Clarifying soil testing: I. Saturated paste and dilute extracts

Superintendents who know how to interpret soil tests correctly can save their grass.

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Knowing the soil nutritional content and irrigation water quality of a particular site is critical to the development of successful fertilization, irrigation and soil management programs. Everybody knows that, right? And all of us recognize that the increasing use of effluent, reclaimed and nonpotable water and the growing incidence of salt-affected soils make educated use of soil and water testing even more essential (1) (Figure 1). As important as this information is, it is also overwhelmingly confusing and mysterious and, as a result, frequently misused.

Why so misunderstood?

Several good reasons lie behind all the misunderstanding. For example, different testing labs use different forms and different units to report results; the ranking scale for various measurements may not be provided or may be provided only in part; and different labs use different methods to achieve their results.

Layered on top of these differences is the queasy question of whose recommendations to trust because some soil and water testing is performed by companies that also sell fer-

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Figure 1. The increasing use of effluent, reclaimed and nonpotable water and the growing incidence of salt-affected soils make educated use of soil and water testing even more essential.

KEY points

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- **Because soil-testing labs** vary widely in their methods and interpretations, superintendents must know what types of tests to request and how to read the results.
- **On salt-affected sites** or sites with poor irrigation water quality, monitoring soil salinity (by electrical conductivity, ECe) and sodium permeability hazard (by sodium adsorption ratio, SAR) is essential for proper management decisions.
- **The SPE (saturated paste extract) procedure** is the standard means for measuring ECe, electrical conductivity, the SAR sodium adsorption ratio of soil and boron concentration.
- **Alternatives to the SPE procedure** often produce unreliable results.
- **Except for boron levels,** results from the SPE procedure should not be used to assess soil fertility.

tilizer, soil and water amendments.

Finally, some of the underlying principles are frequently explained in terms of equations and chemical symbols that are difficult to interpret and have a strange power, bringing back the nightmarish feelings associated with high school chemistry classes.

Regardless of where a soil test is conducted (university lab, commercial lab or a laboratory associated with a fertilizer company) or who provides the initial interpretation (laboratory, consultant or golf course superintendent), it is essential that the superintendent understand the soil test results and make the final interpretation with consideration for site-specific conditions. This article is the first of a series that will be published periodically by *GCM* to assist the golf course superintendent in bringing some clarity to this bewildering subject.

Extraction methods

In this article, we focus on the different extraction methods that laboratories use to measure soil salinity status and whether these methods can be used for assessing nutritional status of the soil. Understanding this is important, because use of the right extraction method will give you sound data that can keep your management programs responsive to the ever-changing conditions at your location. Using the incorrect extraction method (unfortunately, some labs do not use the right methods) can provide misleading — and, to be blunt, just plain wrong — information that can send a superintendent and his or her programs backward rather than forward.

Extraction: What it is, and why it matters

Soil macronutrient (nitrogen, N; phosphorus, P; potassium, K; calcium, Ca; magnesium, Mg; sulfur, S) and micronutrient (iron, Fe; manganese, Mn; copper, Cu; zinc, Zn; molybdenum, Mo; chlorine, Cl; boron, B; nickel, Ni) ions and compounds are soil salts along with sodium (Na). These are present in many different chemical forms ranging from water-soluble to very insoluble minerals. Different chemical fractions include:

- Salts dissolved in the soil solution as cations (positive charge) and anions (negative charge). These ions are readily available for plant uptake, but if the total salts concentration is too high, a saline condition can occur.
- Readily soluble salts that precipitate out of solution but can easily dissolve with rain or irrigation application. For example, as the soil starts to dry between irrigation events, Na^+ and Cl^- ions in solution may start to precipitate as sodium chloride (NaCl) crystals. If high levels of soluble salts are present as precipitated compounds, the soil will be saline.
- Cations on the soil cation-exchange sites, measured as the soil cation exchange capacity (CEC). The CEC nutrients are the most important pool of cations available for plants. Weak acids like ammonium acetate are often used to determine the CEC cations.
- Compounds that are slowly soluble, that is, they dissolve over a growing season and release nutrients for plant use. These are the second-most important pool of plant-available nutrients. Various chemical extractants such as weak acids, bicarbonates and chelates are used to determine the quantity of available nutrients from this pool.
- Very insoluble compounds and minerals that do not release significant quantities of nutrients or other salts over a growing season. These nutrients are not available to the plant.

