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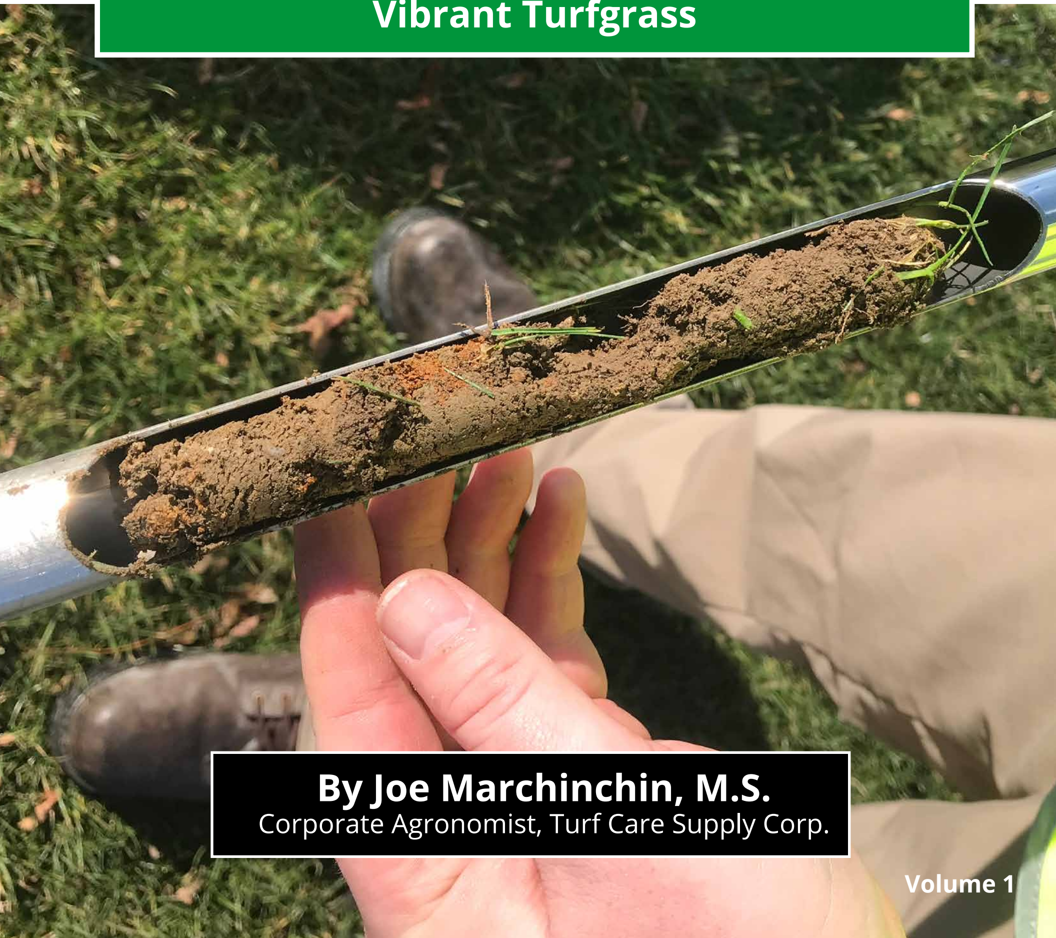
How to Read and Interpret A Soil Test

A Field Service Manual for Growing Healthy, Vibrant Turfgrass



By Joe Marchinchin, M.S.
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Volume 1

How to Read and Interpret A Soil Test:

A Field Service Manual for Growing Healthy, Vibrant Turfgrass (Volume 1)

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INTRODUCTION

Whether participating in a turf/agronomic conference or watching an informative video online, we've all heard that infamous suggestion prior to fertilization, "First, make sure to perform a soil test." If you're a superintendent of a golf course, there's a good chance that regular soil tests are an important component of your turf maintenance program. If you're a landscape professional (or LCO), you might only conduct a soil test if your client's turf health is struggling, or the client agrees to pay for it. If you're a typical D.I.Y./homeowner who just wants to get his/her fertilizer down, odds are you're going to skip it.

Realistically, if you want vibrant, healthy, lush green turf, you should perform a soil test and condition the soil at least once per year. Yes, depending on the lab and the nature of the services requested, soil tests can sometimes get expensive. But what is the cost of conducting an annual soil test versus the cost of replacing dead or dying turf with new seed or sod (including labor, new soil amendments, fertilizers, and control products), all due to lack of proper soil maintenance? Complete soil tests are very comprehensive, testing everything from pH and organic content, to macro and micronutrients. The good news is, **most labs offer a selection of specific tests a la carte**, which means as your soil becomes properly conditioned with time, you may no longer need a full panel of annual soil tests.

GETTING STARTED

Why perform a soil test?

A soil test helps agronomists, greenskeepers, lawn care operators and property owners determine which soil amendments and nutrients to add to the soil, and how much. **Without soil test data, applicators can only guess what to apply** (or not to apply) based on visual cues from the soil and overall plant vigor.

What questions are commonly addressed by a standard soil test?

- What is the macro and micronutrient content of my soil?
- What is the pH of my soil?
- What is the organic matter content of my soil?
- What is the cation exchange capacity (CEC) of my soil?
- What is my soil's texture?
- Does my soil suffer from heavy metal contamination?

What data is typically shown on a soil test?

A complete panel of standardized tests typically includes all of the following data:

- Macronutrient content (N, P, K, S) (often with fertilizer recommendations)
- Micronutrient content (Ca, Mg, Mn, Fe, Zn, Cu, B) (often with fertilizer recommendations)
- Other element/ion content (Na, Cl)
- Heavy metal content (Cd, Ni, Pb, Cr, Hg, As, Ba) (this is usually a separate add-on test)
- pH
- Cation exchange capacity (CEC) (with computed percent cation saturation)

- Excess lime rating
- Soluble salts
- Particle size analysis (with soil texture interpretation)
- Organic & Inorganic matter content (the ratio)

Now that we know which tests are typically conducted in a standard full soil analysis, let's go through each test one by one. In this handbook, **we'll cover pertinent background information related to each test and explain how to interpret your test results.**

It is our hope that the knowledge you gain here will help you make decisions so that you can positively influence soil to maximize the health and appearance of turf.

SAMPLE SOIL REPORT

A typical soil report (see fig. 1) will feature a full compliment of tests. As we'll learn, data from certain tests within a soil report often correlate with data from other tests.

In other words, **as you become familiar with reading and understanding soil reports, you'll begin to pick up on patterns** that will help you:

1. Validate your data
2. Make better decisions based on the data from the entire soil report, not just one or two individual tests that help comprise the report

Now that you have an idea of what a comprehensive soil report typically looks like, let's dive into analyzing each section, starting with the macronutrients.

Figure 1. Soil Test Analysis

Lab Number *293*	Sample Identification	Organic Matter L.O.I.		Phosphorus P1 Weak Bray 1:7		Phosphorus P2 Strong Bray 1:7		Phosphorus Olsen Bicarbonate		Potassium K (Neutral Ammonium Acetate (Exchangable))		Magnesium Mg (Neutral Ammonium Acetate (Exchangable))		Calcium Calcium (Neutral Ammonium Acetate (Exchangable))		Sodium Na (Neutral Ammonium Acetate (Exchangable))		pH Soil pH 1:1	pH Buffer Index	Cation Exchange Capacity C.E.C.	Percent Base Saturation (Computed)				
		Percent	Rate	Percent	Rate	PPM	Rate	PPM	Rate	PPM	Rate	PPM	Rate	PPM	Rate	PPM	Rate			Meq/100g	% K	% Mg	% Ca	% H	% Na
4962	W IA 1	2.8	M	18	M	34	M			139	M	343	VH	2438	M			5.7	6.6	19.5	1.8	14.7	62.5	21.0	
4963	W IA 2	2.0	L	10	L	21	M			188	H	478	VH	2274	M			5.6	6.5	20.7	2.3	19.2	54.9	23.6	
4964	W IA 3	2.7	M	21	M	35	M			251	H	562	VH	3564	H			6.6	6.8	24.6	2.6	19.0	72.4	6.0	
4965	C IA 6	3.7	H	99	VH	129	VH			288	VH	348	VH	2439	H			6.3	6.7	17.7	4.2	16.4	68.9	10.5	
4966	E NE	3.4	M	61	VH	117	VH			435	VH	325	VH	2355	H	12		6.4	6.8	17.2	6.5	15.7	68.5	9.0	0.3
4967	NE NE	0.9	VL	9	L	18	L			210	VH	127	VH	651	M			6.0	6.9	5.8	9.3	18.2	56.1	16.4	
4968	W NE	2.3	L	9	L	130	VH	23	VH	434	VH	416	VH	3057	H	161	VH	8.3		20.6	5.4	16.8	74.4	0.0	3.4
4969	E SD 1	3.1	M	16	M	32	M			160	M	586	VH	2165	M			6.2	6.7	18.3	2.2	26.7	59.2	11.9	
4970	E SD 2	3.2	M	31	VH	56	H			245	VH	710	VH	1910	M			5.9	6.6	19.4	3.2	30.5	49.2	17.1	

