

SOIL SAMPLING AND SOIL TESTING

Soil testing has been promoted for many years as the basis for making sound lime and fertilizer use decisions. However, misunderstandings still exist on what can and cannot be gained from testing. A testament to these misunderstandings is the number of acres that do not have good historical soil test information. There are several components to sound soil testing programs, namely: 1) proper collection and care of the sample, 2) appropriate test procedures, 3) well researched interpretation guidelines of the test results and 4) development of appropriate nutrient rate recommendations and 5) integration of rate requirements into overall nutrient management programs.

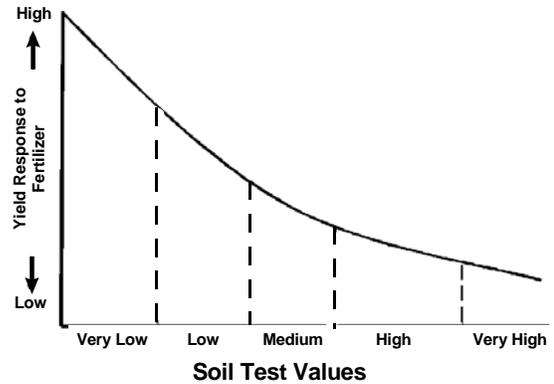
Soil test information is the cornerstone for developing cost effective, efficient and environmentally sound nutrient management programs. In fact, developing a sound nutrient management plan is not possible without the implementation of a sound soil testing program. Without good soil test historical information, it is impossible for farmers and their advisors to intelligently decide which nutrients, if any, need to be applied, how much of each nutrient is required and the best method/time of nutrient application.

Critical to the building of a good historical soil test information data base is the proper collection of soil samples to be submitted to the laboratory. Soil sampling is the foundation upon which the entire soil testing/nutrient management planning process rests. If the foundation is bad (soil sampling technique), the integrity of the whole house built upon this foundation is questionable (nutrient management decisions). As a result, it is very important that the people collecting soil samples be properly trained to do the job correctly.

The purpose of soil testing is to estimate the ability of the soil to supply required nutrients to growing crops and/or aid in diagnosing certain soil problems that may hinder efficient

crop growth and development. In general, crops are more dependent on nutrients supplied as fertilizers as low soil test levels and become less responsive to fertilizer nutrients as soil test levels increase.

Typical Yield Response to Fertilizer



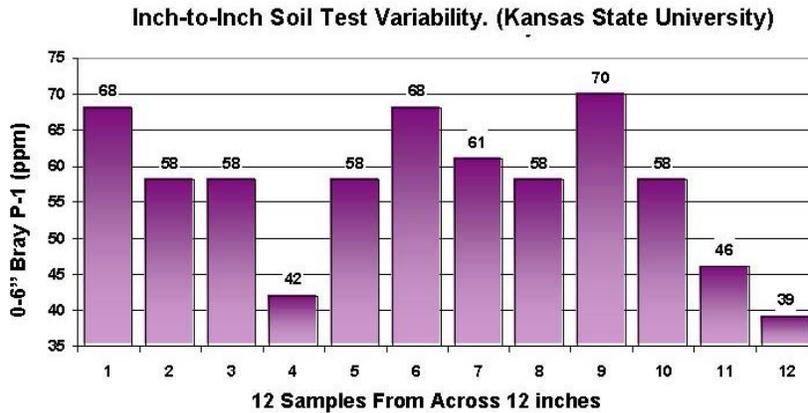
Without knowledge of the soils ability to supply required nutrients to the growing crop—it is impossible to determine which supplemental nutrients must be applied to provide for efficient and profitable crop production.

Soil testing is also used to aid in developing liming programs, for identifying and correcting soil salinity and alkali problems and for arriving at appropriate herbicide rates in weed management programs.

Collection and Care Of Soil Samples

A sample is taken from the field for the chemical or physical measurements desired, because it is neither practical nor possible to test an entire field. The accuracy with which these measurements characterize the true field conditions depend on obtaining a representative soil sample. An acre of soil to a 6-inch depth weighs about 2,000,000 pounds. This means that the sampler is using a sample weighing roughly a pound to represent several million pounds of soil depending on the

within a field.



acres represented by the sample. Thus, there is plenty of room for error. This has led to the statement that “That test is no better than the sample collected in the field.”

