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Interpreting Soil Tests for Turfgrass

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잔디 토양 분석의 해석

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ABSTRACT

Soil testing laboratories unfamiliar with turfgrasses will often overestimate the plant's need for phosphorus and underestimate the need for potassium. This is partly due to differences in rooting between grasses and many garden plants and crops. The grasses are generally more efficient in extracting phosphorus from the soil, reducing their need for phosphorus fertilizer. The fact that crop yield is often the primary objective in field crop production, and is usually of little interest in turfgrass management, may affect soil test interpretation for potassium. Potassium levels above those required for maximum tissue yield of grasses may improve stress tolerance and turfgrasses will usually benefit from higher applications of this element. There are also differences in soil testing philosophies. Some laboratories use the sufficiency level of available nutrients(SLAN) approach, whereas others prefer the basic cation saturation ratio(BCSR) approach. Some will use a combination of the two methods. The use of the BCSR theory easily lends itself to abuse and questionable fertilizer applications and products are sometimes recommended citing imbalances in cation ratios. The usefulness of the BCSR ratio theory of soil testing varies with soil texture and interpretations on tests performed on sand-based media are particularly a problem. Other soil testing problems occur when sand-based media used on sports fields and golf greens contain free calcium carbonate. The ammonium acetate extractant at pH 7.0 dissolves excessive amounts of calcium that can bias cation exchange capacity measurements and measurements of cation ratios.

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Adjusting the pH of the extractant to 8.1 can improve the accuracy of the testing procedure for calcareous media.

Key words: *BCSR, potassium, SLAN, soil test, turfgrass*

INTRODUCTION

Soil testing is the process of measuring the plant-available nutrient status of the soil and of forming recommendations on which to base the fertility program. The process can also be available tool in evaluating salinity and for the identification of potential toxicities. Properly performed soil tests can provide important information on which to base a successful turfgrass management program(Christians, 1997).

Importance of Understanding CEC and pH

The standard soil test reporting form includes a series of measurements. The first thing that appears on most soil test forms is the cation exchange capacity(CEC). The units of the CEC test are milli-equivalents(meq)/100 g of soil. The number of meq is an estimate of the number of negative charges available to hold cations(positively charged ions). Table 1 lists relative CEC values for varying types of soil.

Sands are very low in CEC and have a much lower ability to hold and exchange cations than clays. Heavily trafficked areas such as golf course greens and sports fields are generally constructed of sands because of the tendency of heavier soils to compact. Organic matter is generally added to the sand media to help increase the CEC and water-holding capacity. Even when organic matter is added, CECs are still quite low. The CEC is not a measure of soil fertility, but of "potential" soil fertility. It measures the number of charges only. Determination of which cations are on the CEC sites is another part of soil testing.

The pH is usually the second item listed on most soil test forms. The pH values listed on the form is filled with useful information about the soil's ability to supply plant nutrients. Soil pH generally ranges from a low of 3 to a high of 11. Everything below 7 is called acidic and everything above 7 is called alkaline or basic. The midpoint 7 is the neutral point. The pH scale is

Table 1. Relative soil CEC values among soil properties.

Properties	CEC[z](meq 100 g^{-1})
Sand	< 1 - 6
Clay loam soil	25 - 30
Clay	80 - 120
Organic matter	150 - 500
Sand green	< 1 - 14

[z]CEC: cation exchange capacity

logarithmic, meaning that a change of pH from 5 to 6 is a change by a factor of 10, not 1. A change from 5 to 7 on the scale is a change by a factor of 100.

The pH value can reveal useful information about availability of nutrient elements to the plant, as well as provide clues to what is on the CEC sites. Acidic soils(those with low pH values) will have high amounts of H^+(aluminum may also play a role in very acidic soils) on the CEC sites, and will, by default, be low in the basic cations, such as calcium(Ca^{+2}), magnesium(Mg^{+2}), and potassium(K^+). Soils with pH levels above 8.2 may have high levels of sodium(Na^+) on the CEC sites and further testing to measure Na^+ levels are recommended whenever the pH exceeds 8.2. High pH soils can result in reduced availability of nutrients, such as iron(Fe^{+2}), manganese(Mn^{+2}), and zinc(Zn^+). A balanced availability of plant essential nutrients is found in the pH range of 6 to 7. Soils that have very low pH values should be limed to raise the pH. Excessively high pH values can be very difficult to lower. It is quite possible to grow quality turf in higher pH soils with appropriate modifications to the fertility program.

