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MONTANA STATE UNIVERSITY EXTENSION

MontGuide

Interpretation of Soil Test Reports for Agriculture

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Soil testing and interpreting soil test results are critical for determining optimum fertilizer rates.

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THE PURPOSE OF THIS GUIDE IS TO PROVIDE producers, Extension agents and crop advisers with the tools to better understand and interpret soil test reports. Data in soil reports is used to determine fertilizer rates and any need for soil amendments, thereby improving crop yield and profit. In addition, data is only worthwhile if the tested soil sample accurately represents the sampled field. Therefore, a summary of sampling methods is provided.

SOIL SAMPLING

To obtain meaningful and accurate soil test results, it is important to collect soil samples from the correct depth and from multiple locations within a field. Plan soil sampling to allow adequate time for soil analysis and fertilizer purchase prior to application and a minimum of 10 samples should be collected and composited (mixed) from each field.

Soil samples are typically collected using hand probes, hand augers (Figure 1), spades, shovels or vehicle-mounted hydraulic probes or augers (Figure 2). Unless they are the only option, avoid shovels and spades because they are not designed to obtain the same amount of soil from each depth and location, possibly biasing results. Hand augers are especially useful when sampling at different depths. Many Extension offices have hand probes or augers and may either lend out the tools or assist in soil sampling. Tools should be cleaned between fields and stored away from fertilizers to prevent contamination.

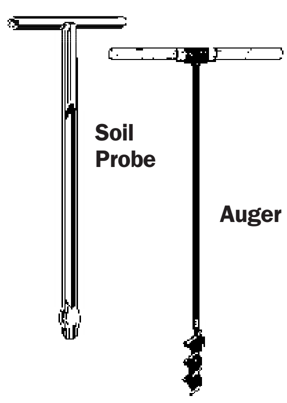

FIGURE 1. Soil sampling hand probe and auger.

Sampling Depth

FIGURE 2. Soil sampling vehicle-mounted hydraulic probe.

Soil samples are generally collected 0-6 inches and 6-24 inches from the soil surface. The lower depth is analyzed for nitrate 'as nitrogen' (nitrate-N), and sometimes for sulfate-sulfur (sulfate-S) and chloride (Cl), because these three nutrients are very soluble and can move in the soil more readily than other nutrients. Because high levels of nitrate-N may accumulate at deeper depths, especially in fallow systems, and because many crops root below two feet, nitrate-N is sometimes sampled below two feet. Unlike fallow systems, there is generally very little N below two feet in continuously cropped systems.

Sampling Time

Ideally, soil sampling occurs yearly in the spring to best estimate growing season nutrient availability; however, due to time constraints and soil conditions, it may be more practical to sample soil in the fall or winter. Sampling in the fall does not always capture the true amount of N that will be available at spring seeding because some N is released from soil organic matter (SOM) during the winter months in a process called "mineralization," or conversely, N in a very wet year, can be leached. Fall nitrate-N levels will be similar to spring nitrate-N levels if the fall and winter are cold and dry, because these conditions essentially stop N mineralization and leaching. Coarse or shallow soils (less than two feet) tend to have larger changes in nitrate levels over winter and should be sampled in the spring (Jones et al., 2011). Most importantly, submitted samples should be mixed from at least six samples within the field, and the soils frozen or dried immediately and quickly after sampling to prevent changes in nitrate concentrations. Please contact your local Extension agent for specific information on soil sampling plans and recommended methods to prepare samples for soil testing or refer to Nutrient Management Module 1. Resources mentioned here are listed under "For more information" at the end of this bulletin.

Soil Testing Laboratories

Fertilizer recommendations are only as good as the accuracy of the soil tests on which they are based. A fairly high degree of variability has been observed among testing laboratories. The time spent selecting a good laboratory can quickly pay for itself in the form of accurate fertilizer recommendations, desired crop responses and better economic returns. Laboratories that are part of the North American Proficiency Testing Program (NAPT) or the Agricultural Laboratory Proficiency Program (ALP) can provide you with results from their analysis of standardized soil samples with known nutrient levels. Laboratory analyses have a level of uncertainty based on test methods used and lab proficiency. Unfortunately, studies to date are inconclusive on which soil nutrients or characteristics are consistently reliable and which are less reliable and should be interpreted more broadly (Jacobsen et al., 2002; Miller, 2013). It is recommended that soil samples be sent to the same laboratory each year to ensure greater consistency.