In order to be useful, the soil sample must be taken so that it is representative of the area being sampled. It must accurately represent the field or area sampled in order to obtain soil test results that can be properly interpreted.

Soil sampling is the weakest link in the soil testing-nutrient management plan development process and is the greatest source of error. There is tremendous variability in soil within fields, even in those that appear uniform. Soil sampling must account for this variability in order to ensure sound nutrient management decisions.

Collecting composite samples Variability of soils in many fields is fairly obvious since there may be significant visual differences in topography, soil types, soil color or other factors. But field variability exists that is not evident at first glance – even in fields that appear uniform. Because of the non-uniformity of fields, collecting several soil samples from within a single field and/or compositing many subsamples (individual soil cores) for each sample collected is necessary to accurately define soil characteristics

Most production fields are sampled by collecting 15-20 individual subsamples from a field, or portion of a field, compositing the individual cores in a pail, thoroughly mixing the collected soil and then submitting a single sample to the laboratory for analysis. The idea is to randomly collect enough individual soil cores to ensure that the resulting sample submitted to the laboratory will be representative of the field, or portion of the field, in question.

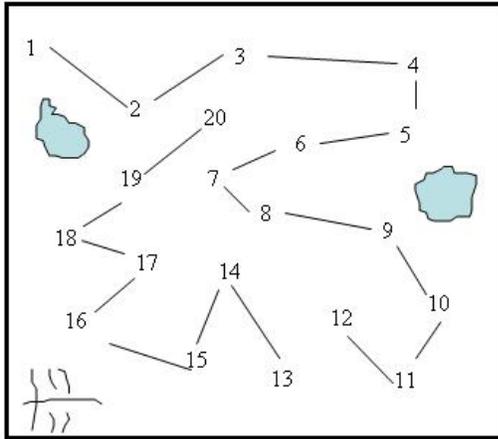
While variability from one end of the field to the next is one reason that 15-20 individual cores need to be composited into a single sample submitted to the laboratory, inch-to-inch variability also exists. This inch-to-inch variability is part of the natural variation in soils, but other factors also contribute. For example, several fertilizer granules may roll into small depressional areas on the soil surface where an individual core is collected from. Likewise livestock or wildlife activities may result in ‘hot spots’ in fields from which a single core is collected from. The way to manage field wide and inch-to-inch variability is to collect enough subsamples (cores) to minimize the effect.

Research conducted by North Dakota State University illustrates the importance of compositing 15 to 20 individual cores into a single sample. In their work, collecting 15 to 20 cores were needed to obtain results +/- 15% of the true average of the field 80% of the time – or +/- 20% of the true average

Reproducibility (%)	Accuracy Level									
	+/- 5%		+/- 10%		+/- 15%		+/- 20%		+/- 25%	
	N	P	N	P	N	P	N	P	N	P
70	90	117	23	30	10	14	7	8	4	5
75	107	143	28	36	13	16	7	10	5	7
80	137	181	34	46	18	21	9	12	6	8
85	171	223	44	55	20	25	11	15	7	9
90	227	298	56	75	25	34	19	14	10	12
95	325	425	81	106	36	48	20	27	14	18

90% of the time. If only 50 or 6 individual cores were collected, the results would be +/- 25% of the true average only 75% of the time. Collecting an adequate number of cores is required to minimize year to year soil test variability.

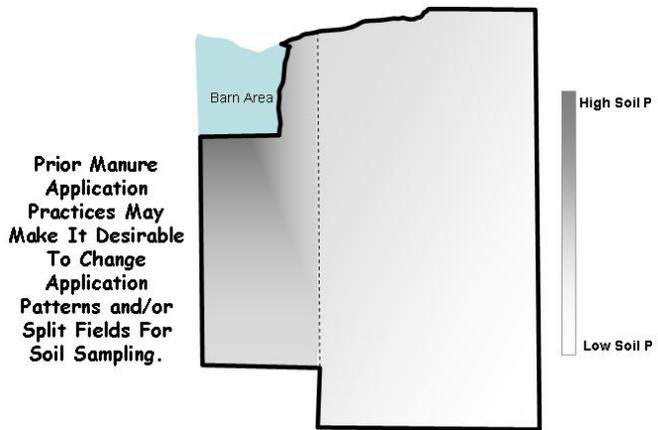
The size of the area to be represented by a single, composited soil sample has relatively little influence on the number of



subsamples required to ensure a 'representative' sample. In general, the size of the field to be sampled, about 15-20 individual cores are needed to minimize the effects of the natural variability found in soils. For fields larger than 50 to 80 acres it would be appropriate to include at least one additional soil core for each five acres in excess of 80 acres. Better yet, submit two separate samples consisting of 15 to 20 cores from larger fields.