Why does this matter? In order to get an

TURFGRASS SALINITY TOLERANCE

Sensitive (<3 dS/m)	Moderate (3-6 dS/m)	Somewhat tolerant (6-10 dS/m)	Tolerant (>10 dS/m)
Annual bluegrass	Annual ryegrass	Creeping bentgrass cv. Seaside	Alkaligrass
Colonial bentgrass	Chewings fescue	Perennial ryegrass	Bermudagrass
Kentucky bluegrass	Creeping bentgrass	Tall fescue	Seashore paspalum*
Rough bluegrass	Hard fescue	Buffalograss	St. Augustinegrass
Centipedegrass	Bahiagrass	Zoysiagrass	

*Some cultivars are salt-tolerant at ECe = 40-50 dS/m.

Table 1. Relative tolerance of turfgrasses to soil salinity (2). Soil salinity is reported in decisiemens per meter (dS/m) and is a measure of salinity or electrical conductivity. Blue = cool-season turf; red = warm-season turf.

Photo courtesy of Rick Brandenburg

Figure 2. For salt-affected soils or sites receiving irrigation water with moderate to high salt levels, an accurate determination of the levels of readily soluble salts and salts dissolved in the soil solution as ions is very important because these are the salts that plant roots experience in a field situation.

accurate picture of the soil's nutritional level, scientists must separate or extract the plant-available nutrients from the soil as effectively as possible (3,4,5,6,7). If the wrong methods are used, some nutrients may not be counted, and the report will show erroneously low readings. The reverse can happen as well; the wrong methods can also lead to readings that are much higher than the actual concentrations in the soil. Because some labs employ the wrong tests to measure the wrong nutrients, it is important to understand and to double-check not only the results, but also the methods used to obtain them.

Extracting water-soluble salts: The SPE procedure

It is not a complete surprise that ions in the soil-solution and soluble precipitated nutrients and salts described above — the first two groups — are most easily separated from the soil using water. Accurate determination of these two pools (separate from what is on the CEC or in the slowly soluble group) is very important for salt-affected soils or sites receiving irrigation water with moderate to high salt levels (Figure 2). The salts in these two fractions are what the plant roots experience in a field situation. The procedure and the quantity of water used in the extraction process affect the accuracy of the results.

The *saturated paste extraction* (SPE) procedure was developed by the U.S. Salinity Laboratory in 1954 (1) to determine the *electrical conductivity* (ECe) and *sodium adsorption ratio* (SAR) of soil. SPE is the standard extract procedure for these chemical determinations, and the vast majority of scientific literature reports the ECe and SAR values based on this method (1,2,3,4). The SPE method is based on bringing a soil sample just to the point of saturation with water, allowing it to equilibrate for at least two hours, and then extracting the soil solution by vacuum through a filter paper. The constituents of the soil solution and the amounts of these constituents are then analyzed using a variety of high-tech analytical tools such as spectrophotometers.

The SPE procedure is used primarily to provide the information needed to determine three important soil characteristics: electrical conductivity, the sodium absorption ratio and boron concentrations.

Electrical conductivity

Electrical conductivity (ECe) is based on the SPE method and is a measure of total soluble salts (TSS). Results are usually reported in units of decisiemens/meter (dS/m) or millimhos/centimeter (mmhos/cm). To estimate TSS, the ECe is multiplied by 640 to give a TSS value in parts per million (ppm) or milligrams/kilogram.

Electrical conductivity measurements are extremely useful for a variety of reasons. First, they can indicate whether soil is saline and therefore likely to cause problems for plant growth. (An ECe above 4.0 dS/m is considered saline.) Second, because different turf species and varieties have different tolerances to salts, the soil ECe can help predict how well a specific turf species or variety is going to perform (Table 1). Finally, regularly measured soil ECe can help in timing leaching events so that they take place before hazardous buildup of soil salts occurs.