Lab Number *293*	Nitrate - N (FIA) Surface			Nitrate - N (FIA) Subsoil 1			Nitrate - N (FIA) Subsoil 2			Nitrate - N (FIA) Total	Sulfur S ICAP		Zinc Zn DTPA		Manganese Mn DTPA		Iron Fe DTPA		Copper Cu DTPA		Boron B SORB/DTPA		Excess Lime Rate	Soluable Salts	
	PPM	LBS/A	DEPTH (in)	PPM	LBS/A	DEPTH (in)	PPM	LBS/A	DEPTH (in)	LBS/A%	PPM	Rate	PPM	Rate	PPM	Rate	PPM	Rate	PPM	Rate	PPM	Rate		mmhos /cm	Rate
4962			0-8								14	M	0.9	L											
4963			0-6								13	M	0.4	VL											
4964			0-8								8	L	0.9	L	8	L	38	VH	1.3	H	0.5	L			
4965			0-8								22	H	11.6	VH											
4966	29	52	0-6							52	11	L	3.9	H	8	L	84	VH	1.6	H	0.8	M	L	0.4	L
4967			0-8								17	M	0.7	L											
4968	14	34	0-8							34	29	VH	2.3	M	3	VL	15	M	0.4	L	1.4	H	H	0.5	L
4969	7	17	0-8							17	72	VH	1.1	M	17	H	66	VH	1.3	H	1.5	H			
4970	12	29	0-8							29	16	M	1.2	M	16	H	77	VH	1.4	H	0.8	M			

Particle Size Analysis			
Sand %	Silt %	Clay %	Soil Texture
44	25	31	CLAY LOAM
60	16	25	SANDY CLAY LOAM
42	36	23	LOAM
40	35	25	LOAM

NITROGEN

What forms of nitrogen can plants take up?

For most plants, to assimilate **nitrogen**, the nitrogen must exist in one of two ionic forms: **ammonium (NH_4+)** or **nitrate (NO_3-)**. In the soil, most nitrogen-containing fertilizers (such as **urea** or **ammonium phosphate**) are first converted into ammonia gas (NH_3) by key soil bacteria. Then, in the presence of water (taking place below the soil surface), ammonia gas is converted into solid ammonium (NH_4+). Because ammonium has a positive charge of +1, it easily sticks to most soils (most soils have a predominantly negative charge, and in nature, opposite charges attract).

Once nitrogen has been converted into the ammoniacal form ("NH_4+ form"), plants have an excellent opportunity to take up nitrogen. Of note, if this reaction takes place above the soil surface, there is an excellent chance the ammonium will convert back to ammonia gas and be lost to the atmosphere in a process called **volatilization** (see fig. 2).

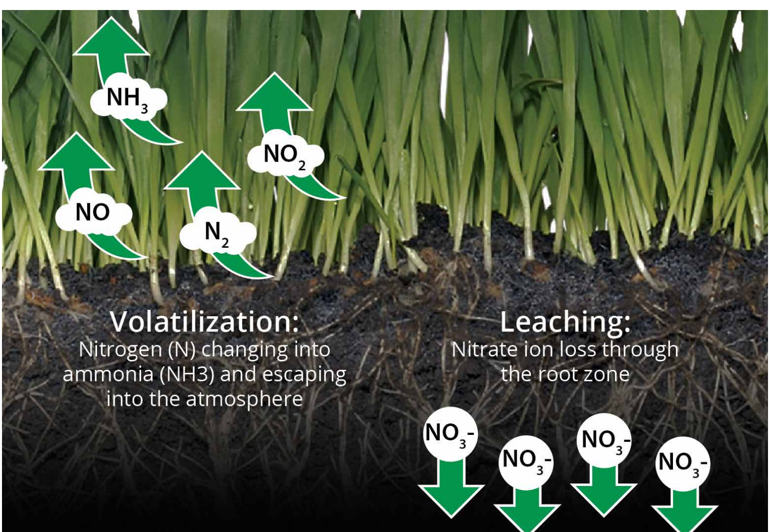


Figure 2. Volatilization and Leaching

Unfortunately, plants aren't the only organisms in the soil that interact with ammonium. Key soil bacteria can convert much of the ammonium (NH_4+) in the soil into nitrate (NO_3-) through multiple conversion steps. Even though nitrate is the only other form of nitrogen plants can take up, nitrate ions are very susceptible to **leaching** (see fig. 2) out of the root zone. This is because nitrate ions are both highly soluble and have a negative charge. (Again, most soils have a predominantly negative charge, and because like charges repel each other, nitrate ions tend to repel from soil particles when soils are saturated in water.) Nitrate ions can also be converted into different forms of nitrogen gas by other soil microbes; this process is called **denitrification**. If this happens, those gases (such as N_2, NO, NO_2) will also **volatize** and be lost to the atmosphere.

In essence, there are many factors in nature that are trying to rob your valuable nitrogen fertilizers from reaching their intended plant targets; hence the creation of slow release nitrogen (such as methylene urea), controlled release nitrogen (such as polymer coated urea), and stabilized nitrogen products (such as NBPT and DCD).

What forms of nitrogen do soil tests test for?

Most soil tests will quantify the level of nitrate in the soil because this is the most common form of nitrogen used by plants. This means that all other forms of nitrogen will not be detected (such as unconverted urea or ammonium); therefore a **nitrate test will NOT report the total nitrogen in the soil.** This is not necessarily a bad thing because organic forms of nitrogen are unusable to the plant. Ultimately, only nitrate and ammonium data tell us how much readily usable nitrogen is ready for plants to take up. (Note: the term **'organic'** refers to a **'carbon-containing'** molecule [such as urea; formula = $CO(NH_2)_2$]; **'inorganic'** refers to a **'non-carbon containing'** molecule [such as nitrate; formula = NO_3-]. For plant nutrients such as nitrogen to be taken up by the plant, they must exist in **'mineral'** or **'non-organic'** form.

NOTE: The term **'mineralized'** simply refers to a nutrient that exists in inorganic form). It is important to remember that fertilizers impregnated with nitrification inhibitors applied to the soil will radically affect the amount of total nitrate in the soil; this could lead one to believe there is much less nitrogen in the soil than in reality.

How is nitrate reported on a soil test?

Nitrate nitrogen is typically reported in parts per million (ppm). Many soil tests will also report the depth of the soil sample, as this data is useful determining how much total nitrate nitrogen is present within a given soil depth (almost always expressed in pounds per acre). Some reports will interpret the raw data and offer an opinion as to whether that value is considered low, medium or high.

Let's look at nitrate nitrogen results from several soil samples (see fig. 3).

Lab Number *293*	Nitrate - N (FIA)									
	Surface			Subsoil 1			Subsoil 2			Total LBS/A%
	PPM	LBS/A	DEPTH (in)	PPM	LBS/A	DEPTH (in)	PPM	LBS/A	DEPTH (in)	
4962			0-8							
4963			0-6							
4964			0-8							
4965			0-8							
4966	29	52	0-6							52
4967			0-8							
4968	14	34	0-8							34
4969	7	17	0-8							17
4970	12	29	0-8							29

Figure 3. Nitrate Nitrogen test results

First, note the 'lab number' column on the left. Each lab number (such as '4962') refers to a different soil sample. This report shows that four soil samples were tested (4966, 4968, 4969, and 4970) for nitrate nitrogen. Next, note that there are 3 sub-columns entitled 'Surface,' 'Subsoil 1,' and 'Subsoil 2.' These sub-columns reference the depth at which the soil samples were extracted. Notice that for these four tests, only the top 6 to 8 inches of soil were sampled (0-8 means the soil core was sampled from 0 to 8 inches down measuring from the surface).