The following presents some examples several possible composite sampling strategies for different fields/situations.

For uniform fields with no apparent differences—a single composite sample from whole field would be appropriate. Soil cores should not be collected from odd places such as headlands, dead furrows, low spots, knolls, etc. If the area covers a large enough portion of a field (e.g. 10-20%), a separate composite sample should be collected from the area and submitted to the laboratory.

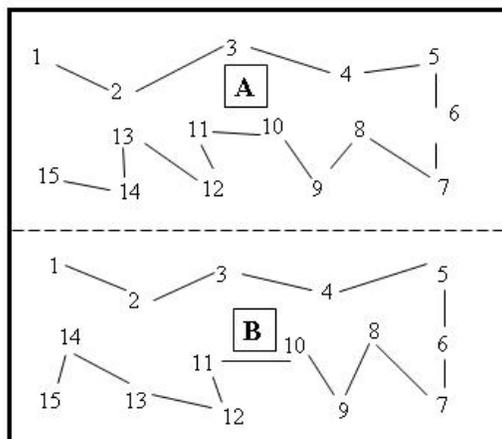


Similar soil in entire field except for a knoll in one corner and a few low spots.

Collecting individual cores from these areas and including in the overall field composite sample will only create a soil in the pail that doesn't exist in the field.

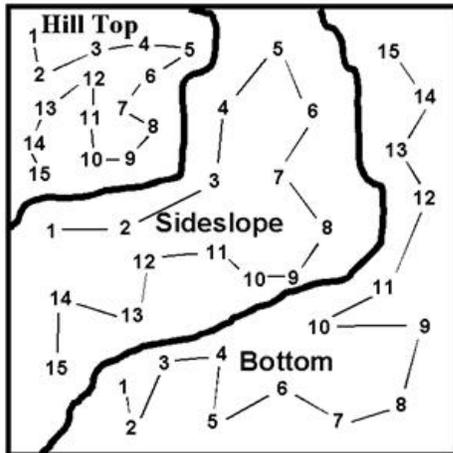
Alternatively, some producers and crop advisors divide whole fields into multiple management zones and collect one composite sample from each soil zone. Examples of

management zones within a field that may differ are soil types, topographies (top, bottom, side of hills), soil texture, manure history, cropping systems, and others. The idea of separating whole fields into smaller management zones is that soil test variability within a management zone will hopefully be less than the variability across management zones.



"A" portion of the field was previously in alfalfa (4 years prior). Sample the two areas separately.

If portions of a field have had different manure management programs, previous crop history or other cultural differences,



Topography would make good 'management zones' in many areas. In this case three separate sample would be collected.

With the advent of precise positioning systems (Differentially corrected Global Positioning System, DGPS) and more powerful and sophisticated computer hardware and software (e.g. Geographical Information Systems, GIS) – intensively collecting multiple soil samples from within a field to accurately identify and map field variability is now a cost effective reality.

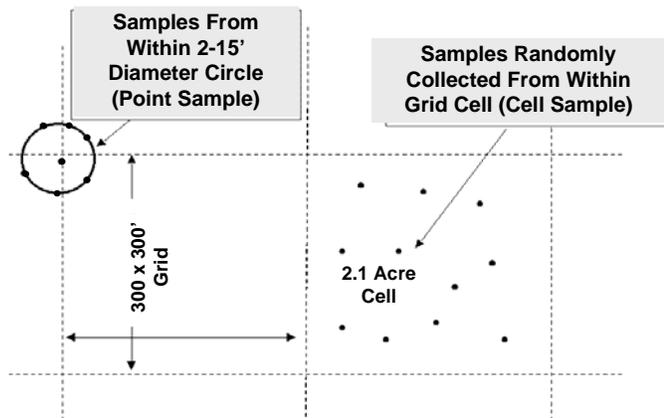
separate composite samples should be collected from each subfield and submitted to the laboratory. While the field might be uniformly managed (e.g. fertilized) the different soil test results should be used to develop the overall, uniform management plan.

