to economic and practical reasons, however, soil-test interpretations and fertilization recommendations are not made from this type of soil sampling.

2. Time of Year to Sample

In northern regions with frozen or snow-covered soils, soil sampling after crop harvest in the fall, or before planting in the spring, are the most common sample timings. Sampling in the fall is most common, however, because fertilizer or manure is often applied in the fall. In regions with mild winters and more than one crop per year, the soil sampling usually is done before the most nutrient demanding or profitable crop. With the exception of pastures and sampling for N for some crops, soil sampling while crops are growing is seldom used because test results do not provide the best estimate of nutrient availability or fertilizer cannot be applied due to practical reasons. The most common in-season sampling for N is the test for soil nitrate to estimate sidedress N fertilization for corn and for N application for wheat at the tillering stage. In addition, sampling some time before planned lime, fertilizer, or manure applications allows sufficient time for the laboratory analyses to be completed and recommendations developed. Suggestions regarding soil sampling for nitrate vary considerably, so local recommendations on specific sampling and use of nitrate testing should be followed.

Because of seasonal variation in soil-test levels, soil sampling should occur at about the same time of the year each time a particular field is sampled. Also, the sampling time should be the same that was used for the soil test calibration. This is particularly important in humid or irrigated regions for the most mobile nutrients nitrate, chloride (Cl), and sulfur (S), and sometimes also for K, manganese (Mn), iron (Fe), and pH. Potassium recycling with crop residue, or grazing cattle, and the equilibrium between soil K pools of different K availability are highly affected by rainfall and alternating freezing and thawing. Although Fe and Mn are immobile nutrients in soils, changes in oxidation/reduction conditions due to moisture and chemical or microbiological processes often result in large temporal variability. Soil pH can vary significantly during the year depending on rainfall due to movement of soluble salts and microbial processes such as nitrification of ammonium fertilizers.

3. Number of Soil Cores per Composite Sample

A sufficient number of soil cores should be collected per composite sample to correctly represent the area being sampled. Recommendations about numbers of cores per sample vary considerably, mainly because of variation in small-scale nutrient variability across nutrients and fields, and range from about 8 to 20 cores per sample across regions and states. Non-uniform nutrient application, such as banding of fertilizer or manure and grazing, often creates high small-scale nutrient variability. Samples taken from a recent band can greatly overestimate the overall fertility level of a field or field area. Broadcast fertilizer or manure application also can create high small-scale nutrient variability with improper equipment use and careless spreading. The small scale variability can be very high, especially in no-till fields. Figure 1 shows an example of the soil-test variability of immobile nutrients that can be expected at various scales, which was obtained from a study of soil-test P variation in several Iowa fields with long histories of fertilizer or manure application. There was very high spatial variability at a very small scale (samples taken every 6 inches) and at a moderate scale (10-core composite samples taken at 10-foot intervals) in manured or high-testing fields. Often there was relatively high variability at moderately low soil-test levels. For example, soil-test P results from single-core samples taken at 6-inch intervals often encompassed two or three interpretation classes.