NOTE: If someone wanted to have additional tests done on the soil below the 'surface' soil, then the report might also say "Sample 4966, Subsoil 1: 8-14, Subsoil 2: 14-20," which means the next sample would be taken between 8 and 14 inches below the surface, and the final sample would be taken between 14 and 20 inches below the surface.

Again, most nitrate ion concentrations in the soil are reported in ppm. This report also converts the ppm value into pounds of nitrate nitrogen per acre. If your report does not provide this conversion, you can use this equation to calculate pounds of nitrate nitrogen per acre from the ppm value:

- (Depth of soil sample in inches) x (ppm) x (0.3) = LBS/acre of nitrate nitrogen

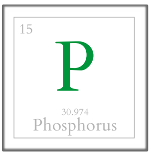
What are good soil nitrate nitrogen values that support healthy turf?

In the eastern United States, an unplanted farm field containing average textured soils with an average amount of organic material will typically show nitrate-N levels between 5-10 ppm. **Healthy turf is typically grown in soils that range anywhere from 3-20 ppm of nitrate-N.** If your soil samples are showing less than 3 ppm of nitrate-N, you probably have a nitrogen deficiency. Nitrate-N values above 20 ppm are often considered 'excess,' and the higher the value above 20 ppm, the more likely the soil will become acidified which could lead to turf burning.

There are many variables that affect how much fertilizer one should put down in order to influence a change in nitrate-N soil ppm (i.e. turf variety, average depth of root structure, soil structure, soil pH, the use of nitrification inhibitors, the use of biosolids or other slowly available nitrogen-based fertilizers, etc.).

Before adding any nitrogen-based fertilizers to the soil (or lime to neutralize an acidic soil), discuss the results of a soil test with an agronomist who understands your turf variety and soil conditions. Last, don't forget that many states and counties restrict the total amount of nitrogen you can apply to turf in a growing season, as well as when you can apply it.

PHOSPHORUS



Phosphorus is needed in large quantities by turf during seed establishment, sod establishment, and/or periods of rapid growth/cell division. Once turf has become established, significantly less phosphorus is required to maintain healthy turf growth and metabolism in subsequent years. Because of this, very little, if any phosphorus is applied to established turf. (This is why most turf fertilizers are phosphorus-free, with exception to 'starter' and 'general purpose' fertilizers.) The application of too much phosphorus can lead to leaching and ultimately the eutrophication of waterways (the formation of toxic algal blooms). Testing soils for phosphorus helps ensure that phosphorus levels remain within a safe range in the soil.

How is phosphorus tested?

There are four common phosphorus tests that laboratories perform:

- **P1 – Weak Bray Test** (often used in agriculture; okay for turf)
- **P2 – Strong Bray Test** (often used in agriculture; okay for turf)
- **Olsen Bicarbonate Test** (used when soil pH levels are unusually high; okay for turf)
- **Mehlich-3 Test** (good to use across a large range of soil pH values; ideal for turf)

Regardless of which test a laboratory uses, phosphorous levels are typically reported in ppm. The only difference between the P1 and P2 Bray test is the P2 Strong Bray Test extraction solution is 4 times more acidic than the P1 Bray Weak extraction solution; this means that the P2 Strong Bray test will extract more phosphorus from soil samples. When the same soil sample is run across both P1 and P2 tests, a 1:2 ratio is typically observed respectively, however the ratio could be as high as 1:5. The Olsen Bicarbonate Test is typically used when soil pH levels are so high, there is concern that the pH will interfere with the efficacy of the P1 or P2 Bray Tests. Last, the Mehlich-3 Test is another commonly used method to test for phosphorus and other nutrients in soils. This test can be used across a wide range of pH values, making it an ideal choice for regions with highly diverse soils.

What are good soil phosphorus values that support healthy turf?

If using the P1 – Weak Bray test, 20-30 ppm of P is considered 'good' or 'typical' for most turfgrass soils. If the results are below 20 ppm, a small phosphorus application is usually recommended. If the test value is higher than 35 ppm, the soil does not need any additional phosphorus.

NOTE: Occasionally, phosphorus ppm values come in very high- for example 60-100 ppm. Extremely high values usually indicate that a high-phosphorus containing fertilizer was recently applied. If very high values are reported on a soil test, check the values of micronutrient metals such as iron, zinc, or magnesium. If these micronutrients are also unusually high, these results suggest that manure or biosolids were likely recently applied.

If using the Olsen Bicarbonate Test, 15-20 ppm of P is considered 'good' or 'typical' for most turfgrasses. Remember, this test is only used in high pH situations.

If using the Mehlich-3 Test, 25-50 ppm of P is considered 'desirable' for most turfgrasses. Again, don't add any phosphorus if test results exceed 50 ppm P. Use a starter fertilizer sparingly if your test results fall below 25 ppm P.

Looking at the Figure 4 results, we see that 9 soil samples were tested for phosphorus. We also see that P1-Weak Bray Tests and P2-Strong Bray Tests were performed for all 9 samples. Note that sample 4968 was the only soil sample to have the additional Olsen Bicarbonate Test performed; that's because this soil's pH was unusually high (8.3). The other 8 samples had pH's ranging from 5.6 to 6.6. 'Good' results for the Olsen Bicarbonate Test are considered between 15-20 ppm, therefore a value of 23 suggests our phosphorus values are high. Last, note that each test value has a corresponding 'rate' or rating designation next to it. In this report, this laboratory has provided the reader with its own interpretation as to the level of phosphorus in each soil sample.

Lab Number *293*	Sample Identification	Phosphorus							
		P1 Weak Bray 1:7		P2 Strong Bray 1:7		Olsen Bicarbonate		Olsen Bicarbonate	
		Percent	Rate	PPM	Rate	PPM	Rate	PPM	Rate
4962	W IA 1	18	M	34	M				
4963	W IA 2	10	L	21	M				
4964	W IA 3	21	M	35	M				
4965	C IA 6	99	VH	129	VH				
4966	E NE	61	VH	117	VH				
4967	NE NE	9	L	18	L				
4968	W NE	9	L	130	VH	23	VH	23	VH
4969	E SD 1	16	M	32	M				
4970	E SD 2	31	VH	56	H				

Figure 4. Phosphorus test results

Key: L=low, M=medium, H=high, VH=very high.

Remember, some plants require more raw nutrients than others, so these interpretations are based on ‘average’ soil conditions and ‘average’ plant nutrient uptake. The data is what it is, but the results are always open for interpretation.

Let’s analyze one more example; sample 4965, which is a soil sample from central Iowa. The P1 and P2 Bray tests came in at 99 and 129 respectfully. Both results are marked ‘VH,’ suggesting the lab believes phosphorus levels are very high in the soil. Even though this sample doesn’t exhibit the typical 1:2 ratio between P1 and P2 Bray tests, both interpretations match each other, therefore we have a high degree of confidence that phosphorus levels are indeed high in the soil.

If your soil test shows excess levels of phosphorus, there’s not much you can do to reduce that value, but there are steps you can take to ensure the problem doesn’t get worse. Phosphorus tends to be immobile in the soil due to its low solubility, therefore it is imperative that any fertilizers you add to your turf are phosphorus free.

NOTE: Biosolids and manures may be great organic sources of fertilizer, but they usually come with a heavy phosphorus load. Make sure you know the phosphorus content of any fertilizers you apply so that the problem doesn’t compound.

POTASSIUM – MAGNESIUM – CALCIUM

Potassium, Magnesium, and Calcium are all essential plant macronutrients. In most soils, potassium, magnesium, and calcium base levels are usually adequate. **Potassium's** primary role in plants is to help regulate gas exchange and water content through the opening and closing of stomates (tiny pores on leaf blades) (see fig. 5). Potassium also helps plants defend against a variety of biotic and abiotic stresses. A single **magnesium** atom can be found at the center of every chlorophyll molecule in all plants; without magnesium, photosynthesis (the conversion of sunlight into usable energy for the purpose of fixing carbon and manufacturing sugar) would not be possible. **Calcium** is important for cell wall formation and tethering.