Similarly, if two or more distinct soil types exist in the field, you should consider collecting separate samples from each. The same is true for fields with varying topographies or landscapes. Separate samples collected from each landscape position would help identify the variability that exists in the field and provide necessary information for developing an overall management plan.

Manure applications have also resulted in variability within fields and should also be considered when developing soil sampling scheme strategies.

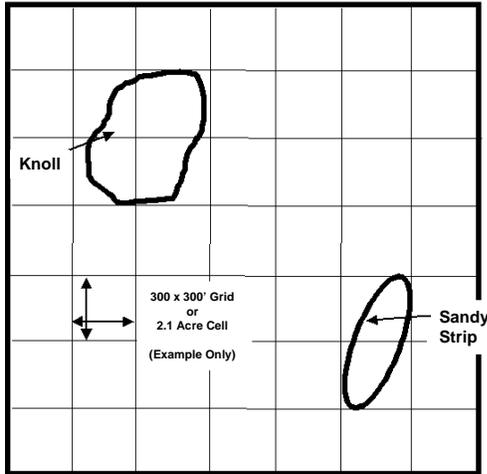
While farmers and their advisors have long recognized that fields vary widely in productive capability and soil characteristics, individual subsamples were randomly collected in order to get average soil test values for the whole field. While most wanted to identify variability existing in individual fields, there really was no efficient and economical way of handling, storing and interpreting multiple soil test results within a given field. Additionally, we had no way of accurately identifying where individual soil samples were collected from in a field in order to revisit those sites in future years.

Grid cell sampling is most commonly accomplished by laying out a previously identified grid over a field and then randomly collecting composite soil samples from within each cell of a field (see illustration). Each of these cells essentially is a subfield within the whole field with the soil test values being the average for each cell (2.1 acre subfields in the example below). A soil test map of a grid cell sampled field would essentially consist of numerous squares (subfields). The advantage of grid cell sampling is that interpolated data is not being generated for the field, only measured values are used. A major limitation is the cost of collecting composite sample from numerous small fields within the overall field in question.



Grid point sampling is accomplished by laying out the same type of grid over a field and then, using the grid as a guide, collecting soil samples from a particular spot, or point, in the field. Typically, several subsamples from

within a radius of 5 to 15' of the identified point are composited in order to eliminate the 'inch-to-inch' variability present in soils. Soil test results from grid point sampling schemes are applicable to individual points in a field and are not intended to be an average for any given area (subfield) of the field.



Field Grid Layout

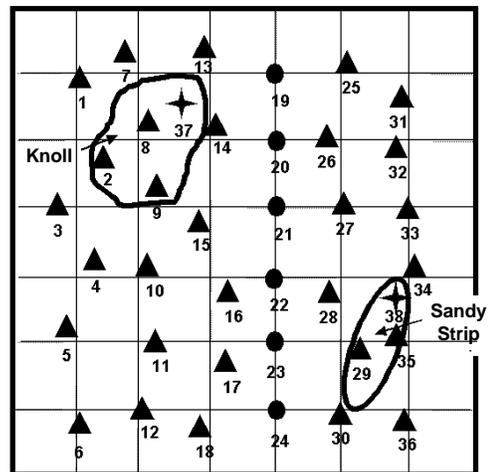
After processing point sample data with GIS computer software, a soil test map of a point sampled field might have smooth gradations across the range of soil test values within the field. While there is error associated with the interpolated locations between known points, the information developed should be better than knowing nothing about variability within a field. By exercising some common sense and grid point data can provide valuable nutrient management information. A major advantage of grid point sampling as compared to grid cell sampling systems is that much less labor is involved in collecting a given number of samples from a field. Several years ago the computer software did not exist to efficiently handle point sampled fields, and as a result, many early adopters of intensive soil sampling systems used cell sampling techniques. That has changed over the past several years, however.