VARIATION FOR 10-CORE COMPOSITE SAMPLES

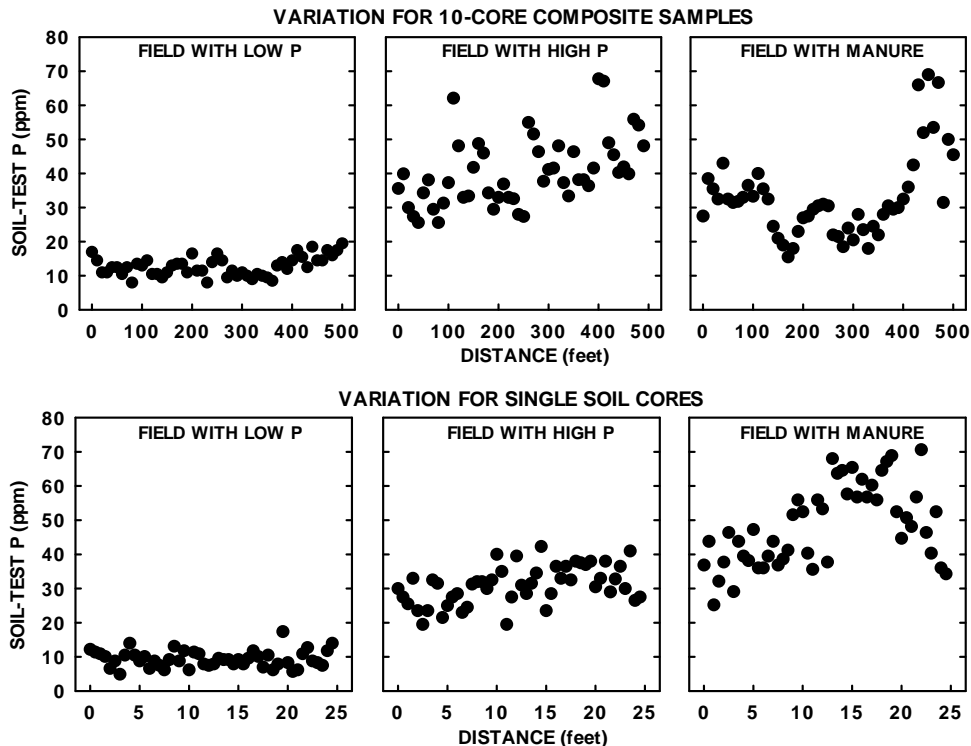**VARIATION FOR SINGLE SOIL CORES**

Figure 1. Soil-test P variation for composite or single-core soil samples taken at different scales from three typical Iowa fields. Adapted from Mallarino, A.P. 1996. Spatial variability patterns of phosphorus and potassium in no-tilled soils for two sampling scales. Soil Sci. Soc. Am. J. 60:1473-1481.

Even one or two soil cores with very high nutrient levels can significantly skew the average test result for a composite sample value, and may result in too low nutrient application rates for a major portion of the area sampled. Therefore, there is benefit from taking 15 to 20 soil cores per composite soil sample for most nutrients and most field conditions. Research has shown that the accuracy of soil-test results increase as the number of cores included in composite samples increases. The example in Fig. 2 shows that collecting 20 cores would result in a difference of 15 to 20% from the true average value for the sample area. Although the magnitude of the error varies greatly from field to field depending on the small-scale variability, the error always decreases exponentially with increasing number of cores. This exponential relationship means there is a large gain in accuracy when the numbers of cores are increased from very few cores, but a small gain when many cores are already collected.
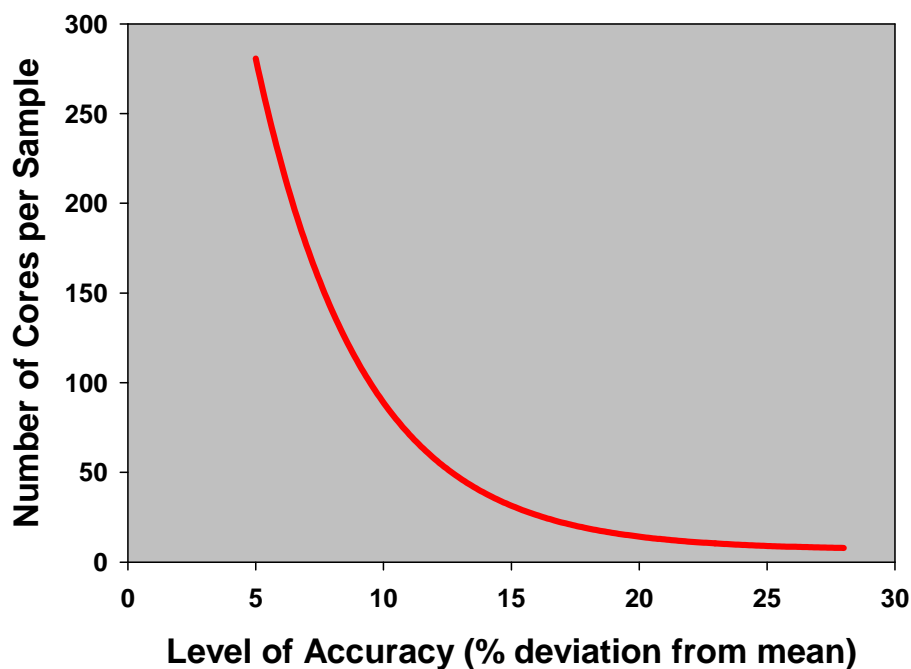
Figure 2. Number of cores required for a composite soil sample for soil-test P determination according to different accuracy levels. Adapted from Swenson, L.J., W.C. Dahnke, and D.D. Patterson. 1984. Sampling for soil testing. North Dakota State Univ., Dept. of Soil Sci., Res. Rep. No. 8.