Although most soil testing laboratories will test tissue samples, it is best to check first. *Soil, Plant and Water Analytical Laboratories for Montana Agriculture* explains the variety of analytical tests, methodologies and reporting units provided by laboratories as the basis for nutrient recommendations. A list of analytical laboratories in the region may be found on page 7.

TISSUE SAMPLING

In Montana, crop tissue sampled periodically during the growing season and tested for nutrient deficiencies has often led to inconsistent results, due to inconsistent tissue sampling, handling, preparation and shipping (Jackson, pers. comm.). Because it can take a couple of weeks between sending tissue samples, receiving test results and purchasing/applying fertilizer, yield losses may have already resulted by the time fertilizer is applied. Therefore, it is recommended to identify potential nutrient deficiencies by soil testing prior to the growing season. If you do decide to tissue test, please contact your local Extension agent for specific information on tissue sampling and sample preparation. The following guidelines are general guidelines only.

Although the specific plant part to be collected is plant-specific, the general recommendation is to collect recently mature leaves just below the new growth from at least 10 plants. Check with the laboratory to determine how many leaves they need for their analysis. Samples should be free of soil, fertilizer, dust and any other potential contaminants. A dry brush works best and the samples may be wiped with a cloth dampened with distilled water.

Do not wash samples under running water for risk of potential nutrient leaching. Samples should be air-dried in a shaded area and placed in a clean paper bag or envelope for delivery to a laboratory. Samples should not be placed in a metal container due to risk of contamination. If a nutrient deficiency is suspected, tissue sampling should occur when the symptoms first appear. Tissue samples from plants with deficiency symptoms should be collected along with samples from healthy plants for comparison. Although sufficiency ranges can likely be found on the Internet or in textbooks to compare with your tissue test results, these values have been determined for other regions, and not for Montana. Therefore, comparing your nutrient levels with healthy plants is likely the best comparison.

Again, tissue analysis should only be used to supplement a routine soil test done prior to the growing season. Tissue testing determines the availability of nutrients prior to the time that the test was taken; it is not a good estimate of current fertilizer needs. Visual assessment for in-season deficiency may also be useful; however, once nutrient deficiency symptoms appear, yield has likely already been hurt. See Nutrient Management Module 9 for more information on visual assessment. The remainder of this guide focuses on soil testing.

YIELD GOALS

Nitrogen fertilizer recommendations are based on yield goals; therefore, yield goals will be requested by your laboratory. Records of yield from previous harvests should be used to determine realistic, but progressive yield goals for each field. Appropriate yield goals for each field should be high enough to take advantage of high production years when they do occur, but not so high as to risk losing nutrients or reducing profits when weather conditions are not favorable. Appropriate yield goals are about five percent higher than the "Olympic" average (the lowest and highest yield are removed before averaging) over the past five years. If no records exist, yields can be roughly estimated by knowing soil available water, growing season precipitation and average yield per inch of water. Refer to *Estimating Small Grains Yield Potential from Stored Soil Water & Rainfall* for assistance in the determination of yield goals.

SOIL TEST DATA INTERPRETATION

Please refer to Figure 3 for a sample soil test report.

Macronutrients

Macronutrients that may be tested in your soil include N, phosphorus (P), potassium (K), S, calcium (Ca) and magnesium (Mg). Nitrogen, P and K are considered "primary" macronutrients, because they are required in higher quantities than S, Ca and Mg ("secondary" macronutrients), and because plants develop N, P and K deficiencies more often. In general, Ca and Mg are present in quantities well above the necessary levels in Montana soils and will not be discussed further.

Nitrogen. Plant available N includes nitrate (NO_3^-) and ammonium (NH_4^+). Of the two, nitrate is measured much more often in soil tests, because ammonium is quickly converted to nitrate, making ammonium levels relatively low compared to nitrate levels. Generally, in a soil test report, N is reported as NO_3^--N in lb N/acre. Nitrate can be produced through decomposition of SOM or easily leached through the soil from rainfall or irrigation; therefore, soil N tests are representative of current N levels and do not necessarily reflect future conditions.