Grid point sampling is preferred when intensively sampling fields if the intent is to identify the location and amount of variability within a field. Grid cell sampling, by design, masks much of the variability within a field

since the intent is to get an average of each small subfield.

It is probably best to not worry about sampling precisely at the predetermined grid locations. Many cultural operations, such as tillage, harvesting, fertilizer applications and other field operations, are performed in straight patterns in fields. Any of these operations can result in altering soil characteristics in these straight patterns and may provide misleading results if the sampling grid is laid out in a pattern similar to the cultural practice.

Additionally, there exists variability in fields that can be completely missed if strict adherence to predetermined grids is practiced. Notice the knoll and sandy strip in the field below. If this field had been sampled precisely at the computer generated grid points (such as samples #19-24), only one sample would have been taken from the knoll area – and the sandy strip would have been missed entirely. It is best to evaluate individual point sampling locations in the field in order to best represent the features and variability present (directed grid sampling).



Directed Grid Sampling

The selected grid size/identified sampling locations are useful in identifying general sampling locations in order to approximate the number of samples desired – but there should be a certain amount of randomness applied to selecting the actual sampling point.

Note in the field above that most of the samples were randomly distributed around each grid intersection.

Also, if additional samples are deemed to be needed in order to adequately describe field variability, simply take additional samples regardless of the computer generated grid. In the field above, note that sample #37 was added in order to fully define the knoll. Another sample (#38) may also be useful in describing the sandy strip.

It may also be desirable to collect additional samples from areas where one feature in a field transitions to another. In the example above, samples at the edge of the knoll and sandy strip would provide better information than simply taking a sample or two from the center of these areas.

The number of point samples that need to be collected from a field in order to adequately describe soil variability varies from field to field, from one geographic area to another and whether the variability of the soil characteristics being measured are in the responsive range. The optimum number of samples will also be very difficult to identify. There are many opinions being put forward, with most ranging from one-quarter acre per sample (~100 x 100' grid) to 2.5 acres per sample (330 x 330' grid).

Ideally, the optimum grid size would probably be one sample per acre (~210 X 210' grid), although this is probably not logistically or economically practical at this time. While this intensive a grid will normally provide better information than coarser grid sizes, most growers do not wish to make this large an investment at this time. It is likely that we will move toward one acre grid sizes in the future, however, as we become more efficient in collecting the samples.

From a practical standpoint, the largest grid size that should probably be considered is about two acres per sample (~300 x 300' grid) – if the exact field sampling locations are evaluated in the field and if additional samples are taken in order to define unique

areas. Some situations (alluvial flood plains with interspersed sand/clay lenses, for example) may require more intensive sampling. The following table provides a few standard grid sizes (ft) required to achieve a certain number of acres per sample or conversely the acres per sample resulting from various grid sizes.

Relation Between Grid Size and Acres per Sample	
Grid Size (ft)	Acres per Sample
100 x 100	0.23
150 x 150	0.52
180 x 180	0.74
200 x 200	0.92
210 X 210	1.00
250 x 250	1.43
295 X 295	2.00
300 x 300	2.07
330 x 330	2.50
360 X 360	3.00
400 x 400	3.67

Soil Sampling Depth

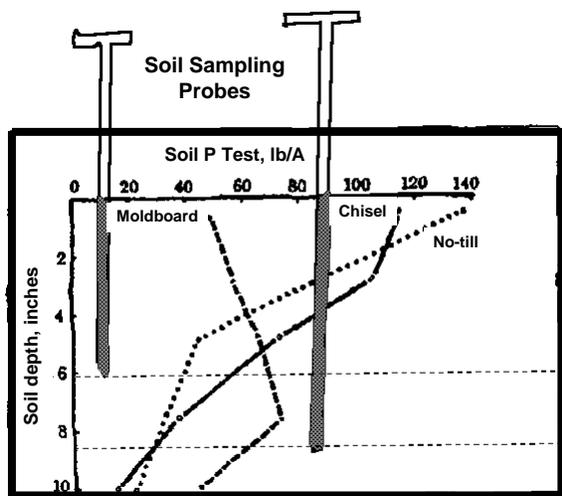
For most soil characteristics (P, K, organic matter, pH, micronutrients, etc.) routine soil samples should be taken to a depth of about 6-7 inches in order to ensure that the soil test results can be properly interpreted. Most soil test correlation/calibration research in Kansas and elsewhere was based on 6-7 inch soil samples. Consequently, in order to properly interpret soil test results we need to sample to the same depth as past research.