4. Number and Distribution of Samples across a Field

The most appropriate number of samples and location distribution across a field depends on the magnitude of the variability, but should also involve consideration of cost/benefits and how the fertilizer or manure will be applied. More samples always result in better estimates of nutrient availability, but the crop response to fertilizer addition may not offset the increased sampling and testing costs. Also, a dense sampling approach cannot be economically justified when the nutrient application rate will be the same across the field no matter differences in test results. In relatively uniform fields or areas smaller than about 20 to 25 acres, a single composite sample from cores taken in a random or zigzag manner often is sufficient. Larger fields often have higher variability and are usually subdivided into smaller sampling areas. Non-uniform fields can be subdivided on the basis of obvious differences, such as slope position or soil type, or past management such as incorporating past multiple fields into one larger field. However, even small fields can be highly variable in P and K with long histories of fertilizer or manure application.

Historically, the objectives of soil sampling have been to determine the average nutrient status of a field or field areas with clearly different soil types or topography. The development and adoption of precision

agriculture technologies have revolutionized soil sampling and nutrient application, however, by allowing for better measurement and management of within-field nutrient variability. Technologies well adapted to soil sampling [such as global positioning devices (GPS) and on the go measurement of apparent electrical conductivity (EC)], estimating yield and nutrient removal with harvest (yield monitors), and nutrient application (variable-rate technology) are widely used in many regions of the U.S. Instead of focusing on an entire field, producers can now diagnose fertility levels and crop nutrient removal and manage areas within fields. Knowledge of factors influencing soil nutrient level variation, such as soil type, topography, cropping history, manure application, fertilizer application, yield levels, land leveling for irrigation, and others will help determine the most effective sampling and nutrient application approaches.

Therefore, several soil sampling methods are available, each adapted better to different nutrients and conditions, and having advantages or disadvantages. In general, there are three soil sampling approaches that are being used or can be used: The traditional sampling "by soil map unit and topography", grid sampling and zone sampling.

Sampling by soil map unit and topography

Most commonly referred to as "sampling by soil type", this is the approach most universities and soil testing laboratories have recommended for decades. The approach recognizes the impact that soil parent materials, topography, and other soil formation factors have on the level of crop available soil nutrients. Therefore, soil survey map units, which always consider soil series and often both erosion and slope phases, are used to delineate different sampling areas within fields. The approach includes separating sampling areas based on different crop, soil and nutrient management practices, and also considers the presence of old or current animal feeding locations, homesteads, or watering ponds that could result in nutrient variation. Also, the approach sometimes recommends sampling separately two or three areas of an apparently uniform soil map unit or field.

