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Monitoring Soil Nutrients Using a Management Unit Approach

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What's in this publication?

This publication focuses on how to design a soil nutrient monitoring strategy that fits today's requirements for record keeping and increased accuracy in managing nitrogen (N), phosphorus (P), and other nutrients. We advocate the use of management units or zones for soil testing and nutrient application. To measure a real change in soil test values over time, you will need to use consistent management units over many growing seasons.

In this publication, a management unit is considered an area in a field that is soil-sampled and fertilized separately for one or more nutrients. Different management unit delineations may be more appropriate for insect, weed, and disease control; irrigation water management; and other cultural practices.

The management unit approach is designed to provide better information to make nutrient management decisions at a reasonable cost. This approach combines the ease of traditional whole-field sampling and the power of an intensive grid sampling method (see pages 2–3). With a management unit approach, a grower can vary the amount and type of nutrient applications within a field without the need for grid sampling.

A monitoring strategy will answer only the questions it was designed to answer. Each field will have a specific soil sampling strategy. Key questions to consider when developing a soil testing strategy for nutrient management are discussed in this publication, including time of sampling, depth of sampling, number of subsamples, and location for sampling in the management unit.

A soil sampling protocol designed to measure changes in soil nutrient status over time must minimize random variability in soil test results. This is especially important when soil sampling is part of a required nutrient management plan. This publication suggests strategies for minimizing random variability.

Two examples of nutrient monitoring are provided to illustrate the process of deciding when, where, and how to sample, as well as how to interpret the soil test results. One example uses reference sampling areas

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within management units, and the other uses random sampling throughout the management unit. These examples are intended to illustrate the process of using management units to make nutrient management decisions.

What are the advantages of the management unit approach?

The sidebars on this page and the following page describe two approaches to sampling: whole-field sampling and grid sampling. Each sampling strategy has limitations that can be overcome by adopting a management unit approach, as described in this publication.

The goal of using a management unit approach is to save money, and often time, compared to grid-based sampling methods, while obtaining more accurate data than that provided by whole-field sampling. The management unit approach is designed to provide many of the benefits of grid sampling while overcoming its high cost and other limitations. In many cases, this process allows growers to make fertilizer or amendment applications without the use of global positioning system (GPS) units and expensive variable-rate controllers.

Developing and using management units can allow a producer to apply amendments in varying amounts within a field. Higher levels of a particular nutrient can be applied in areas of the field that are likely to respond or have not reached a critical limit, while less or none can be applied in areas that have higher values and are less likely to respond. In most cases, this type of sampling plan satisfies many regulatory requirements while allowing the crop to be managed in a reasonable way.

Whole-field sampling

The whole-field soil sampling approach is a simple protocol used for many cropping systems. Soil cores are collected from the entire field, mixed together, and a single composite sample is sent to a laboratory for analysis.

The problem with whole-field sampling is that it treats the entire field the same regardless of differences in landscape position, soil characteristics, or cropping history. Thus, conclusions drawn from the soil test may not be appropriate for each part of the field. Often, average nutrient levels are found in only a small part of the field. The rest of the field is either higher or lower than the average. Basing fertilizer application on the field average means that some areas will be overfertilized and others will be underfertilized.

What criteria are used to divide a field into management units?

When deciding how to divide a field into management units, both soil features and the grower's needs and priorities for managing each field should be considered. The goal is to divide fields into areas that are more uniform than the field as a whole.

The basis for consideration can include inherent variability (soil texture, topography, mineralogy, drainage, soil test values), variability associated with current management (tillage, irrigation water distribution), and historical variability (previous crop yields, manure application, field leveling, old fence lines) within a field. The minimum size of a management unit should be defined by equipment size, so that each management unit is large enough to be fertilized separately.

Grid sampling

The most accurate picture of the characteristics of a field would be produced by sampling every point within the field. Since it is impractical to do so, grid sampling can be used as an improvement over whole-field sampling. First, a field is systematically divided into areas of uniform size and shape (called cells) to form a grid. Cells often consist of 1 to 5 acres. Then, samples (consisting of a composite of 10 or more cores) are taken from each cell and analyzed. Thus, each cell has its own sample and analysis result.