For no-till systems and alfalfa, the same 0 to 6" depth is recommended for P, K, Zn and organic matter. For pure no-till systems and alfalfa, it is recommended that a 0 to 2" sample be collected and evaluated for soil acidity and lime requirement.

Many people collect samples from 0-8 or even 0-10 or 0-12 inch depths. In the past, deep tillage operations such as moldboard plowing and other deeper tillage operations to a depth of 8-10 inches was common, and soil nutrients were distributed relatively uniformly throughout the surface 8-10 inches.

Consequently, sampling depth was less critical under these conditions since a 0-6 and 0-9 inch samples would provide about the same results. If there is a good soil test history for a field based on 0-8" samples it is best to continue sampling to this depth since a soil test history is worth a great deal.

But with the advent of less and shallower tillage, soil test results may become stratified. In general the less aggressive the tillage system employed, the greater the tendency for immobile nutrients such as P, K and Zn to accumulate near the soil surface. Sampling deeper than 0-6 or 7 inches will result in lower than expected soil test values (relative to research base) and the soil test results will not be interpreted correctly. Additionally, other soil test characteristics - such as soil pH, buffer pH, organic matter, free lime, etc. - will also be inaccurately interpreted.



Distribution of soil P after three years of tillage and fertilization. (Minnesota)

For mobile nutrients such as nitrate, sulfur and chloride, a separate 0 to 24" sampling is recommended - or the soil depth if there is an impenetrable layer at a shallower depth. For crops where too much N may have negative effects on quality, such as sugar beets, nitrate-N samples to 2-4 feet are preferred. Also, there are certain areas of the country that have regulations dictating deep nitrate-N samples for all crops receiving fertilizer nitrogen.

Whatever the soil sampling depth, it is important to be consistent. Varying sampling depths can have a major effect on soil test results when evaluating results across many fields or individual fields from year to year. Everyone that samples fields should know the depth to be collected from and understand the importance being consistent. The importance of appropriate, consistent sampling depths cannot be overemphasized!!

When Should Soil Samples Be Collected?

Soil samples can be collected anytime field conditions permit. A good time for most spring-planted crops is the previous fall. With early fall sampling, soil test results are normally received back in time to develop nutrient management plans over the winter while planning the next crop. Also, getting samples taken and analyzed well in advance of spring fertilization is advisable so you are ready for the spring season.

For forage crops, late summer is a good time to sample, although it can be done anytime. For fall-planted crops, sample well ahead of the late summer fertilization time frame.

The best time to sample is anytime well in advance of planting a crop that fits in the business plan of both the farmer and crop advisor that will be sampling the fields. Year-to-year, it is also best to be consistent in the time of year that samples are collected. Pick a time that works for both the people collecting the samples and the farmers rotations/tillage system.

How Often Do Soils Need To Be Sampled?

Residual soil nitrate-N, sulfate-S and chloride need to be sampled each year since they are mobile in soils and can fluctuate a great deal year.

For phosphorus, potassium, zinc, organic matter and soil pH, samples need to be collected every three years or so – after a field soil test history has been established. . Sampling every year is desirable but may not be feasible. The more often fields are sampled, the more information you have to work with and the greater your confidence in the information will be.

Care of Samples

Care should be taken to ensure that collected soil samples are properly cared for. Do not leave samples sitting in closed up vehicles after collection. Take them to where they will be protected from contamination. Preferably get them submitted to the laboratory as soon as possible.

If the samples are sent to the lab within a day or so of sampling they should not be dried with the exception of nitrate-N. For nitrate-N, or for samples that will not be immediately sent to the laboratory, the samples should be air dried in an area that will not result in contamination. Samples can be contaminated by just a few fertilizer granules, grain/grain dust, cigarette ashes and other foreign materials.

- Do not apply heat (no ovens).
- Do not use a microwave oven.
- A fan may be used to speed drying.
- Spread out on clean paper.
- Protection from contamination by *any* source, especially fertilizer, dust, cigarette ashes, etc.