An example of this sampling approach is shown in Figure 3. This 80-acre field was originally farmed as four, 20-acre fields that were managed differently. First, identify the areas that are odd or dissimilar. Areas A and B probably have very high fertility levels. Area C would be expected to have a higher soil pH than the remaining original fields. Areas D and E would be different soils and could have vastly different soil pH, organic matter (OM), and fertility levels than the adjoining soils. Old fence lines are to be avoided. The original fields should be sampled separately, unless a previous comprehensive sampling has shown no fertility differences. Samples 1 and 2 are taken because the soils differ, sample 3 would be sufficient for the original 20-acre field, samples 4 to 6 represent three different soils, and samples 7 and 8 each represent about 10 acres of an apparently uniform area.
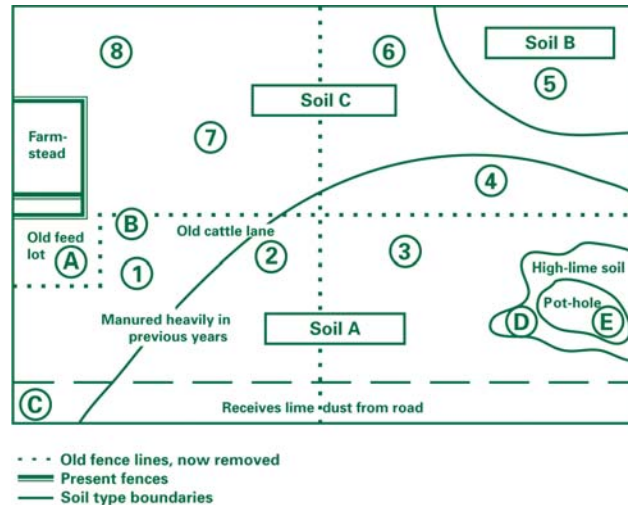
*Figure 3. Example of sampling map for an 80-acre tract, which is now farmed as one field.
Numbers designate soil sample areas and letters designate areas either
not sampled or sampled separately. Adapted from Take a Good Soil Sample to
Help Make Good Decisions, 2003, PM 287, Iowa State University.*

The main assumption supporting this "soil type" approach are that soil factors indeed result in different nutrient levels, nutrient removal, or nutrient use efficiency; and that the nutrient variation is lower within these sampling units than across units. Obviously, these assumptions may, or may not, be true for all fields. For example, differences in soil formation factors or previous management practices may not be sufficiently different to result in relevant average differences between units. Also, long histories of nutrient application and soil or crop management may have over-ridden any natural variation between soils, or may have introduced very high variation within each soil unit. Research and surveys have shown that today this is the case in many fields. This is the reason that alternative soil sampling approaches began to be used and recommended since the mid-1990s.

Grid Sampling

Grid sampling uses a systematic approach that divides fields into squares or rectangles of equal size (usually referred to as "cells"). The location of each grid cell usually is geo-referenced using GPS devices. The cell size varies greatly depending on subjective factors, which among others include sampling and testing costs. In the mid-1990s cell sizes were 4 to 10 acres, but recently a 2.5-acre size is the most commonly used. Several studies have suggested that for grid sampling to be effective, the cell size should be smaller than about 5 acres. Soil samples are collected from within each of these grid cells following "grid point" or "grid cell" approaches. The grid point approach involves collecting one composite sample made up of a number of soil cores (generally 5 to 15) from a small

central area of each cell or from the intersection of the grid lines. This approach emphasizes a good representation of a small area each time samples are taking over time over trying to represent well the entire area of a cell. The size of the "point" sampled varies greatly, but usually ranges from 1,000 to 10,000 square feet, and research has suggested should not be larger so the method is distinct from the "cell" approach. The grid cell approach involves collecting a set of cores randomly from the cell trying to represent its entire area as much as possible. Neither approach is better across all conditions but the grid point sampling usually is preferred because it is faster. The results of analyses of the soil samples collected with either grid sampling approach may be used directly for fertilizer or lime recommendations (in effect, treating each grid as a small field) or they may be entered into a computer mapping program that uses different interpolation procedures to assign values to non-sampled areas to produce a continuous map of soil test results and eventually a nutrient application map. Sampling at high densities allows for more accurate, but more expensive soil-test and nutrient application maps.

As a general rule, grid sampling should be considered if the previous management practices have significantly altered soil nutrient levels across the field and nutrient variability no longer follows the distribution of soil map units or topography. Figures 4 and 5 show the results of using a grid sampling approach for several soil properties in an Iowa field with a long history of fertilizer application. The field almost completely encompassed one dominant soil map unit (soil series, erosion and slope phase), but dense grid sampling revealed very high variability for almost all properties sampled.