Sodium adsorption ratio

The *sodium adsorption ratio* (SAR) is a measure of sodium permeability hazard or the potential for excess sodium to cause structural deterioration of the soil, which greatly impedes water movement and aeration. The soil-solution concentrations of Na, Ca and Mg expressed in milliequivalents per liter (meq/L) that are used in the SAR formula are based on the SPE procedure. SAR levels above 12 are considered adverse for soil and plant health. Ideally, SAR levels are 3 or lower.

Boron

The SPE procedure can also be used to obtain information on boron concentrations in the soil. Because boron deficiencies are rare (levels of 0.1-2 ppm are considered sufficient), this measurement is typically of use to ensure that boron levels are not too high. Cases of boron toxicity (levels above 6 ppm by SPE) typically occur when irrigation water is high in boron, when soils are naturally high in boron (this sometimes occurs in arid or semiarid climates), or when boron-containing fertilizers or compost amendments are applied in excess. Boron concentration can also be determined by a hot-water extraction method.

Alternatives to the SPE procedure: Reliability is an issue

Some labs use alternative methods known as dilute-water extraction procedures to quantify soluble salts, that is, using 1:2 or 1:5 soil:water dilutions. These methods are popular because they are somewhat easier to conduct than SPE procedures. However, dilute-water extractions are, in our opinion, not as accurate or reliable for quantifying TSS for several reasons (4,5,6,7).

Overestimates are possible. The dilute-water extract procedure is less predictable in its relationship to field soil-water content and more likely to remove salts from soil exchange sites and some of the slowly soluble salts. This would cause an overestimate of the concentration of soluble salts.

Measurements are indirect. Because these methods dilute the soil extracts, results obtained from dilute-water extracts must be mathematically converted, using correlation methods, to obtain a correct measurement of ECe. In other words, the dilute extraction methods provide only indirect measurements and are not as straightforward or accurate as the directly measured SPE-based determinations.

Correlations used by labs may vary. A reasonably accurate conversion of dilute EC to ECe requires an estimate of soil texture or percent clay content and the inclusion of a factor based on Cl content to estimate the ratio of soluble to slowly soluble salt (5). If the estimate of soil texture is incorrect, the conversion will be incorrect. Simpler conversion formulas have been developed for a narrow set of soils typical of a certain location. These formulas are reasonably accurate, but they do not apply to all soils.

EC measurements are not standardized. Some labs that use dilute extractions will report the EC value that results from analysis of the dilute solution, and different labs may use a different dilution, whereas others will adjust their results to a true ECe. This can result in big discrepancies. For example, an EC of 3.0 dS/m obtained using a dilute-extract method may actually be an ECe of 6 to 7 dS/m. These differences are very important when a golf course superintendent is managing a salt-sensitive plant. In addition, the differences make it impossible to compare results from one lab to the next.

Indirect SAR calculations. The dilute methods often remove more calcium and magnesium than the SPE method, which can lead to erroneous calculation of SAR values. Although some labs take this into account by performing mathematical conversions, the SAR value is obtained indirectly and is subject to error.

We hope that the above information has shown convincingly that the SPE procedure is the best way to determine ECe and SAR values accurately. Insist that the soil-testing laboratory use the SPE for determining these important parameters.

SOIL-EXTRACTABLE NUTRIENTS

	Greens		Fairways			
	Mehlich III	SPE	Mehlich III	SPE		
Parameter	ppm		ppm		$r^{2\dagger}$	CV (%)‡
P	106	1.5	71	0.5	<0.001	59
Ca	2,716	38	3,771	103	0.35**	29
Mg	343	13	907	36	0.52**	38
K	170	37	318	19	0.001**	50
Na	39	22	108	42	0.86**	34
SO_4	62	38	215	118	0.61**	39
B	1.0	0.10	1.5	0.13	0.51**	34
Fe	248	0.77	247	0.71	<0.001	42
Mn	33	0.03	67	0.02	<10.001*	94
Cu	4.4	0.03	5.6	0.02	<1	56
Zn	20	0.05	11	0.02	0.12**	92

†Coefficient of determination (r^2), which is a measure of the strength of the correlation, where a 1:1 relationship (ideal) would have $r^2 = 1.00$. An acceptable r^2 for a good, strong correlation whould be $r^2 > 0.80$.
‡Coefficient of variability, a measure of scatter of the data. The ideal is CV < 10%.
*Significant probability of *F*-test at 5% probability level.
** Significant probability of *F*-test at 1% probability level.