Soil samples collected for nitrate-N analysis should be dried the day they are sampled. If drying cannot be accomplished at this time,

the samples can be frozen. Failure to follow this procedure will result in higher nitrate readings due to mineralization of organic N in the sample bag which may result in less fertilizer N being recommended than is actually needed.

Equipment For Soil Sampling

- Use lab supplied sample bags or boxes.
- Hand probe (shallow), power probe (deeper) or augers works well. The collected sample must be uniform and consistent.
- Clean plastic pail with rounded corners. No galvanized or rusty buckets!.
- Spray lubricants may help in wet soils.
- GPS for individual core locations (not absolutely necessary, but encouraged)

Selecting A Laboratory.

When deciding on which lab to submit samples to, it is important to keep in mind why you are hiring them. The following list includes the reasons for selecting a laboratory (in order from most important to least important).*

1. Accurate analytical results (good quality control--participates in Soil Test Proficiency Programs).
2. Appropriate soil test methods (tests that can be confidently interpreted).
3. Good service. For example, re-runs sample if error suspected, adopting new technologies such as bar-coding, etc.
4. Fast turn-around time, ability to return results electronically.
5. Cost.
6. Documentation of goals and objectives of recommendations they provide (if any).
7. The labs fertilizer recommendations.

* Numbers 1-4 above are the most Important when evaluating lab to use.

The KSU soil testing laboratory offers soil tests for all nutrients that are recommended. There are, however, many commercial laboratories operating today that have good quality control, perform appropriate

procedures, have good service and provide quick turn-around time at an affordable cost. Of the seven factors noted above, factors 1 through 4 are most important when evaluating laboratories.

Fertilizer rate recommendations and soil test procedures from different laboratories may vary considerably. It is very important that appropriate procedures are used, but you really are not hiring a laboratory for the recommendation generated by a computer, sitting beside a desk, in a laboratory, many miles away. Regardless of which laboratory is used, the analytical results should be locally interpreted in order to develop field/farmer specific nutrient management plans.

Don't split samples and send to multiple laboratories as a 'test'. If you do not have confidence in the analytical capabilities of the laboratory you are using, you should visit with them in order to gain confidence in them – or you should use a laboratory that you do have confidence in.

The main reason that people have wanted to send soil samples to different laboratories is to compare fertilizer rate recommendations – not analytical results. Soil test lab proficiency programs and lab professionalism help ensure accurate analytical results. Evaluate your laboratory on that basis, not split samples.

Appropriate Soil Tests

Laboratories can analyze samples for many, many things – but there are only certain soil test results that have meaning. For example, while laboratories can analyze and report results for extractable copper – the results are largely meaningless since deficiencies have not been observed in Kansas. If crop responses do not occur, it is impossible to develop a research calibrated soil test procedure. In fact, for any given area – it is unusual for more than a handful of essential plant nutrients to be deficient.

The following table presents several soil test procedures used by various laboratories.

While this information is most relevant to the Kansas and the Great Plains, it is also somewhat applicable to other parts of the country. Keep in mind that these are subjective ratings that may be open to discussion.

The bottom line is this - Only ask to have tests run that be interpreted based on appropriate research and reliable information.

Usefulness Of Common Soil Test Procedures For The Great Plains & Corn Belt

- * Unreliable and/or Provides Little Or No Useful Information
- ** Limited Reliability and/or Usefulness Is Limited Only A Few Very Specific Situations/Locations
- *** Fairly Reliable and/or Test Is Widely Used But Is Useful Only In Certain Situations/Locations
- **** Good Reliability and Test Generally Provides Useful Results For Many Situations/Locations
- ***** Excellent Reliability and Test Has Extensive/Wide Ranging Research Base Supporting It's Use