Within Mapping Unit Soil Test Variation

Soil P	Soil K	Soil pH	Soil Nitrate
16-86 ppm	111-302 ppm	5.6-7.0	2-28 ppm

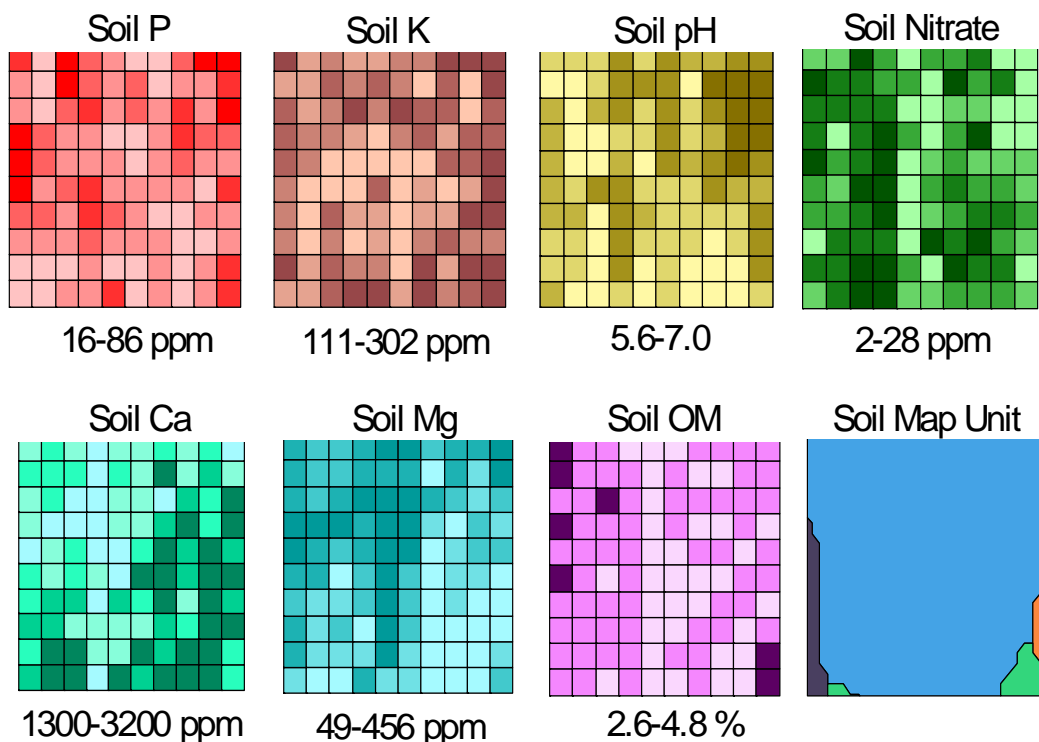| Soil Ca	Soil Mg	Soil OM	Soil Map Unit
1300-3200 ppm	49-456 ppm	2.6-4.8 %	

Figure 4. Example of a grid sampling for soil P, K, pH, nitrate-N, Ca, Mg, and OM (OM) in an Iowa field with mainly one dominant soil map unit.