Phosphorus and Potassium. Unlike N, P is highly immobile in the soil, making it less plant-available. Based on the results from 4.5 million soil samples collected throughout much of the U.S. and Canada from Fall 2009 to Spring 2010, the Northern Great Plains continue to have the lowest soil P levels (Fixen et al., 2010). Most Montana soils are high in calcium which ties up P, making it relatively unavailable to plants. Seventy percent of Montana soils tested below critical P levels for major crops in 2010 (Fixen et al., 2010).

There are three major soil tests used for available P: the Bray-1 and Mehlich-3 tests for acidic soils, and the Olsen P tests for neutral to alkaline soils. In Montana's alkaline soils, P is typically tested using Olsen P, also known as bicarbonate-P. Unfortunately, Bray and Mehlich test results do not convert readily to Olsen P, and because P fertilizer guidelines in *Fertilizer Guidelines for Montana Crops* are based on Olsen P, ask the soil testing lab to only test with Olsen P. In addition, Olsen P is fairly robust and works below pH 7. Bray, however, does not generally work well at higher pH (greater than 7).

Similar to P, most of the K in Montana soils is contained in minerals. Most Montana soils have medium-to-high available K levels due to relatively high amounts

FIGURE 3. Sample Soil Test Report and Fertilizer Recommendations

Name: Producer		**Sample Date:** April 1, 2007		
Lab Number: 12345		**Your Sample Number:** 1		
Crop to be Grown: Spring Wheat		**Previous Crop:** Fallow		
Sampling Depth: 0 to 24 inches		**Yield Goal:** 50 bu/acre		
Soil Test Results			**Interpretation**	**Recommendation**
Nitrate-N	0-6 in	37 lb/acre		
	6-24 in	36 lb/acre		
	0-24 in	73 lb/acre	Medium	90 lb N/acre
Olsen Phosphorus	0-6 in	15 ppm	Medium	20 lb P_2O_5/acre
Potassium	0-6 in	192 ppm	Medium	40 lb K_2O/acre
Sulfate-S	0-6 in	6 lb/acre		
	6-24 in	54 lb/acre		
	0-24 in	60 lb/acre	High	----------
Boron	0-6 in	0.5 ppm	Medium	1 lb B/acre
Copper	0-6 in	1.7 ppm	Very High	----------
Iron	0-6 in	47 ppm	Very High	----------
Manganese	0-6 in	10 ppm	Very High	----------
Zinc	0-6 in	1.3 ppm	High	----------
Soluble Salts	0-6 in	0.3	Low	----------
Organic Matter	0-6 in	3.4%	Medium	----------
Soil pH	0-6 in	7.7	Medium/High	----------
CEC	0-6 in	17.8	Medium	
Soil Texture	0-6 in	Sandy Loam		

of clay and low amounts of leaching. Although Montana soils are generally higher in K than much of North America, 11 percent of Montana soils tested below critical K levels for major crops in 2010 (Fixen et al., 2010). The common soil K extractant is ammonium acetate.

Over the growing season, K is removed from solution and soil exchange sites by crops, so K soil tests will be lower in late summer. Highest K levels will be measured in the spring just after the soil thaws and before plant uptake becomes substantial. It is recommended that soil be tested for K in the spring to provide the most accurate estimate of available K for crops that season. Plants can continuously absorb K beyond yield requirements, so it is important to test soil for nutrient availability to reduce profit loss from over-fertilization. Alfalfa is especially prone to excessive uptake of K ("luxury consumption").

Sulfur. Like P and K, only a small fraction of the total soil S is readily available to plants. Although the other secondary macronutrients are readily abundant in Montana soils, S deficiencies in Montana have been on the rise. Soil testing is not reliable to determine sulfur sufficiency. Visual symptoms along with soil type and location in the landscape can help determine plant sulfur deficiency. Loam or more coarse-textured soils, especially on eroded ridge tops, are more susceptible to sulfur deficiency, particularly after high rainfall. Unfortunately, responses to S fertilizer are much less consistent than for P and K, partly because concentrations of available S below typical sampling depths can be very high due to high levels of gypsum ($CaSO_4 \cdot 2H_2O$) in Montana soils.