The purpose of grid sampling is to create a detailed map of the field that allows the grower to identify areas that will receive a unique management practice. Using software that estimates soil test results between cells, patterns of estimated nutrient availability can be determined and a nutrient application map created.

The main challenge of grid sampling is its expense. A 125-acre field can have as many as 125 individual samples (if the field is divided into 1-acre cells). On a farm of several hundred acres, the cost of sampling (labor and equipment) and lab fees can become prohibitive. On the other hand, some labs give a substantial discount to growers who grid sample.

Grid sampling does not need to be done every year for most soil tests. The cost could be spread over a rotation by sampling intensively before one crop to create management units and then taking a few samples in subsequent years to verify the spatial patterns of soil nutrients.

Another limitation to grid sampling is that the grid spacing chosen may either obscure or exaggerate variability caused by a regular pattern such as wheel rows or movable sprinkler lines. However, modified versions of grid sampling patterns can overcome this potential weakness.

Dividing a field into management units is a combination of art and science. The management unit approach for soil sampling described in this publication enables growers to use their knowledge of the field to help define management units. Often, management units can be delineated on the basis of soil color or other landscape features that are easy to identify visually.

Certain field features, such as areas where soil was removed for field leveling, are not clearly delineated on most maps. However, you might be able to obtain cut-and-fill maps from the operator who did the leveling. Such maps can be quite useful in delineating nutrient management units.

Consider using other sources of information to delineate management units. Maps produced from remote sensing data (e.g., aerial photos or satellite imagery) and yield monitors are useful visual aids. Other tools include geographic information systems (GIS) software and GPS units.

Time and skill are required to manipulate the raw map data into a format that allows overlay of maps for the same field. After a multiple layer map is created, many factors can be considered simultaneously to delineate management units. These maps are also useful for recording soil sampling locations within the field.

Where should I collect soil samples from within a management unit?

Collect soil cores throughout each management unit (unit sampling) or from a smaller reference sampling area within a management unit (Figure 1). Select one of these approaches, and use it consistently.

In the center-pivot irrigated field shown in Figure 1, each of the three management units is delineated by one or more soil properties or management practices. For example, Management Unit 1 may be an eroded hilltop, Management Unit 2 may consist of side slopes with shallow topsoil, and Management Unit 3 may consist of bottomlands with poor drainage and high organic matter. The sampling plan for the field on the left (A) uses a zigzag pattern to collect subsamples, or cores, across the entire management unit. Soil cores collected within each management unit are composited into one sample for that management unit. In the field on the right (B), reference sampling areas are established away from the edges of the field but near access points such as the pivot road.

The sampling location for each core may or may not be recorded (georeferenced).