Figure 5 is another example that shows how a tenfold range in sampling density at a research site near Lincoln, Nebraska, resulted in significantly different patterns. In this case, the coarser sampling grid missed a systematic variation pattern in soil nitrate, probably related to livestock fencing. The average recommended N rate for the field at the higher grid density was 148 lb N/acre. The average recommended N rate was 162 lb N/acre at the lower grid density; where 45 percent of the field received a different N recommendation with the coarser grid. The coarse grid was denser than most commercial grid sampling practiced by fertilizer dealers and crop consultants.
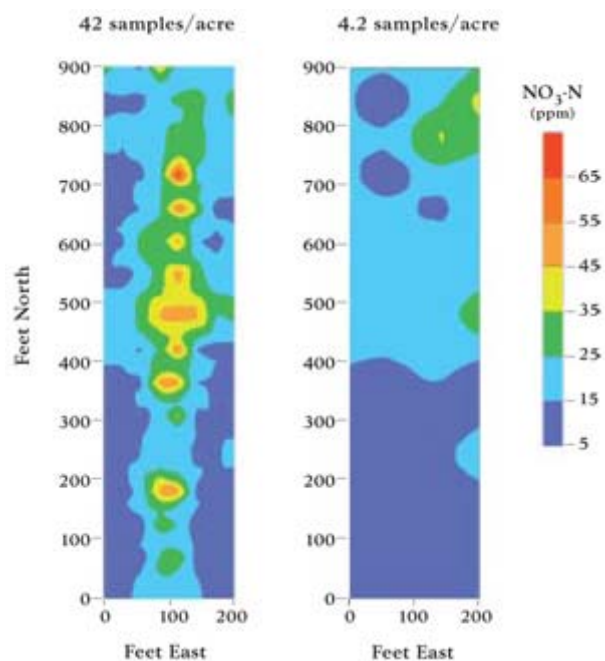
Figure 5. Interpolated nitrate-N map from a field sampled with different grid sampling density. Adapted from Ferguson and Hergert (2009), "Soil Sampling for Precision Agriculture" (EC154), University of Nebraska-Lincoln.

The very high within-field variability in these and many other fields (even within one soil map unit) clearly justifies dense grid soil sampling for nutrient application using variable rate technology. In other situations, however, accurate soil test maps can be generated at much lower sampling densities. The issue is to know how densely a field should be sampled so that the increased accuracy and precision of soil test results and crop response offsets increased costs. No general rule is possible, however, because the optimum grid density obviously depends on the field, what soil properties are being assessed, the costs of soil sampling, testing, and VRT application; and the nutrient/crop price ratios. These issues, plus the increased availability and decreasing costs of several precision agriculture technologies, have encouraged crop consultants and researchers to consider a third soil sampling approach.

Zone Sampling

Zone sampling is the most recently suggested sampling approach, and attempts to improve the traditional approach of sampling by soil map units while providing an alternative to the usually denser and costly grid sampling approach. The basic assumption is that maps of soil or crop canopy

characteristics provide additional useful information to delineate sampling zones that may differ in nutrient availability. Soil cores are collected at random from within each zone and are bulked together to provide one composite sample per zone and one soil-test value for each unit. Several information "layers" can be used to delineate sampling zones. For example, aerial or satellite images could distinguish between soils with different percentages of OM, crop canopy that reveal nutrient deficiencies and even areas with different growth patterns. Yield monitor maps and apparent electrical conductivity maps also may be helpful in identifying zones that could be sampled separately. This approach assumes that the soil or crop characteristics used to delineate zones result in relatively homogenous nutrient availability within each zone compared with the entire field area. A downside to zone sampling may be that the management of the field over time for crop production, such as crop harvest, fertilizer application, manure application and liming, may have over-ridden any natural nutrient variation related to soil or crop canopy characteristics used to delineate zones. If the variation within a zone is as large as between zones, then this sampling approach will not be effective. For example, if soil map units and images of bare soil to reveal OM variation are part of the zone delineation decision, but after many years of fertilization or liming, patterns of soil-test P, K, or pH variation may not follow soil or OM variation.

5. Frequency of Sampling

Typically suggestions are to collect samples every three to four years for most nutrients, except the most mobile ones. More frequent (every 2 years) or annual sampling is recommended in fields where rapid changes in soil-test levels are expected (such as in sandy soils) or for high value crops. Sampling for mobile nutrients, like nitrate, usually needs to be done yearly. To optimize nutrient use efficiency and economic benefits from fertilization for the more immobile nutrients (P, K, and several secondary and micronutrients), a more frequent sampling may be justified in low-testing soils than in soils where nutrient levels are adequate and the main benefit of sampling and fertilization is to maintain soil test levels over time. Regardless of the sampling frequency, records of changes in soil-test values over time should be kept for each location sampled. This record may be required in nutrient management plans and allows for comparison of test results over time, which helps understand effects of nutrient management practices on soil-test levels. Also, frequent sampling will provide trends of soil test trends over time, which together with records of nutrient application and yield can help when test results are odd or unexpected. Decisions about the frequency of sampling also should consider the sampling approach in relation to number of samples collected from each field, because of the cost/benefit of denser and more frequent sampling. No general rule is possible to follow because the optimum frequency and density of