Micronutrients

Micronutrients include copper (Cu), iron (Fe), manganese (Mn), zinc (Zn), boron (B), Cl, nickel (Ni) and molybdenum (Mo), all of which are naturally present in the soil. In general, Ni and Mo are present in quantities well above the necessary levels in Montana soils. Zinc and Cl tend to be low, especially for crops with high demands for Zn and Cl (Fixen et al., 2010). Because fewer micronutrient deficiencies are observed than macronutrient deficiencies, there has been little work in Montana to determine crop-specific micronutrient needs, yet general levels are shown in Table 1.

Soil Organic Matter

A two-percent SOM content is considered normal for Montana soils. Soils that contain greater amounts of SOM will mineralize more N and soils testing lower in SOM will mineralize less N. General guidelines are to reduce fertilizer N recommendations by 20 lb/acre for soils with greater than three percent SOM, and to increase fertilizer N recommendations by 20 lb/acre for soils with less than one percent SOM.

Soil pH

Soil pH is a measure of acidity or alkalinity. The pH scale ranges from 0-14, with 7 being neutral. Values less than 7 are acidic and values greater than 7 are alkaline. Most crops grow best with a soil pH between 6 (somewhat acidic) and 7.5 (slightly alkaline). In eastern Montana, surface soil pH is typically between 7-8, while western Montana soils tend to be slightly more acidic. Maximum nutrient availability occurs when pH is optimal for the

TABLE 1. Soil nutrient classes, toxicity levels and optimal pH. All levels displayed are for soil samples collected in the 0 – 6 inch soil depth.

Nutrient	Low Levels	Medium Levels	High Levels[a]	Toxicity Levels	Optimal pH
			ppm		
Nitrogen (N)	NA[b]	NA[b]	NA[b]	NA[c]	6.5 – 8
Phosphorus (P)	< 8	8 – 16	> 16	NA	6.5 – 8
Potassium (K)	< 150	150 – 250	> 250	800[d]	6.5 – 8
Sulfur (S)	NA	NA	NA	NA	6.5 – 8
Boron (B)	< 0.5	0.5 – 1.0	> 1.0	5[e]	5 – 7
Chloride (Cl)	NA	NA	NA	NA	5 – 7
Copper (Cu)	< 0.25	0.25 – 0.5	> 0.5	NA	5 – 7
Iron (Fe)	< 2.5	2.5 – 5.0	> 5.0	NA	5 – 7
Manganese (Mn)	< 0.5	0.5 – 1.0	> 1.0	NA	5 – 7
Zinc (Zn)	< 0.25	0.25 – 0.5	> 0.5	60[f]	5 – 7

[a] Comparable to critical levels; [b] Crop and yield goal dependent; [c] Crop and soil moisture dependent; [d] Horneck et al. (2011); [e] Westerman (1990);
[f] D. Neuman, pers. comm; NA – not available

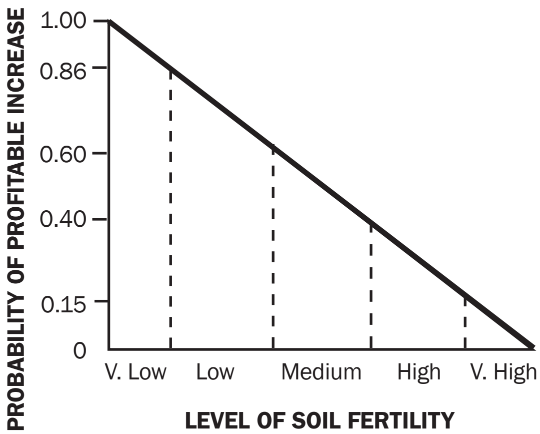

FIGURE 4. The effect of soil test level on the probability of a profitable yield increase from fertilization.

soil nutrient (Table 1). When soil pH is outside of these optimal ranges nutrients can be less available to plants, potentially resulting in deficiencies.