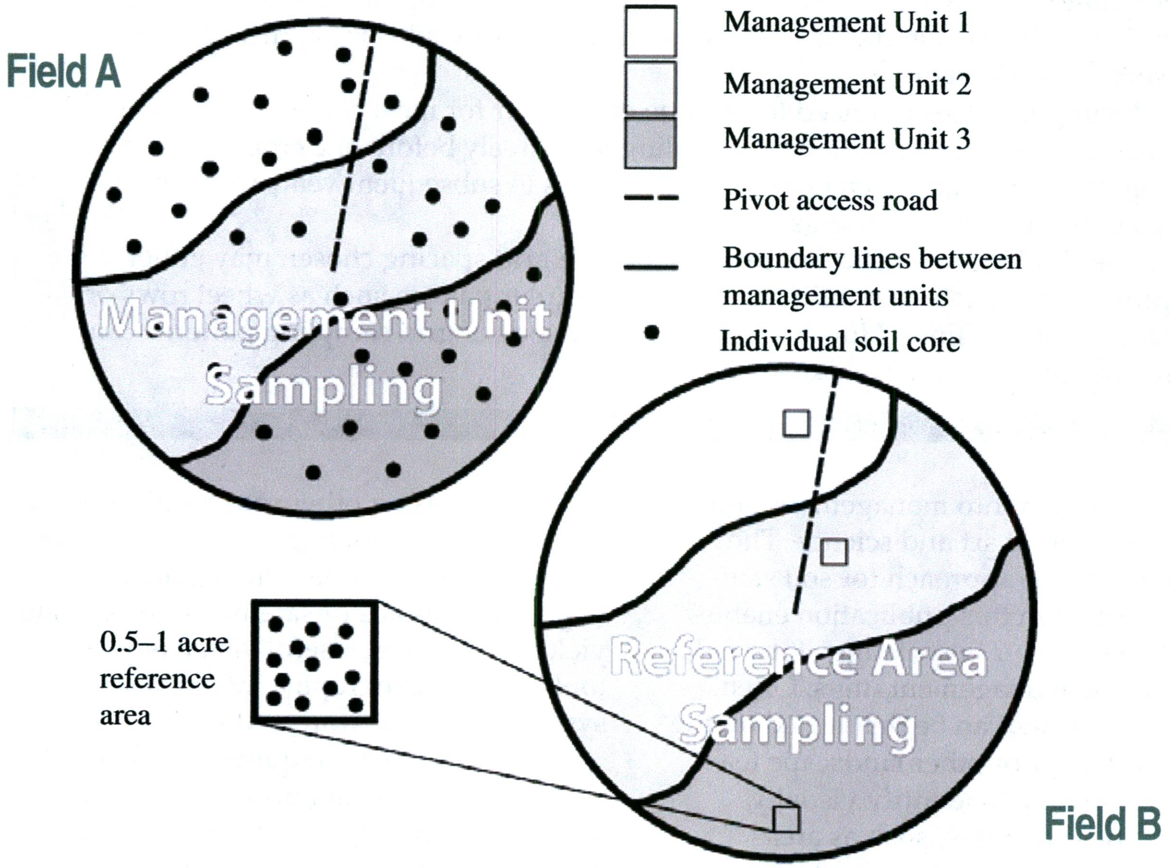

Figure 1.—Aerial view of two fields with a center-pivot overhead sprinkler irrigation system that have been divided into three management units. The top left field (A) illustrates a random sampling approach for sampling within each management unit. The lower right field (B) illustrates the reference sampling area approach for sampling within each management unit.

The benefit of georeferencing sampling locations is that in subsequent years you can return to the same areas with some degree of accuracy and minimize year-to-year variability. Georeferencing commonly is done with a GPS unit. Currently, the least expensive units can be accurate to ± 15 to 20 feet, under ideal conditions. Alternatively, it may be possible to install markers in the field that will withstand farming practices, allowing them to be found for future sampling.

For either the unit or reference sampling approach, avoid collecting samples from small, atypical areas such as animal feeding areas, gate and watering areas, corral and home sites, old roads, field edges, and eroded hilltops. It might be useful to analyze such samples separately for possible consideration as separate management units.

Management unit sampling approach

Take individual soil cores (10 or more) randomly over the entire management unit and mix them into a composite (Figure 1a).

Advantages of sampling randomly within management units include:

- One sample represents the entire management unit.
- Likely to provide better data than the reference sampling area approach when uniformity in soil or management practices (e.g., manure application) is uncertain.

Disadvantages of sampling randomly within management units include:

- Sample collection requires more time compared to sample collection by the reference sampling area approach (described at right).
- Heavy sampling equipment, if required, must be moved across the management unit.

Reference sampling area approach

Reference sampling areas are smaller sampling areas within a management unit. They can be used for representative soil sampling and other crop monitoring activities, such as plant tissue sampling, soil moisture measurement, or crop yield estimates. This method is most beneficial when heavy sampling equipment is used or when the management unit is very uniform.

The intensity of management and variability of the field should dictate how large an area can be represented by one reference sampling area. A local expert (university Extension personnel; private certified crop advisor, agronomist, or soil scientist; or Natural Resources Conservation Service personnel) can be consulted to assist you in determining what might be appropriate for your situation.

Reference sampling areas should be representative of the entire management unit and easy to access. To make sure a reference sampling area is representative, compare soil test values from proposed reference sampling area(s) with soil test values for a composite sample taken from the entire management unit (see "Management unit sampling approach").

Within each management unit, select an area of 0.5 to 1 acre for each reference sampling area (Figure 1b). Plan to georeference the four corners of the sampling area to minimize year-to-year variability. Ways to georeference reference sampling areas, besides using GPS, include using specific tree numbers in an orchard, measuring the distance from a fence or fixed equipment, or installing markers.

Advantages of reference sampling areas include the following.

- Fields can be sampled more quickly.
- It is easier to georeference sampling locations.