Figure 5. Stomates (tiny pores) on a magnified leaf blade

How are Potassium, Magnesium, and Calcium tested?

Potassium, magnesium, and calcium are typically quantified using either the **Neutral Ammonium Acetate Test** or the **Mehlich-3 Test.** The selected test is usually indicated on the report. All three of these macronutrients are cations (meaning each of these ions has a positive charge: K^+, Ca^{+2} Mg^{+2}) and are tested using the principals of cation exchange capacity (CEC). Let's break these nutrients down one at a time.

What are good soil potassium values that support healthy turf?

Turf is unusual in that thousands of studies have shown that most turfgrass varieties can look healthy whether potassium levels in the soil are sparse or abundant. This data makes it difficult to pinpoint an ideal range, however **if using the Neutral Ammonium Acetate Test, 200 ppm of K in the soil should be more than adequate for most turfgrass varieties. If using the Mehlich-3 Test, 40-80 ppm K is considered 'desirable' for turf.** If either test suggests your potassium levels are low, consider supplementing your turf with potash or langbeinite (KMAG).

NOTE: Don't use KMAG if your magnesium levels are already very high.

What are good soil magnesium and calcium values that support healthy turf?

Unfortunately, no current scientific methodologies for making ppm recommendations for magnesium and calcium currently exist for turf, therefore we cannot recommend a ppm range for these nutrients in the soil. At best, we can take averages of these nutrient levels in soils where turf is performing well and adjust our target soil accordingly. **Of note, many soils with adequate organic matter contain somewhere around 2000 ppm of calcium and at least 100 ppm of magnesium**, so these values may provide a good starting point for nutrient adjustments (consult an agronomist who knows your soil type and turfgrass variety for help). Currently, the only way to tell if plants are suffering from either a calcium or magnesium deficiency is to take a sample of fresh leaf tissue and perform a nutrient analysis directly on the plant. If nutrient values are low in plant tissues, check the results of a soil test to see if a correlation in the soil profile can be detected.

Let's look at potassium, magnesium, and calcium results from several soil samples in the table (see fig. 6).

		Neutral Ammonium Acetate (Exchangable)							
Lab Number *293*	**Sample Identification**	**Potassium** K		**Magnesium** Mg		**Calcium** Calcium		**Sodium** Na	
		PPM	Rate	PPM	Rate	PPM	Rate	PPM	Rate
4962	W IA 1	139	M	343	VH	2438	M		
4963	W IA 2	188	H	478	VH	2274	M		
4964	W IA 3	251	H	562	VH	3564	H		
4965	C IA 6	288	VH	348	VH	2439	H		
4966	E NE	435	VH	325	VH	2355	H	12	
4967	NE NE	210	VH	127	VH	651	M		
4968	W NE	434	VH	416	VH	3057	H	161	VH
4969	E SD 1	160	M	586	VH	2165	M		
4970	E SD 2	245	VH	710	VH	1910	M		

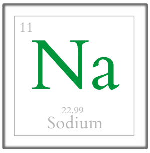
Figure 6. Potassium, Magnesium and Calcium test results

Using soil sample 4962 as an example, this sample from western Iowa is showing 139 ppm of K, 343 ppm of Mg, and 2438 ppm of Ca.

NOTE: The lab has chosen to give interpretations of the nutrient levels for each of these nutrients (K is medium, Mg is very high, and Ca is medium). It should be noted that these interpretations are being provided because the soil samples in question have been obtained from farm that intends to grow cash crops with the goal of attaining a certain yield. If these soil samples had come from turf, interpretations may not have been given.

The conclusion drawn from these tests is that these three nutrients appear to be abundant in all 9 samples with exception of calcium in sample 4967. In the case of sample 4967 (reporting 651 ppm Ca), a retest would be recommended. If a retest confirms this low test value, a mild liming application might be recommended to boost calcium levels and adjust the pH.

SODIUM



Saline soils are a problem in some parts of the United States, particularly in coastal regions and some of the more arid western states. In terms of nutritional value, **sodium** is only needed by plants in trace amounts. Too much sodium can draw water out of plant cells and lead to cell desiccation. Too much sodium in the soil can also interfere with water and nutrient uptake. Because most soils where turfgrass is grown have innately low sodium levels, most labs do not automatically test for sodium, so it's usually up to user to make this request. Sodium is commonly extracted and quantified using the Neutral Ammonium Acetate Test.

What are good soil sodium values that support healthy turf?

While each turfgrass variety has a different tolerance for sodium in the soil, **the general rule is, the lower the value the better.** Typical soils may show a range of values between 1 and 160 ppm. Sodium values below 80 ppm are considered 'low,' 81-120 ppm are considered 'medium,' 121-160 ppm are considered 'high,' and above 160 ppm are considered 'very high.' Soils that are very high in sodium are referred to as **sodic.** These soils are problematic for turf and other plants because sodium tends to displace other cation nutrients (such as magnesium, iron, etc.) that would otherwise cling to soil particles in the root zone. In this situation (when it rains), desirable nutrients can leach away leaving behind undesirable sodium ions.

Let’s look at sodium results from soil samples in the table (see fig. 7).

		Neutral Ammonium Acetate (Exchangable)							
Lab Number *293*	**Sample Identification**	**Potassium** K		**Magnesium** Mg		**Calcium** Calcium		**Sodium** Na	
		PPM	Rate	PPM	Rate	PPM	Rate	PPM	Rate
4962	W IA 1	139	M	343	VH	2438	M		
4963	W IA 2	188	H	478	VH	2274	M		
4964	W IA 3	251	H	562	VH	3564	H		
4965	C IA 6	288	VH	348	VH	2439	H		
4966	E NE	435	VH	325	VH	2355	H	12	
4967	NE NE	210	VH	127	VH	651	M		
4968	W NE	434	VH	416	VH	3057	H	161	VH
4969	E SD 1	160	M	586	VH	2165	M		
4970	E SD 2	245	VH	710	VH	1910	M		

Figure 7. Sodium test results

In Figure 7, only two soil samples were tested for sodium. As shown, sample 4966 is showing 12 ppm Na, which is considered ‘very low,’ and sample 4968 is showing 161 ppm Na, which is considered ‘very high’ (as indicated). If sodium levels are high, consider a gypsum application to flush the sodium out of the soil. When soils are adequately irrigated, calcium ions will attempt to displace the undesirable sodium ions.

WHAT IS PH?

Strictly by definition, pH is the concentration of hydrogen ions in a solution calculated on a logarithmic scale. pH is used to determine the acidity or alkalinity of a solution (or in our case, the soil). The scale typically runs from 1-14, with a pH of 7 being neutral (see fig. 8), however some very strong acids and bases can exceed this scale. **All organisms consist of tissues and/or metabolic systems that perform optimally under certain pH ranges.**

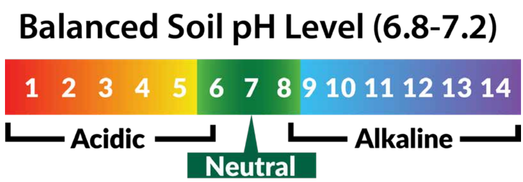


Figure 8. ph Scale

What are good soil pH values that support healthy turf?

Most turfgrass varieties prefer soils that are slightly acidic (somewhere between 6.5 and 7). Knowing your soil's pH is imperative because highly acidic or alkaline soils can interfere with soil nutrient chelation and plant nutrient uptake. Highly acidic or alkaline soils can also burn plant tissues and disrupt metabolic processes. The soil's pH will also influence the percent base saturation of key cations in the soil (we'll discuss 'percent base saturation' shortly).

As shown in Figure 9, the pH values of most of the samples range between 5.6 and 6.6, with 8.3 being an outlier. For those pHs below 6.5, a slight liming application would probably be recommended. For the soil sample with a pH of 8.3, an application of elemental sulfur or ammonium sulfate might be recommended.