Liming is an option to increase pH in acidic soils. Decreasing soil pH is difficult. Fertilizing with ammonia-based fertilizers may decrease soil pH over time. Adding elemental S can decrease soil pH but it requires 10,000 lb/ac to lower the soil pH from 8 down to 7.5 in a soil with 1.5 percent calcium carbonate (Agvise Labs, unpublished data).

Soluble Salts

Soluble salts can cause severe water stress and nutritional imbalances in plants. Generally, seedlings are more sensitive than established plants to elevated soluble salt levels. Values higher than 4 mmhos/cm (or 'dS/m') may damage plants, though some crops, such as barley, are more tolerant to salts than others. A soluble salt level can quickly change in the soil due to leaching; therefore, consider sampling a few times per year if you think you have a salt problem. Please see Soil and Water Management Module 2 for more information.

Cation Exchange Capacity (CEC)

This parameter is only occasionally tested. The cation (positively charged particle) exchange capacity (CEC) is directly affected by soil pH and SOM content. A high CEC is desired and is indicative of a high capacity for the soil to hold cations (e.g. K^+, NH_4^+, Cu_2^+, Fe_2^+, and Mn_2^+). A CEC above 10 "milliequivalents" per 100 grams (10 meq/100 g) is considered adequate. The producer has almost no control over CEC.

Soil Nutrient Levels

Your soil test results will typically indicate whether a nutrient level is low, medium (moderate) or high (adequate). These levels are known as "nutrient classes" or categories and some labs may break these classes down further to very low, low, medium, high and very high. The cutoff between a medium and high level is sometimes referred to as a 'critical level' and provides a value that indicates when fertilizer should (below critical level) or should not (above critical level) be added.

Classes represent the chance of a yield response to fertilizer applications (Figure 4); at a low soil test level, there is approximately a 75 percent chance of a yield response to fertilizer applications, whereas, at a high soil test level there is approximately a 25 percent chance of a yield response to fertilizer applications. The probability of a yield response to fertilizer in the medium soil test range is estimated to be about 50 percent. To compare your nutrient level to MSU's established nutrient classes, refer to Table 1. Because there are so many factors such as moisture that affect nutrient availability and yield, fertilizing a soil that has a low or medium soil test level increases the likelihood that there will be a yield response, but does not guarantee a yield response. The chance for a yield response from fertilizing is higher at lower soil test levels, but again, it is not guaranteed. The chance of a yield response from fertilizing a soil with very high nutrient levels, is very low.

Fertilizer Recommendations

Soil test results typically include a fertilizer recommendation. Fertilizer recommendations are based upon the previous crop, the crop to be grown and the yield goals (just for N).

Recommended fertilizer rates may need to be adjusted based on climate and soil properties at your specific location due to the high degree of variability throughout the state of Montana and between labs. Out-of-state labs often do not use Montana guidelines. Please contact your local Extension agent or crop adviser for specific recommendations regarding your soil test results. If you want to determine your own fertilizer rates, especially

CALCULATION BOX. Fertilizer blend applied to meet P recommendations.

Using a fertilizer blend of 10-50-5:

Fraction of fertilizer = 10% N (0.10 lb N/lb fertilizer), 50% P_2O_5 (0.50 lb P_2O_5/lb fertilizer) and 5% K_2O (0.05 lb K_2O/lb fertilizer)

APPLICATION AMOUNT:

To apply 10 lb P_2O_5 using a fertilizer blend of 10-50-5:

Fertilizer Needed ÷ Fraction of Fertilizer = Fertilizer Blend Applied

(10 lb P_2O_5/acre) ÷ (0.50 lb P_2O_5/lb Fertilizer) = 20 lb Fertilizer/acre

when using an out of state laboratory, please see *Developing Fertilizer Recommendations for Agriculture*.