sampling varies greatly with the nutrient, the within-field nutrient variability, temporal nutrient variability, and crop/nutrient price ratio.

Sample Handling and Testing Procedures

After the sample has been collected, contamination must be avoided. Common sources of contamination include dirty sampling tools, cross-contamination from containers or tools and storage containers. Contamination for N, P, or K testing seldom is a serious problem because the obvious importance of keeping tools or samples away from fertilizers usually is recognized. Contamination is more frequent and serious for micronutrients, however, mainly for copper (Cu), iron (Fe), and Zn from galvanized or steel buckets, probes and grinders. Even ash from cigarettes or sweat from hands can be a source of contamination. Soils should be shipped to the testing laboratory only in suitable containers and the best is to use plastic lined sample bags that often are provided at no charge by soil testing laboratories.

Collected cores should be mixed thoroughly to form a composite sample. Moist cores should be crushed and mixed to provide a homogenous sample so error when subsampling in the laboratory is minimized. If more cores are collected than can fit into the sample container, adequate mixing is essential so a representative sample of one to two pounds is sent to the laboratory. If the samples are not shipped immediately to the laboratory, they should be kept in a cool place or in a refrigerator if stored more than 2-3 days. This is not important for all nutrients, but is for nitrate and S, for example. If the mixed sample is to be dried before delivery to the laboratory, the drying should be done at temperatures no greater than 104 degrees F (40 degrees C).

Several soil test methods are available to measure the availability of individual nutrients in collected soil samples. Issues related to testing procedures are not addressed in this article. Different methods are often recommended for different regions or states of the U.S. because different tests are more appropriate for some soils than others and because of tradition or availability of research data. Producers and crop advisers should always be certain that soil test interpretations used to develop fertilizer recommendations are based on research using the same laboratory analysis procedures that are used to generate soil test results. The specific procedures recommended for testing soils in each state or region are often described in regional publications prepared by regional soil testing and plant analysis committees. For example, these include the NCR Publication 221, "Recommended Chemical Soil Test Procedures for the North Central Region" prepared by the North Central Research and Extension Committee on Soil Testing and Plant Analysis (NCERA-13) and Bulletin 409 "Procedures Used by State Soil Testing Laboratories in the Southern Region of the United States" prepared by the Southern Extension and Research Activities

committee Methodology, Interpretation, and Implementation of Soil, Plant, Byproduct and Water Analyses (SERA-6). Specific soil-test interpretations for several soil test methods and nutrient recommendations for crops are prepared and published by most states.

Summary

The application of appropriate rates of fertilizer and manure nutrients for crop production with minimal impact on the environment is highly dependent on the information derived from soil samples collected and analyzed to estimate levels of crop-available nutrients in soils. Therefore, samples collected should provide the best representation of the field or sub-field area sampled. Important issues to be considered include the sampling depth, time of year when samples are taken, number of soil cores per composite sample, number and distribution of samples across a field and sampling frequency. Seldom does one single composite soil sample adequately represent an entire field and sampling approaches can be implemented that are useful for precision nutrient management using precision agriculture technologies such as variable-rate application. To guide more precise fertilizer applications to optimize the profitability of nutrient management or to address environmental concerns, entire fields can be divided into smaller areas and sampled accordingly. Regardless of the method used for collecting multiple samples or dividing fields into smaller areas, a sufficient number of soil cores should be collected for each composite sample so that the sample adequately represents the area sampled. Without representative samples, recommendations based on test results will not be accurate.