Lab Number *293*	Sample Identification	pH	
		Soil pH 1:1	Buffer Index
4962	W IA 1	5.7	6.6
4963	W IA 2	5.6	6.5
4964	W IA 3	6.6	6.8
4965	C IA 6	6.3	6.7
4966	E NE	6.4	6.8
4967	NE NE	6.0	6.9
4968	W NE	8.3	
4969	E SD 1	6.2	6.7
4970	E SD 2	5.9	6.6

Figure 9. pH soil test results

Notice a 2nd column(see fig. 9) under pH called **'buffer index.'** The buffer index is a measure of how many hydrogen ions (sometime referred to as **'reserve acidity'**) are in the soil that are not detected by a pH meter in a soil sample dissolved in water. These hydrogen ions (also referred to as 'protons') are precipitated and detected using a buffer extraction solution. **The buffer index is used to help calculate how much lime is needed to raise the soil pH to a certain level.** This test does not show liming recommendations; it only gives the buffer index value.

In the event you need to raise or lower the pH of your soil, the following tables (see fig. 10 & 11) provide suggested application rates of limestone and elemental sulfur based on soil texture. Consult an agronomist to ensure these suggested application rates are amenable with your situation.

Approximate Amounts of Ground Limestone Needed to Raise pH* for Various Soil Textures					
lbs. ground limestone/1,000 f2					
Change in pH desi	Sand	Sandy Loam	Loam	Silt Loam	Clay Loam
4.0 to 6.5	60	115	161	193	230
4.5 to 6.5	51	96	133	161	193
5.0 to 6.5	41	78	106	129	152
5.5 to 6.5	28	60	78	92	106
6.0 to 6.5	14	32	41	51	55

*For NEW lawns, incorporate into soil to a depth of 6 inches before planting. For ESTABLISHED turfgrasses, reduce the rate by half and apply only during spring or fall in conjunction with core cultivation. Do not apply more than 50 pounds/1,000 square feet at one time. If using calcium oxide (CaO) or calcium hydroxide
Source: Kansas State University Agricultural Experiement Station and Cooperative Extension Service.

Figure 10. Approximate Amounts of Limestone Needed to Raise pH

Approximate Amounts of Elemental Sulfur Needed to Lower pH* for Various Soil Textures			
lbs. sulfur/1,000 f2			
Change in pH desired	Sand	Loam	Clay
4.0 to 6.5	46	57	69
4.5 to 6.5	28	34	46
5.0 to 6.5	11	18	23
5.5 to 6.5	2	4	7

* For NEW lawns, incorporate into soil to a depth of 6 inches before planting. For ESTABLISHED turfgrasses, reduce the rate by half and apply only during spring or fall in conjunction with core cultivation, and do not apply more than 5 pounds/1,000 square feet at one time. If applying to bentgrass putting greens do not apply more than 2 pounds/1,000 square feet at one time. If applying to annual bluegrass putting greens do not apply more
Source: Kansas State University Agricultural Experiement Station and Cooperative Extension Service.

Figure 11. Approximate Amounts of Sulfur Needed to Lower pH

NOTE: it takes time for lime to dissolve, work its way into the soil, and begin to neutralize an acidic, therefore gradual/split applications may be preferred over one mass application.

CATION EXCHANGE CAPACITY

Strictly by definition, **Cation Exchange Capacity (CEC)** is a measure of how many cations can be retained on soil particle surfaces. In many ways, soils are like magnets. Some magnets are relatively weak, such as a refrigerator magnet. Others, such as rare earth magnets, are extremely difficult to pry apart once they stick to each other. In other words, some soils are good at holding water and nutrients in place, while others are poor. Cations are ions that have a positive charge. Most cations have a charge of +1 or +2. Common cations in the soil include Potassium (K^{+1}), Magnesium (Mg^{+2}), Calcium (Ca^{+2}), Sodium (Na^{+1}), Manganese (Mn^{+2}), Zinc (Zn^{+2}), Copper (Cu^{+2}), Iron (Fe^{+2}), and Hydrogen ions (also called protons, H^{+1}).

How is CEC measured?

CEC is measured in 'millequivalents per 100 grams of soil' (units reported as = meq/100g). This value represents the number of cations the soil can hold in terms of the total number of electrical charges the soil can hold. Long story short, in general, the higher this number, the better. Low CEC values suggest that the soil is very sandy, and that nutrients will easily leach out of the root zone. High CEC values suggest the soil is loaded with clay and organic materials that do an excellent job holding nutrients in place.

What are ideal CEC values that support healthy turf?

While there is no 'universally ideal' CEC value that fits every turfgrass variety, climate, and soil type, soil CEC values typically range between 12-25 for most well-performing turfgrasses. Soils with CEC values higher than 25 are generally considered to be in 'excellent' condition.

Soil Texture and CEC Values

Soil Texture	Typical CEC (meq/100 g soil)
Sands	3-5
Loams	10-15
Silt loams	15-25
Clay and clay loams	20-50
Organic soils	50-100

Let's look at the CEC results from samples in the table (see fig. 12)

Lab Number *293*	Sample Identification	Cation Exchange Capacity C.E.C. Meq/100g
4962	W IA 1	19.5
4963	W IA 2	20.7
4964	W IA 3	24.6
4965	C IA 6	17.7
4966	E NE	17.2
4967	NE NE	5.8
4968	W NE	20.6
4969	E SD 1	18.3
4970	E SD 2	19.4

Figure 12. Cation Exchange Capacity test results

Looking Figure 12, most CEC values range from 17.2 to 24.6. These values are considered "normal" or "typical" of soils where most common turfgrass varieties perform well. The only outliner is sample 4967, reporting a value of 5.8. A CEC value of 5.8 suggests this soil cannot hold nutrients very well, which means this soil is probably sandy and doesn't contain much organic matter.

NOTE: This soil is low in phosphorus, and much lower in calcium than the other 8 samples, once again confirming that this soil is struggling to hold nutrients.

If your CEC values are low... consider adding organic material to the soil such as humic substances or biosolids. These materials do an excellent job chelating macro and micronutrients. Organic substances also increase soil water retention, helping to mitigate the effects of prolonged drought. NOTE: Remember that many organic substances (such as biosolids and manures) come with an N-P-K load, so make sure these soil amendments fit into your overall fertilization plan.

NOTE: For more information on the science behind Cation Exchange Capacity, see TurfCare's TurfReport blog, What is CEC & How Does It Impact Soil Fertility? https://www.turfcaresupply.com/joe-knows-cation-exchange-capacity

PERCENT BASE SATURATION

Now that we have a basic understanding of Cation Exchange Capacity, **Percent Base Saturation** is simply the concentration of the five most common cations in most soils relative to each other. Potassium, Magnesium, Calcium, Hydrogen and Sodium are taken into consideration. These five percentages should add up to 100% in the report.

What are 'ideal' or 'typical' range values for Percent Base Saturation that support healthy turf?

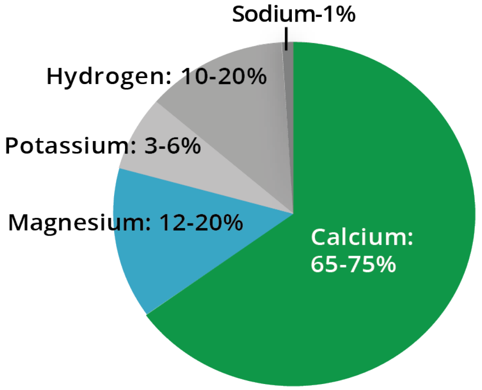
Again, while nutrient needs will vary across different species of turfgrass, in general, 'typical' soils that sustain healthy turf can expect the following cations to be distributed in the approximate ranges listed below:

- Potassium: 3-6% range is ideal
- Magnesium: 12-20% range is ideal
- Calcium: 65-75% range is ideal
- Hydrogen: under 10% is ideal, but 10-20% is common

NOTE: proton (H^+) concentrations of less than 10% typically yield a soil pH of 6.5 or above

- Sodium: a trace amount is ideal; the lower this percentage, the better

Pie chart of 'ideal' or 'typical' range values for Percent Base Saturation



Let's look at the Percent Base Saturation results from samples in the table (see fig. 13)