The recommended nutrient rates shown on a soil test report are for the actual amount of nutrient, not the amount of fertilizer. To determine fertilizer amounts, you will need to know the fertilizer 'grade' (the three numbers on every fertilizer). Grade equates to the percentage of total N, available phosphorus (P_2O_5) and soluble potassium (K_2O) present. For example, if a fertilizer is labeled 10-50-5, it contains 10 percent N, 50 percent P_2O_5 and 5 percent K_2O. If a significant source of a particular nutrient, other than N, P or K, is in the fertilizer, it is typically labeled as a fourth value. This is most often seen with fertilizers containing S (e.g., 21-0-0-24(S)). See the Calculation Box for an example fertilizer calculation based on a recommended P rate using a fertilizer blend. This sample calculation may also be used to determine the amount of fertilizer to apply to reach a specific N or K recommendation.

CONCLUSION

By using this guide to help interpret a soil test report, you can gain a better understanding of the soil fertility status of your fields or your producers' fields. This should provide the foundation to allow you to adjust fertilizer applications to optimize plant growth and fertilizer use. If you want to calculate your own fertilizer rates, please see *Developing Fertilizer Recommendations for Agriculture*. If you still have questions regarding your soil test report or fertilizer recommendations, please contact your local Extension agent (www.msuextension.org/localoffices.cfm) or crop adviser.

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FOR MORE INFORMATION

These bulletins, and many others, can be found by title under "Extension Publications" at http://landresources.montana.edu/soilfertility/, unless another link is provided, or by contacting MSU Extension Publications at (406) 994-3273, or online at www.msuextension.org/store/.

Developing Fertilizer Recommendations for Agriculture (MT200703AG)

Estimating Small Grains Yield Potential from Stored Soil Water & Rainfall (MT198325AG)

Fertilizer Guidelines for Montana Crops (EB0161)

Nutrient Management Modules (4449-1 to 4449-15)

No. 1. *Soil Sampling and Laboratory Selection*

No. 9. *Plant Nutrient Functions and Deficiency and Toxicity Symptoms*

Soil and Water Management Modules (4481-1 to 4481-5)

No. 2. *Salinity and Sodicity Management*

Soil, Plant, and Water Analytical Laboratories for Montana Agriculture (EB0150)

Soil, Plant and Water Analytical Laboratories

Italicized give recommendations based on Montana guidelines.

AgSource - Harris Laboratories
300 Speedway Circle
Lincoln, NE 68502
402-476-0300
http://agsource.crinet.com/page3777/

Agvise Laboratories
604 Hwy 15 West
PO Box 510
Northwood, ND, 58267
701-587-6010
www.agvise.com

B & C Ag Consultants
315 S 26th St.
Billings, MT 59107
406-259-5779

CSU Soil Water & Plant Testing Laboratory
200 W Lake St
Campus Delivery 1120
Fort Collins, CO 80523-1120
970-491-5061
www.soiltestinglab.colostate.edu

Energy Laboratories, Inc.
P.O. Box 30916
Billings, MT 59107
406-252-6325 or 800-735-4489
www.energylab.com

Midwest Laboratories, Inc.
13611 B Street
Omaha, NE 68144
402-334-7770
www.midwestlabs.com

MVTL Laboratories, Inc.
326 Center Street,
New Ulm, MN, 56073
800 782-3557
http://www.mvtl.com/
(the lab in Bismark does not do soil tests)

Sathe Analytical Laboratory, Inc.
302 2nd St. W.
Williston, ND 58801
701-572-3632
Email: sathelabs@nemont.net
(provide values without a recommendation)

Soil Testing Laboratory
North Dakota State University
1360 Bolley Dr.
Fargo, ND 58102
701-231-8942
www.ndsu.edu/soils/services/soil_testing_lab/

University of Idaho
Analytical Sciences Laboratory
Holm Research Center
2222 W. Sixth St.
Moscow, ID 83844
208-885-7081
www.webpages.uidaho.edu/asl/
(provide values without a recommendation)

USU Analytical Lab
9400 Old Main Hill
Logan, UT 84322-4830
435-797-2217
http://www.usual.usu.edu

Manure Analysis Proficiency (MAP) labs are listed by MN Dept. of Ag at www2.mda.state.mn.us/webapp/lis/maplabs.jsp

Note: There are likely other laboratories in the Northern Great Plains that can meet your analytical needs.

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