Table 2. Results of soil-extractable nutrients using Mehlich III (0.015 M NH_4F + 0.20 M CH_3COOH + 0.25 M NH_4NO_3 + 0.013 M HNO_3 = 0.0005 M EDTA chelating agent) and SPE (saturated paste extract) and comparison of extraction methods from 96 golf course soil samples.

Extracted nutrients ≠ soil fertility

Macro- and micronutrient concentrations can be measured by the SPE procedure, but these will not accurately reflect the soil's nutrient-supplying power and are inferior to more traditional and powerful extractants such as acids, bicarbonates and chelating agents in a variety of methods like Mehlich, Bray and Olson procedures (7). Water-based procedures, SPE or dilute, remove little or none of the two most important plant-available nutrient pools, namely, nutrients on the CEC and those in the slowly soluble fractions. Stronger chemicals (acids, bicarbonates, chelating agents) are necessary to assess these important fractions accurately. Thus, SPE is *not* the best method for determining soil fertility levels and can be very misleading.

A study: 24 Midwestern courses

In 1998, Steve Davis, in cooperation with Larry Stowell and R.N. Carrow, organized a study on 24 golf courses in the Midwest from Chicago to St. Louis. Soil and turfgrass tissue tests were obtained from sites superintendents considered their best and worst greens and best and worst fairways. With Stowell organizing the soil testing, half of the 96 soil samples were analyzed using Mehlich III extractant (as representative of a traditional, more vigorous acid-based extractant) and half were analyzed with the SPE water-based procedure. Table 2 provides the extractable levels of each nutrient for both extractants and the linear correlation information for comparing the methods.

Mehlich III vs. SPE

Mehlich III extracted much higher quantities of nutrients than SPE because it uses a double acid with chelating agent versus water. The absolute quantities obtained by both Mehlich III and SPE were most similar for Na, K and SO_4. This occurs because, with the exception of Na or K on the CEC sites, the common Na and K compounds in soil are primarily water-soluble and therefore extractable by water. Most of the plant-available sulfate also resides in solution or in soluble compounds that are water-extractable.

Sometimes a significant relationship (*F*-test < 0.05) can be observed between two methods, but it is a weak relationship. This is illustrated by Zn and Mn.

Of all the parameters, only Na exhibited a reasonable correlation of the two methods as demonstrated by a significant *F*-test, high r^2 and a marginal coefficient of variation.

This study demonstrates that levels of nutrients extracted by the SPE procedure substantially differ from the traditional Mehlich III extractant and that using SPE data for nutrient recommendations is not a science-based approach except for Na and SO_4, B, and a very rough approximation of K. Use of 1:2, 1:5 or other soil:water ratios would exhibit the same problems as the SPE approach.

SPE on low CEC sands

Some have suggested that the SPE would provide a better estimate of nutrient status than traditional extractants on low CEC sands. We disagree because of two problems with this approach. First, even on low CEC sands, the nutrients on the CEC are much greater than what is in the soil solution or what is readily soluble at any time. Nutrient levels obtained by the SPE procedure are, therefore, often less than 1% of what would be extracted by a Mehlich III procedure, with the exception of K, SO_4 and Na levels, which are usually 10-50% of Mehlich III. If salts in the soil solution and soluble precipitated salts were allowed to build up, the turf would be exposed to a salt stress, which is the reason we measure ECe and leach any excess salts.

Second, the soil-solution and soluble precipitated salts can be leached readily by rain or irrigation and are therefore no longer available to the plant. Thus, the water-based extractions are not as predictive over a growing season as are the more powerful extractants.

Coming up

In the next article in this series, we will discuss the pros and cons of the more vigorous extraction procedures, such as Mehlich III. Of special importance will be a discussion of the best conditions for using different extractants.

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