Lab Number *293*	Sample Identification	Percent Base Saturation (Computed) % K	% Mg	% Ca	% H	% Na
4962	W IA 1	1.8	14.7	62.5	21.0	
4963	W IA 2	2.3	19.2	54.9	23.6	
4964	W IA 3	2.6	19.0	72.4	6.0	
4965	C IA 6	4.2	16.4	68.9	10.5	
4966	E NE	6.5	15.7	68.5	9.0	0.3
4967	NE NE	9.3	18.2	56.1	16.4	
4968	W NE	5.4	16.8	74.4	0.0	3.4
4969	E SD 1	2.2	26.7	59.2	11.9	
4970	E SD 2	3.2	30.5	49.2	17.1	

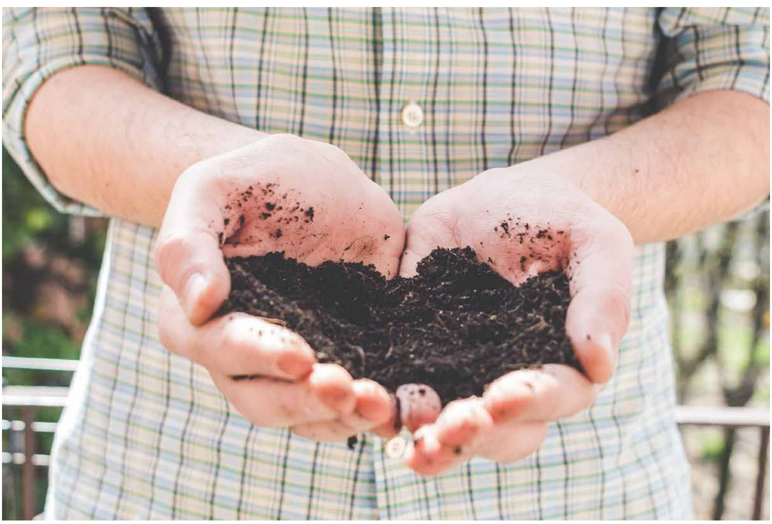
Figure 13. Percent Base Saturation test results

Figure 13 shows the percent breakdown of the five most common cations in each soil sample relative to each other. Note that in all cases, the percentages add up to 100% (as they should). Only two samples reported sodium percentages- that's because the sodium levels in the other 7 samples were too low to be reported. In general, these percentages don't deviate too far from the 'ideal' or 'typical' percent base saturation ranges we listed. Significant deviation could indicate a nutrient deficiency, nutrient toxicity, or an undesirable pH. Should these values appear to be abnormal, refer to the element section in this booklet for more guidance. Consult with an agronomist, if needed.

ORGANIC MATTER

Properties of Organic & Inorganic Matter

Organic matter is the carbon-based component of soil that was once living, but has undergone degradation through microbial digestion, heat, pressure, or any combination thereof. **Sand, silt, and clay are considered inorganic substances** because they are non-carbon containing (the exception to this rule is limestone; formula = $CaCO_3$ – even though lime contains carbon, it is considered inorganic). The only difference among sand, silt, and clay is particle size (sand consists of large particles, clay consists of microscopic particles, and silt is somewhere in the middle).



Humic substances (consisting of **humins, humic acids,** and **fulvic acids**) derived from **compost** (including grass clippings), **peat, biosolids,** and **manure** are all examples of organic matter. **Organic matter is extremely valuable in soils because it reduces soil compaction, increases water retention, chelates macro and micronutrients, and stimulates plants to produce well-developed root systems.** Soils that have little or no organic matter struggle to support turfgrass, or any plant life for that matter. For example, turf cannot grow in pure sand because sand is not capable of holding water and nutrients in place in the rootzone, nor are the conditions ideal for root hairs to take up water and nutrients. Remember, organic substances also hold organic forms of nitrogen, phosphorus, and other nutrients. Organic substances can act as both soil conditioners and fertilizers, however the nutrients embedded in organic substances can only be taken up by plants once they have been **mineralized** (in other words, converted into an inorganic form.) Pure humic substances tend to have very high CEC values and can be great for remediating poor soils, however humic substances applied at too high a quantity can shift the soil pH acidic.

NOTE: Before adding significant quantities of organic matter to any soil, consider the results of a full soil test, and consult an agronomist who understands your objectives.

What are ideal percentages of organic soil matter that support healthy turf?

In general, most soils supporting turfgrass could benefit from the supplementation of extra organic matter, but only to a certain extent, as too much organic matter can turn the soil acidic. It is important to establish an ideal balance of organic to inorganic matter. **Most soils supporting healthy turf are composed of 2-6% organic matter, with higher percentages usually preferred.** In general, soils below 2.5% organic material are considered 'organically poor.' Soils between 2.5-3.5% organic matter are considered 'average' or 'medium,' and soils above 3.5% are considered 'high' or 'ideal.' Only soils in excess of 20% organic matter are officially designated as 'organic soils.'

Let's look at the Organic Matter results from samples in table (see fig. 14)

Lab Number *293*	Sample Identification	Organic Matter L.O.I.	
		Percent	Rate
4962	W IA 1	2.8	M
4963	W IA 2	2.0	L
4964	W IA 3	2.7	M
4965	C IA 6	3.7	H
4966	E NE	3.4	M
4967	NE NE	0.9	VL
4968	W NE	2.3	L
4969	E SD 1	3.1	M
4970	E SD 2	3.2	M

Figure 14. Organic Matter test results

Figure 14 shows that the percentage of organic matter in each soil sample ranges from 2.0 to 3.7, except for sample 4967, reporting a value of 0.9%. This soil test also provides the reader with an interpretation of each result, indicating whether the organic content of each soil sample is very low (VL), low (L), medium (M), or high (H). In the event a soil sample shows a low percentage of organic matter, consider supplementing your turf with organic matter (such as purified humic substances, compost, biosolids, or manure). Be careful not to substantially drop the pH of the soil with any soil amendments you select. Also, remember that some organic substances contain moderate levels of nitrogen and phosphorus. The application of these soil amendments could significantly alter the application rate of any fertilizers you are currently using. Consult an agronomist for soil specific recommendations that will boost your soil's organic matter profile without resulting in the accidental over application of N, P, or K. An agronomist can help you select the right product at the right application rate.

SULFUR

Sulfur is an elemental component of two key amino acids (methionine and cysteine) found in all organisms, including plants. Without sulfur, every living organism would not be able to produce key proteins that make life possible. Sulfur typically exists in the soil as the polyatomic anion 'sulfate' (SO_4^{-2}). Elemental sulfur is also often used to lower the pH of alkaline soils.

How is sulfur tested?

Two common tests for sulfur quantification in soil samples are the **'ICAP test' (Inductively Coupled Argon Plasma test)** and the **'calcium phosphate extraction test.'** Sulfur can be reported in either lbs/acre or ppm, depending on lab preference. There usually exists a good correlation between soil organic content and sulfur concentration. Many organic materials (such as biosolids and manures) contain moderate to high levels of sulfur which are released into the soil over time with the help of microbes.

What are good sulfur soil levels that support healthy turf?

In general, soils should report at least 20ppm sulfur to be considered 'healthy.' Many soil tests will report the sulfur quantity in addition to an interpretation. Most interpretations will be based on a scale like the one listed below:

- 0-6 ppm = Very Low (VL)
- 7-12 ppm = Low (L)
- 13-18 ppm = Medium (M)
- 19-24 ppm = High (H)
- 24+ ppm = Very High (VH)

Let's look at the sulfur results from samples in the table (see fig. 15)

Lab Number *293*	Sulfur S ICAP PPM	Rate
4962	14	M
4963	13	M
4964	8	L
4965	22	H
4966	11	L
4967	17	M
4968	29	VH
4969	72	VH
4970	16	M

Figure 15. Sulfur test results

Looking at the table (see fig. 15), this soil report indicates the sulfur testing method used was the ICAP test. Sulfur is being reported in ppm. This report also gives the user an interpretation of the data. Across 8 of the 9 soil samples, sulfur quantities range from 8 to 29 ppm. Sample number 4969 is an outlier, reporting 72 ppm, which is unusually high. A small to moderate application of sulfur for those soil samples reporting low to medium values would generally be recommended. **Elemental sulfur, ammonium sulfate, and langbeinite (KMAG)** tend to be the three most cost-effective sulfur-containing fertilizer/soil amendments used with turfgrass.