- You can use more than one reference sampling area within a management unit to allow for differences in known management variables (e.g., irrigation water distribution).
- There is more year-to-year consistency due to less spatial variability.

Disadvantages of reference sampling areas include the following.

- The reference sampling area may not represent the management unit as a whole.
- If georeference coordinates or field markers are lost, the exact location of the reference sampling area may be lost.
- Heavy traffic within the reference area may occur if care is not taken.
- The sampling area will be compromised if a nutrient or other amendment spill occurs within the reference sampling area.

The reference sampling area approach often is used for in-season testing for soil nitrate, because:

- More soil cores can be collected in a given amount of time.
- Fixed soil moisture monitoring sites (e.g., neutron probe) can be located within the same reference sampling area.
- Reduced sampling equipment traffic over the field reduces crop damage and soil compaction.

How to develop a plan for soil nutrient monitoring

Soil test data will answer only the questions the test was designed to answer. The following steps and questions can help you design a monitoring system tailored to your needs (Table 1). Two examples of how to develop a plan are included (see Examples 1 and 2, pages 10–13).

Table 1.—Considerations and questions for designing a soil nutrient monitoring plan.

Soil monitoring considerations	Specific questions
Objectives	• What is (are) your objective(s) for nutrient monitoring? • What nutrients or other soil chemical properties do you want to measure? • Are you required by any agreement to monitor specific nutrients or soil chemical properties?
Where to sample	• Should you collect samples throughout the management unit, or use a reference sampling area? • Do you plan to georeference locations where soil cores are collected? • What method will you use to georeference sampling locations?
How to sample	• When should samples be collected? • What soil sampling depth(s) are appropriate? • How many soil cores will be collected for each composite sample sent to a laboratory for analysis? • Should you sample using a zigzag approach or a systematic sampling method within the sampling area?

Table 2.—Typical frequency for assessment of changes in soil test values.

As needed for specific cropping system	Annually**	Periodic (once per crop rotation or every 3 to 5 years)	Once, if necessary, for initial site assessment
Nitrate-N (NO_3-N)*: preplant, in-season, or postharvest	extractable boron (B), total or sulfate-sulfur (S)***, electrical conductivity (EC)	pH, lime requirement, Bray or Olsen P, extractable bases (K, Ca, Mg, Na), extractable micronutrients (DTPA-Zn, Mn, Cu, Fe)	soil texture, cation exchange capacity (CEC), organic matter

* Soil testing frequency for nitrate-N varies widely for different cropping systems.

** For cropping systems with high-sodium (Na) irrigation water, an annual test for sodium absorption ratio (SAR) is recommended. The SAR test includes determination of exchangeable calcium (Ca), magnesium (Mg), and sodium (Na).

*** For sulfur (S), plant-tissue testing is preferred over soil testing. Soil test sulfur (sulfate-S or total S) is not a good predictor of crop yield response to S fertilizer in many situations.

Objectives

Think carefully about your objectives. Soil testing can be used just to monitor nutrient levels for record-keeping requirements, or it can be used to guide nutrient application decisions. Agricultural professionals (university Extension personnel; private certified crop advisors, agronomists, or soil scientists; and Natural Resources Conservation Service personnel) often can help in designing a customized sampling strategy.

What nutrients or other soil chemical properties do you want to measure?

Soil tests that provide useful information for nutrient management purposes are listed in Table 2.

One of the goals of a soil testing program may be to avoid excessive application of nutrients or salts. Repeated application of organic materials, such as compost, manure, or biosolids, typically results in buildup of one or more nutrients, and possibly soluble salts. As an example, if manure application rates are based on supplying enough N for the crop, other nutrients (e.g., phosphorus and potassium) usually are added at rates greater than crop utilization. Soil testing can be used to track nutrient accumulation over time.

Because each organic material (e.g., manure, biosolids, compost) contains a unique balance of nutrients, a nutrient analysis of the organic material often is helpful in deciding which soil tests are appropriate. General information about the nutrient concentrations present in various organic materials can be found in Extension publications (see "For more information").

Several tests commonly offered by agricultural testing laboratories—organic matter, ammonium-N (NH_4-N), and sulfur (S)—are less useful in assessing management effects on soil fertility. Their shortcomings are discussed briefly here.