Soil Test Procedure	Reliability / Usefulness	Comments Relative To Best Fit and Precautions
Soil/Water pH	*****	Extensive research base supporting test. Indicates if liming is required. Values may vary up to 0.5 unit during year. Value > 7.3 generally indicates the presence of calcium carbonate (free lime). Value > 8.4 Indicates potential alkali/sodic soil problem.
Salt pH	****	Theoretically better than water pH – less variability throughout the year. Lacks widespread research base across most of country. Used by University of Missouri.
Buffer pH or Buffer Index	*****	Extensive research base supports use. Provides best estimate of how much lime required. SMP Buffer most widely used. Woodruff buffer possibly better on low CEC soils (sands).
% Organic Matter	****	Most laboratories used reliable procedures. Primarily used to determine relatively stable organic fraction. Fresh crop residues in soil samples results in faulty (high) values.
Cation Exchange Capacity (CEC)	***	Is most commonly estimated by summing cations (exchangeable K^+ , Ca^{++} , Mg^{++} , Na^+ , H^+) Summing cations provides good reliability on neutral-acid soils – overestimates on calcareous soils. Provides only marginally useful information, within geographic region generally estimates soil texture.
Soluble Salts (EC)	***	Most useful in arid regions to diagnose saline soil problems. Saturated paste extract method more reliable (and larger data base) than 1:1 soil:water method.
Excess Lime	***	Typically only indicates the presence of lime – not the amount. Typically classed as None, Low, Medium, High depending on degree of fizzing from HCl (acid)
Cation Ratios	*	Ca:Mg ratio most frequently referenced. Unreliable for nutritional or potential grass tetany diagnosis. Provides no useful information for crop production or nutrient management planning.
% Base Saturation	*	Estimate of proportion of CEC associated with basic cations (sum of K^+ , Mg^{++} , Ca^{++} and Na^+). Provides no useful information for crop production or nutrient management planning.
% K^+ , Mg^{++} , Ca^{++} , H^+ Saturation	*	Estimated proportion of CEC associated with each cation. Provides no useful information for crop production or nutrient management planning.
Exchangeable Sodium Percentage (ESP)	***	Useful for diagnosing alkali/sodic soils and estimating amendment requirements. Generally requires subsoil samples to determine extent of problems.

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- ***** Excellent Reliability and Test Has Extensive/Wide Ranging Research Base Supporting It's Use

Soil Test Procedure	Reliability / Usefulness	Comments Relative To Best Fit and Precautions
Phosphorus – Bray P-1	* to *****	Highly reliable on non-calcareous soils – Most extensive correlation/calibration research base. Unreliable and inaccurate on calcareous soils – may provide false low results.
Phosphorus – Olsen P	*** to ****	Developed for high pH-calcareous soils – largest research base for these soils. Has small research base for neutral-acid soils, but it is the preferred test for high pH-calcareous soils.
Phosphorus – Mehlich II or Mehlich III	*** to ****	Limited crop response research correlation/calibration base as compared to Bray P-1 or Olsen. Interpretation similar to Bray P-1. Works on Wide range of soils (acid-neutral-calcareous) Interpretation of results further complicated depending on if laboratory uses ICP vs. colorimetric procedure.
Phosphorus – Bray P-2	*	Originally developed to detect residual rock phosphate application to acid soils. While touted by some to measure 'residual P', it is poorly calibrated, provides no useful information and should not be used.
Potassium (exchangeable ammonium acetate)	*** to ****	Generally acceptable performance, especially for historical purposes. Fails to reflect K fertilizer application on some soils while Low soil test values not always associated with K fertilizer response (especially sands).
Zinc – DTPA Extractable	** to ****	Good reliability for responsive crops on calcareous soils. Much less confidence on neutral-acid soils.
Zinc – HCl Extractable	**	Limited research base and reliability on calcareous soils (where most Zn responses expected). Limited research base from low organic matter, sandy, neutral-acid soils
Sulfur - Sulfate	** to ***	Limited calibration base; due to inconsistent crop response. Soil texture (sands), low organic matter and crop grown better indicator of S need.
Iron – DTPA Extractable	**	Lack of calibration data. Limited usefulness on calcareous soils. Not useful for neutral-acid soils.
Calcium	**	Insufficient calibration research base. Calcium deficiencies rare.
Magnesium	**	Insufficient calibration research base. Magnesium deficiencies rare.
Manganese	**	Insufficient calibration research base. Deficiencies rare (most likely on over limed soils in eastern U.S.).
Molybdenum	*	Insufficient calibration research base. Molybdenum deficiencies very rare.
Boron	**	Insufficient calibration research base. Most confident in test for alfalfa grown in WI, MN, MI sands.
Copper	*	Insufficient calibration research base. Copper deficiencies rare. Copper deficiencies most likely (though not very common) for wheat in northern organic soils.