It should be noted that while soil texture significantly influences sulfur's ability to be retained in the root zone, **the application of 1lb of elemental sulfur per 1000 ft^2 translates into roughly a 1 ppm upward shift on a standard soil test** (again, this equation should only be used as a starting point; consult an agronomist before attempting to adjust sulfur levels in your soil). If your soil is reporting an unusually high amount of sulfur, this could be due to either poor drainage (sulfur is very soluble and mobile in the soil) or a recent application of organic substances. In most cases, well-draining soils will see sulfur levels dissipate with enough irrigation and time. Don't forget, adding elemental sulfur lowers the pH of most soils, so bare in mind the soil's starting pH before applying sulfur-containing products.

ZINC, MANGANESE, IRON, COPPER, AND BORON

30	25	26	29	5
Zn	Mn	Fe	Cu	B
65.38	54.938	55.845	63.546	10.81
Zinc	Manganese	Iron	Copper	Boron

These five micronutrients are essential for plant health and their concentrations relative to each other vary greatly in the soil. Most soil tests report these micronutrient quantities in ppm. Some labs use **DTPA** (diethylenetriaminepentaacetic acid) as an extraction solution (as is indicated on the soil test underneath each micronutrient). Other labs use the Mehlich-3 extraction method.

What are good zinc, manganese, iron, copper, and boron soil levels that support healthy turf?

Instead of going in depth through each micronutrient one by one, we'll summarize the key points for each of these micronutrients. Remember, most micronutrients are only needed in trace amounts by plants. Excess micronutrient accumulation in the soil could lead to metal toxicity in plants, so it is important to add micronutrients sparingly should your soil require a micronutrient boost.

Zinc

- Trace amount needed by plants

- 2.0-3.0 ppm is ideal for most turfgrass varieties (using DTPA method)
- Excessive zinc levels are often attributed to recent applications of biosolids / manures
- Tip: If your zinc levels are high in the soil, but low in plant tissues:
    - ◊ Low zinc levels in plant tissues often correlate with large phosphorus soil applications, where phosphorus negatively impacts the plant's ability to take up zinc. If your turf is showing a zinc deficiency, check phosphorus levels in the soil to see if they are excessive.

Manganese

- 10-15 ppm is ideal for most turfgrass varieties (using DTPA method)
- Tip: When the soil pH is unusually low, adding more manganese in what 'appears' to be a manganese-deficiency situation (based on the results of a soil test) may create a manganese toxicity issue; try to balance the soil pH first, then test for manganese once more before adding additional manganese to the soil

NOTE: higher pHs = manganese tie-up in soil. Lower pHs = increased manganese availability in soil.

Iron

- Adequate soil iron levels are imperative for turf to have a lush, dark green appearance (iron is needed to synthesize the green photosynthetic pigment chlorophyll)
- 20-25 ppm is ideal for most turfgrass varieties (using DTPA method)
- Iron levels in excess of 50 ppm are common
- Tip: Iron availability is very pH dependent; higher pHs can tie-up iron in the soil. If you have unusually low iron levels, make pH adjustments first, then apply additional iron if necessary

Copper

- Trace amount needed by plants
- 1 ppm is ideal for most turfgrass varieties (using DTPA method)
- Like other micronutrient cations, a high soil pH can lead to copper tie-up
- If a copper application is needed, apply very sparingly

Boron

- Trace amount needed by plants
- Boron deficiencies in most soils are very rare
- 0.8-1.5 ppm is ideal for most turfgrass varieties (using DTPA method)

NOTE: Excess boron can be very toxic to germinating seeds

◊ Do not apply boron to newly established lawns (seed or sod)

◊ Do not apply boron in a starter fertilizer situation

Let's look at the Zinc, Manganese, Iron, Copper, and Boron results from samples in the table (see fig. 16)

Lab Number *293*	Zinc Zn DTPA		Manganese Mn DTPA		Iron Fe DTPA		Copper Cu DTPA		Boron B SORB/DTPA	
	PPM	Rate	PPM	Rate	PPM	Rate	PPM	Rate	PPM	Rate
4962	0.9	L								
4963	0.4	VL								
4964	0.9	L	8	L	38	VH	1.3	H	0.5	L
4965	11.6	VH								
4966	3.9	H	8	L	84	VH	1.6	H	0.8	M
4967	0.7	L								
4968	2.3	M	3	VL	15	M	0.4	L	1.4	H
4969	1.1	M	17	H	66	VH	1.3	H	1.5	H
4970	1.2	M	16	H	77	VH	1.4	H	0.8	M

Figure 16. Zinc, Manganese, Iron, Copper, Boron soil test results

Without going through each micronutrient and each result, here are a few general observations from this soil report. This report lists the extraction test method used (DTPA) and reports all test values in ppm. Note that some soil samples were not tested for manganese, iron, copper, or boron. The only two outliers from all samples tested were 1.) sample 4965, showing 11.6 ppm of zinc (very high) and 2.) sample 4968, showing 3 ppm of manganese (very low). Remember, soil pH has a major influence on micronutrient availability and uptake, so anytime you encounter unusually low or high micronutrient levels, always check the pH first.

EXCESS LIME RATING

The excess lime rating is a way to determine the soil's level of reactivity to the application of fertilizers or soil amendments that are acidic in nature. If the soil's excess lime rating is low (L), that means acidic compounds can be added to the soil with little or no expected reaction. If the soil's excess lime rating is high, that means a strong reaction is anticipated when acidic compounds are added. In chemistry, when strong acids and strong bases react, the result is the formation of a salt and a water molecule. The concept of excess lime rating is important because it helps users predict the efficacy of acidic compounds once they integrate with the soil.

What are good excess lime ratings that support healthy turf?

In general, low excess lime ratings are desirable. High excess lime ratings generally correlate with high pH values and nutrient tie-up in the soil. If your excess lime rating is unusually high, expect to see a high soil pH as well. **The table (see fig. 17) shows that only two soil samples were tested for excess lime.** Sample 4966 reported a 'low' rating and sample 4968 reported a 'high' rating. Always check to see if excess lime ratings logically correlate with the reported pH, and then make pH adjustments from that data as necessary.

Lab Number *293*	Excess Lime Rate
4962	
4963	
4964	
4965	
4966	L
4967	
4968	H
4969	
4970	

Figure 17. Excess Lime test results

SOLUBLE SALTS

Salts are common in nature and vary by concentration across different soil types. In general, excess salt content is detrimental to plants because salt acts like a magnet for water molecules. Salts tend to desiccate (dry out) plant cells and disrupt nutrient uptake. High salt levels can also interfere with a plant's metabolism and biochemistry. In most cases, testing for soluble salts is usually performed only when excess salts are suspected in the soil, or plants are visibly suffering despite adequate water and nutrition. Soils that contain unusually high levels of sodium are called 'sodic' or 'saline.'

How are soluble salts tested?

Soluble salt levels are measured in millimhos/cm (milli-ohms per centimeter) (electrical resistance is measured in 'ohms'). Salt levels are measured by dissolving a soil sample in either water or a buffer and measuring the electrical conductivity of the solution. (Pure water is an insulator, but dissolved salts will carry an electrical current across a liquid solution. The greater the current (or the less resistance), the higher the salt concentration in the soil.)

What are desirable soluble salt soil values that support healthy turf?

Different turf species and varieties have different capacities to survive and/or thrive in saline soils (for example, various marsh grasses that live in brackish water can tolerate significantly more salt than in-land marsh grasses in a fresh-water environment). As a rule for most turfgrass varieties, **most soils should aim for soluble salt values below 0.8 mmhos/cm.** The lower this number, the better.

Let's look at the soluble salts results from samples in the table (Fig. 16)

Lab Number *293*	Soluable Salts mmhos /cm	Rate
4962		
4963		
4964		
4965		
4966	0.4	L
4967		
4968	0.5	L
4969		
4970		

Figure 18. Soluble Salts Table

In the table above, we see that only two soil samples were tested for soluble salts. Samples 4966 and 4968 reported 0.4 and 0.5 mmhos/cm respectively. This report provides the user with interpretations of each value. In these examples, both ratings are considered 'low,' therefore there is no cause for concern. In the event soluble salt levels come in high, the best course of action is to flush the soil with water. Salt readily dissolves in water, therefore aggressive irrigation will help flush excess salts out of the root zone. Should fertilizer / nitrate leaching be cause for concern with excess irrigation, gypsum (calcium sulfate) can be used to help remediate the soil. Calcium is moderately effective at displacing sodium ions in the soil. (Note: Before applying gypsum to remediate saline soils, review all the results of a soil test with an agronomist in order to help calculate the correct applicate rate.)