Soil sampling for ammonium-N (NH_4-N) is not recommended unless fertilizer or other organic amendments have been applied during the past 30 days, or if soil has remained dry or cold since N application. In most situations, ammonium-N is rapidly converted to nitrate-N (NO_3-N) in soil.

Soil organic matter testing often is part of a "routine" soil test, but it has limited value for nutrient management. Most fertilizer guides for irrigated crops do not use soil organic matter as a basis for nutrient management recommendations. (Some dryland fertilizer guides use soil organic matter values to adjust N recommendations.)

Soil organic matter content changes very slowly in response to management changes (tillage or organic amendment addition). Annual testing of soil organic matter is not recommended because random measurement error usually obscures small changes in organic matter content over time. Periodic soil organic matter testing (once per crop rotation or every 5 years) may be useful in measuring the impact of long-term management changes that are expected to build soil organic matter.

For sulfur (S), plant-tissue testing is preferred over soil testing. Soil test sulfur (sulfate-S or total S) is not a good predictor of crop yield response to S fertilizer in many situations.

Are you required by any agreement to monitor specific nutrients or soil chemical properties?

Nutrient management plans required by state or federal agencies often specify required soil analyses and sampling frequency. At a minimum, a sampling plan should meet agency requirements (if applicable). For example, landowners who participate in the Natural Resources Conservation Service (NRCS) Environmental Quality Incentives Program (EQIP) for nutrient management often are required to collect soil test data according to NRCS specifications.

Where to sample

Collect soil cores throughout each management unit (unit sampling) or from a reference sampling area within each management unit, as discussed previously in "Where should I collect soil samples from within a management unit?"

How to sample

When should samples be collected?

The recommended sampling frequency is based on the rate of change in soil test values over time (Table 2). Tests for soil characteristics that do not change greatly in response to fertilizer or organic amendment addition (e.g., soil texture and cation exchange capacity) often are not necessary.

Timing of soil sampling is most critical for nitrate-nitrogen, because this form of N is mobile in soil water. Generally, it is best to collect soil samples for nitrate-N analysis close to N fertilizer application time.

Soil tests for soil characteristics that change slowly in response to management (periodic soil tests in Table 2) are recommended once per crop rotation or every 3 to 5 years. For these tests, small variations occur seasonally due to soil biological processes, crop residue decomposition, soil water status, and tillage. In determining management effects on these soil test values, develop a consistent protocol for the timing of sample collection.

What soil sampling depth(s) are appropriate?

Consult university fertilizer guides or nutrient management guides for the crop. Determine the soil sampling depth and any other special considerations for soil sampling in a particular cropping system. For many agronomic crops, interpretive tables for soil test values are based on a sample taken to a 0- to 6-inch or a 0- to 12-inch depth. However, some N recommendations are based on sample depths up to 24 or 48 inches.

Using shallower sampling depths, in some cases, can allow for the detection of changes in soil nutrient status before they would be detected using a traditional sampling depth (6 or 12 inches). For pastures and some perennial crops where tillage is absent, nutrients with limited mobility (e.g., P and K) may accumulate near the soil surface. Sampling closer to the soil surface increases the probability of detecting changes in soil test values over time.

In some cases it is useful to split a sample by depth. For example, if the university guide is based on a 12-inch depth, it might be useful to collect two samples, 0 to 3 inches deep and 3 to 12 inches deep. Splitting the samples by depth allows you to compare soil test values for the 0- to 12-inch depth (weighted average of 0- to 3- and 4- to 12-inch depths) with the fertilizer guide, while also evaluating changes in surface soil test values (0 to 3 inches) over time. Table 3 shows how to calculate a weighted average.

How many soil cores should you collect for a composite sample?

Increasing the number of soil cores (subsamples) taken in a sampling area generally increases the accuracy of the data. Fewer soil cores are needed to represent a smaller sampling area (Table 4). Mix soil cores thoroughly and submit a

Table 3.—Calculating a weighted average.

How measured	Sample depth (inches)	Soil core length (inches)	Soil test value (ppm)
Sampled	0–3	3	40
Sampled	4–12	9	20
Calculated*	0–12	12	25

*Weighted average of 0- to 3- and 4- to 12-inch depths is derived by:
[(core length x soil test value) + (core length x soil test value)] ÷ total sample depth

Example: [(3 x 40) + (9 x 20)] ÷ 12 = 25

Table 4.—Minimum number of cores per sample and size of sampling areas.