PARTICLE SIZE ANALYSIS

Soils consist of organic and inorganic components. Particle size analysis is a representation of the ratio of differently sized inorganic particles comprising a soil sample. Generally, sand, silt and clay are all comprised of the same basic inorganic materials. Sand particles are the largest, followed by silt particles, and then clay (which is microscopic in size). Particle size analysis is important because the ratio of these differently sized particles is a good predictor of how well a soil will retain water and nutrients.

The effect of particle size on CEC

Particle size has a profound effect on a soil's ability to hold cation nutrients (recall the Cation Exchange Capacity section of this manual). This is because 'more' smaller particles per unit area generally hold more cations than 'fewer' larger particles per the same unit area; this is due to 'more' smaller particles having more total surface area. Clay particles are microscopic and can generally hold significantly more cations than silt or sand, therefore sandy soils generally have low cation exchange capacity values, and clay soils generally have much higher CEC values.

What is a loam?

A loam is a type of soil with 'roughly' equal parts of sand, silt and clay. Loam nomenclature is based on the ratio of the different components. **For particle size and soil percent composition nomenclature, (see fig. 19 & 20)**

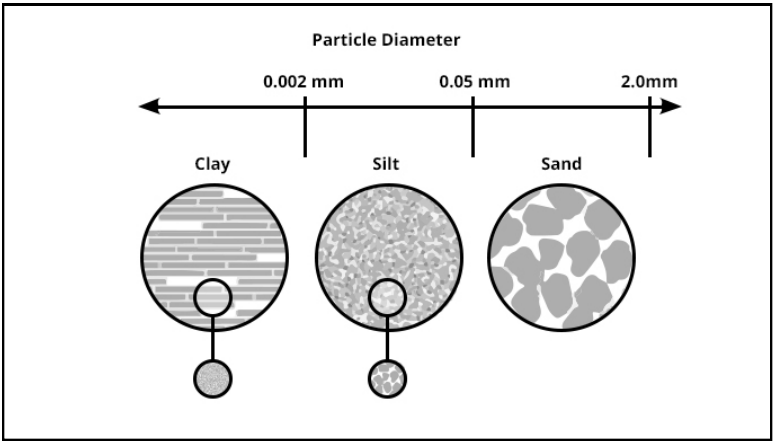


Figure 19. Particle Diameter Chart

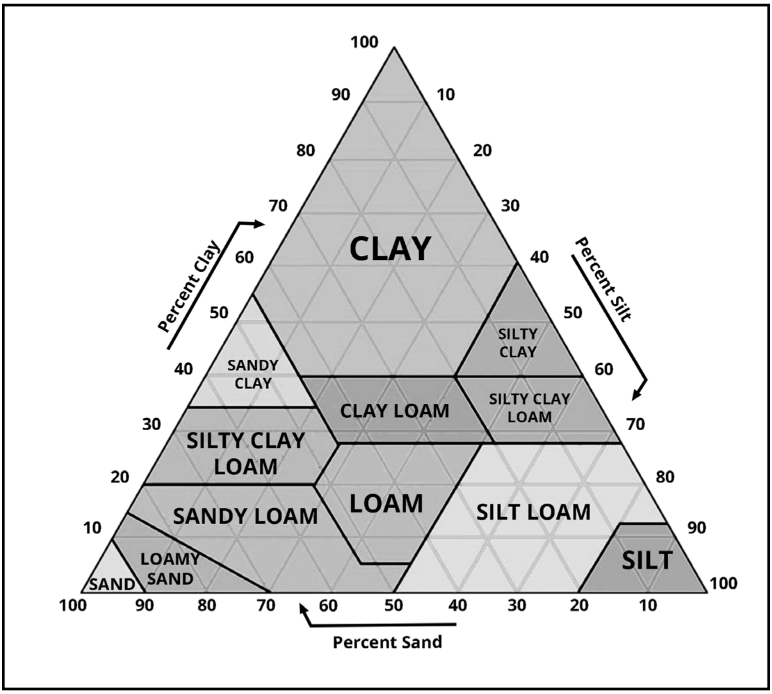


Figure 20. Soil Percent Composition Chart

What physical soil traits are ideal for growing healthy turf?

Turfgrass grows best in soils that are well-drained, yet have the capacity to retain water and nutrients. **An ideal soil won't lean too heavily in any single component.** Sandy soils struggle to retain water or nutrients. While clay soils tend to have higher CEC values, they are usually too compact; this leads to hindered root development and gas exchange. Silty soils tend to be slippery when wet and are more susceptible to erosion. Although silty soils are generally considered desirable in crop production, turfgrass grown in silt tends to 'give' under the pressure of foot traffic and mechanical agitation.

Let's look at the Particle Size Analysis results in the table (see fig. 21)

Particle Size Analysis			
Sand %	Silt %	Clay %	Soil Texture
44	25	31	CLAY LOAM
60	16	25	SANDY CLAY LOAM
42	36	23	LOAM
40	35	25	LOAM

Figure 21. Particle Size Analysis test results

The table above shows the particle size breakdown of 4 unnamed soil samples. An interpretation of the soil texture has been provided. Of all 4 samples, the sandy clay loam is likely to struggle the most to retain water and nutrients. The sandy clay loam is also very likely to have the lowest Cation Exchange Capacity (CEC) value. The **clay loam** might suffer from minor compaction issues, suggesting that this soil may benefit from **mechanical aeration.** Both loams have ideal characteristics for growing turfgrass (at least from a soil texture perspective). If your soils are high in sand or clay, consider topdressing your turf with organically rich top soil. Organic matter will increase a sandy soil's CEC and water holding capacity, and increase the depth of a viable root zone for heavily clay soils (with the help of core aeration). **Gypsum** has also been shown to help reduce **highly compacted soils.** For turfgrass grown in silty soils, consider adding a thin application of a sand-clay mix for stability. For bare ground (unplanted turf), cover the surface with a generous layer of organically-rich top soil before seeding or sodding.

FINAL THOUGHTS

When it comes to growing healthy turf, ornamentals, or other plants, it often seems that so much emphasis is placed on finding the right fertilizer and applying it at the right application rate. While a sound fertilization plan is important, it is just as important to remember that there is no substitute for good soil. Poor soils will struggle to hold water and nutrients, and struggle to support beneficial soil microbial communities that are essential for plant growth. Proper soil conditioning will ensure that your turf and ornamentals have the best possible chance of thriving, and that your valuable fertilizer inputs stay in the rootzone (as opposed to volatizing or leaching away). Good soils stimulate well-developed roots systems, and well-developed root systems are the foundation for healthy turf that can survive an onslaught of biotic and abiotic stresses.

I hope you found the information in this manual to be of exceptional value. If so, please email us; we'd love to receive your feedback!

We also welcome suggestions for future revisions of this manual. If there are specialty topics you believe would enhance this manual, let us know and we'll look in to covering them in future editions.

Wishing you nothing but the greenest and most vibrant lawns and ornamentals,

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Special thanks to all these additional resources:

https://www.paceturf.org/member/Documents/0109.pdf

https://www.agry.purdue.edu/ext/corn/news/timeless/assessavailablen.html

https://turf.unl.edu/turfinfo/Ideal%20Fertilizer%20Ratio.pdf

https://turf.unl.edu/NebGuides/g2265.pdf

http://www.basicknowledge101.com/pdf/Sodium%20Affected%20Soils.pdf

https://www.agvise.com/wp-content/uploads/2012/07/Interrpreting-a-Soil-Test-Report-high-res.pdf

https://www.homeguides.sfgate.com/ideal-percentage-organic-matter-soil-73408.html

https://midwestlabs.com/resource/sulfur-test-interpretation/

https://www.lawn-care-academy.com/clay-soil.html

https://www.bookstore.ksre.ksu.edu/pubs/MF2311.pdf