	Whole field	Entire management unit	Reference sampling area within management unit
Minimum cores/sample	20	10	5–8
Minimum acres/site	100% of field	varies	1% or less of management unit

composite sample to the laboratory. Check with the laboratory to determine the amount of soil needed for the desired analyses.

Should you sample in a zigzag pattern or use a systematic sampling method within the sampling area?

For some crops, a zigzag pattern or other haphazard approach to collecting soil cores is appropriate. Systematic sampling perpendicular to a furrow-irrigated bed, fertilizer band, or perennial crop row sometimes is used to reduce variability in test results. If you choose a systematic sampling method, you must use it consistently in order to compare soil test values over time.

Sampling checklist

Consistent sampling techniques are essential. Make sure each of the following aspects (each was discussed above) will be handled before going to the field to take soil samples:

- Nutrients to be monitored
- Size and location of management units or reference sampling areas
- Sampling depth(s)
- Number of cores per composite sample
- Systematic sampling instructions (if applicable)

See "For more information" for publications describing routine soil sampling collection and handling techniques.

Example 1: Monitoring nitrogen in a silage corn field

Two years ago a grower purchased a 75-acre field. The new owner has no soil test data and little information on how the field was managed. He plans to conventionally till the field and plant it to silage corn and is concerned about how best to manage nitrogen fertilization. He uses best management practices to ensure timely and even distribution of irrigation water via overhead sprinklers.

The grower has a 20-year old aerial photo of the field and the soil survey report for the area. The photo shows that there was a corral in a part of the field. The grower decides that the former corral area will need to be a separate management unit (Management Unit 1), and the rest of the field will be the second management unit (Management Unit 2).

Developing a monitoring plan

Nutrient monitoring objectives

The grower wants to determine an appropriate nitrogen application rate for silage corn in this field. From a longer term perspective, by creating management units, he will be able to more closely meet the nutritional needs of the crops and, ideally, to reduce his fertilizer expenses and possible nitrate loss from the field.

Because part of the field has been a corral, the grower suspects this area may have a higher nutrient-supplying capacity than the rest of the field. The grower does not own livestock and will not be applying manure to the field.

Table 5.—PSNT and at-harvest stalk nitrate-nitrogen for Example 1.

	Nitrate-nitrogen (mg/kg or ppm)	
	Management Unit 1 (old corral site)	**Management Unit 2 (rest of field)**
Soil test (PSNT) at six-leaf growth stage	30	10
Corn stalk at harvest	4,500	5,500

Sampling approach

The grower wants to keep his sampling plan fairly simple by using reference sampling areas in the two management units. The reference sampling areas are located on the same side of the field and are fairly close to the road for easy access. Should plant tissue testing become necessary, those samples also will be taken from the reference sampling areas.

The grower has a GPS unit and uses it to record the location of the four corners of the reference sampling areas in the two management units. He collects 10 cores (5 cores is the minimum per unit) in each reference sampling area to create a representative sample.

Both soil and plant tissue testing will be used to monitor crop N status. Soil samples (0- to 12-inch depth) will be collected at the six-leaf growth stage. Plant tissue (corn stalks) will be collected at harvest. A university nutrient management guide, *The Presidedress Soil Nitrate Test (PSNT) for Western Oregon and Western Washington,* will be used to determine methods used in soil and plant tissue sampling. The guide also will be used to interpret soil test and plant tissue test results.

Results

Table 5 shows the results of soil and tissue testing for both management units.

The presidedress soil nitrate test value for Management Unit 1 (previous corral site) was above the 25 ppm nitrate-N sufficiency level given in the nutrient management guide. Thus, fertilizer N was not applied to this unit. Nitrogen was applied at sidedress time to Management Unit 2 at a rate of 100 lb N per acre as recommended in the guide.

The at-harvest stalk nitrate-N concentration in corn from Management Unit 1 was in the range required for optimum yield (above 3,500 ppm) given in the nutrient management guide. This result confirmed the decision not to sidedress N fertilizer in that management unit. Corn in Management Unit 2 had an at-harvest stalk nitrate value of 5,500 ppm, indicating that sufficient N was present for maximum yield. By using the management unit approach, yields were maintained and N fertilizer use was reduced.

Example 2: Monitoring soil phosphorus over a 6-year period

A grower has a 105-acre field that is irrigated with overhead sprinklers mounted on a wheel line. He wants to utilize composted manure from a drylot dairy and commercial fertilizers to supply nutrients for potatoes, a spring small grain crop, and a winter small grain crop grown in a 3-year rotation.

The grower worked with a consulting soil scientist to define management units for this field. The field was leveled many

Table 6.—Nutrient management strategies for Example 2.

Management unit	Initial soil test P	Strategy
1	15	Apply compost every year.
2	21	Apply compost every third year.
3	29	No compost applied.

years ago when it was furrow irrigated. Bare-soil aerial photographs were used to delineate management units defined by the amount of exposed subsoil. Soil color was directly related to topsoil depth, soil organic matter content, and soil test values. The management unit with the lightest color on the aerial photo, Management Unit 1, had the lowest organic matter content and the lowest soil test P value (15 ppm bicarbonate extractable P). Management Unit 3 had the highest organic matter content and the highest soil test P (29 ppm). Management Unit 2 had intermediate organic matter and intermediate soil test P (21 ppm).

Developing a monitoring plan

Nutrient monitoring objectives

The goal of the soil testing program is to efficiently use a combination of composted manure and fertilizer P to satisfy crop needs. Composted manure will be applied each year to Management Unit 1 (lowest soil test P) and every third year to Management Unit 2 (intermediate soil test P). Management Unit 3 will not receive composted manure application because it has higher soil test P values. (See Table 6.)

The phosphorus fertilizer rate for each crop will be determined using university nutrient management guides in conjunction with P soil test values for Management Unit 2 (intermediate soil test P) (Table 6). Phosphorus fertilizer (if needed for a particular crop) will be placed near the row at a single rate across the entire field. The grower does not have equipment capable of delivering a variable rate fertilizer application.

Sampling approach

Annual sampling will be used to track changes in soil test P over time. Because composted manure distribution across the field is not always uniform, the grower chooses a random sampling scheme, collecting soil cores in a zigzag pattern through each management unit. He records each management unit boundary and soil core collection location with a GPS unit to minimize year-to-year variation.

Management units will be sampled every year in the late winter or early spring. Samples will be taken at the 0- to 12-inch depth, as this is the depth recommended in university fertilizer guides for this region. From each management unit, 10 cores will be taken and composited into a single sample.

Results

Figure 2 (page 13) shows that soil test P values remained relatively constant in each management unit in the field over a 6-year period. All crops received adequate P for maximum yield.

The management unit approach allowed the grower to continue composted manure application to the portion of the field where additional P has agronomic benefit (Management Unit 1), while avoiding excess P buildup in the portion of the field with higher soil test P values (Management Unit 3). Fertilizer costs were reduced because a portion of crop P needs was supplied by composted manure.

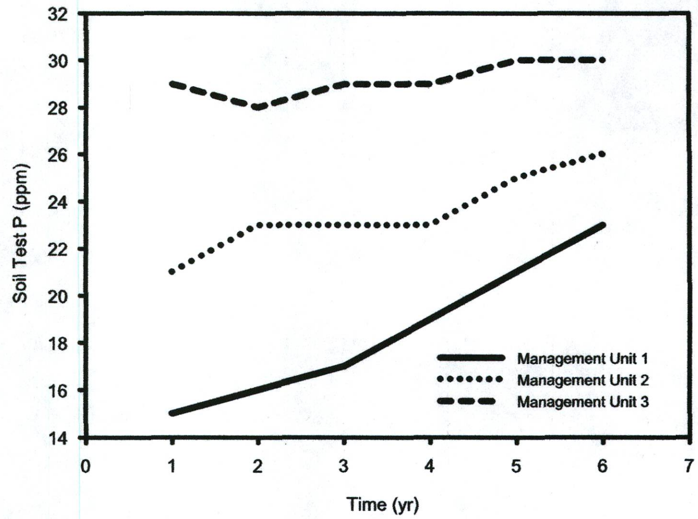

Figure 2.—Soil test P values for three management units in Example 2.

For more information

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