The third measurement listed on many soil test forms is the "buffer pH". The buffer pH provides the soil testing laboratory with an estimate of how much lime is required to raise the pH of acidic soils. Soils can vary in lime requirements by several thousand pounds per acre, and the buffer pH measurement should always be used in making lime recommendations.

To perform the buffer pH test, a buffer solution with a pH of 7.0 is added to a sample of the soil. Soils that are close to a pH 7 will have no effect on the pH of the buffer solution, whereas soils with acidic pHs will lower the pH of the buffer solution. The lower the pH of the soil, the more it lowers the pH of the buffer solution and the more lime will be needed to raise the pH of the soil. The buffer pH section on a standard soil test may be blank. The test is not performed if the soil pH is already 6.5 or above because no liming will be necessary.

Soil Availability of Nutrient

The remainder of most soil test forms list evaluations of the soil availability to provide plant essential elements. In some cases, this may be limited to phosphorus(P) and potassium(K) only, or it may include tests for other elements, including Mg, Ca, S, Zn, Mn, Cu, Fe, and boron(B). The percentage of organic matter may also be included.

Tests are usually not conducted for nitrogen(N). There are tests that accurately assess the N status of the soil for a given point in time, but N levels can vary from day to day and even hour to hour, depending on rainfall and other environmental factors. This is particularly true in irrigated turf grown on sandy soil media, where the N status can vary significantly in a single day. Experience and skill of the turf manager is required to visually evaluate the color and growth of the grass to develop a sound fertilization program for turf.

Procedures have been developed to test for the other essential elements. The information available on which to make interpretations of fertility needs for turf varies. While some tests are quite useful, others provide little information.

Soil testing laboratories vary in the way that they report the results of tests. Vocabulary like "low," "adequate," or "high" are used on some reporting forms, while others list numerical values along with the interpretation of whether the values are low, adequate, or high. The way of expressing numbers may also vary among laboratories. Some United States labs express the results in U.S. pounds per U.S. acre(lb/ac) of available nutrients. Others use parts per million(ppm), meaning that there is one unit available element per million units of soil. For instance, 1 pound per 1 million pounds of soil would be 1 ppm.

Soil tests in the United States are traditionally based on the "acre furrow slice," - the soil in the upper 6 to 7 in. of the profile. This term originated in the early days of soil test development. It relates to the depth of soil turned by a standard plow. An acre furrow slice of soil is considered to weigh 2,000,000 lb. Two pounds per acre is equivalent to 2 parts in 2 million lb. of soil. Two parts in 2 million is the same as 1 part in 1 million, or 1 ppm. Levels expressed in ppm will always be one-half of the lb/ac listing. A soil test of 20 ppm and 40 lb/ac are equivalent. When interpreting soil tests, be sure to identify whether the values are in lb/ac or ppm and interpret the results accordingly. In counties where the metric system is used, the results may also be listed in kilograms per hectare(kg/ha) or available element.

The percentage of base saturation is another basis on which cations may be listed. There is an important distinction in soil testing philosophy between the tests that list percentage of base saturation and those that list weights or ppm of available nutrients. A clear understanding of the two basic philosophies on which soil tests are based is an important part of making fertility recommendations for turf.

Soil Testing Philosophies: SLAN and BCSR

The two basic philosophies behind modern soil test procedures are known as the sufficiency level of available nutrient(SLAN) and the basic cation saturation ratio(BCSR) procedures(McClean, 1977). Some laboratories will use one or the other procedure, whereas others report the results from both types of test on their studies. Where both are listed, they can be used together to develop fertility recommendations.

The oldest of the two philosophies is the SLAN method. It is the method that has traditionally been used by most university soil testing laboratories in the United States. The SLAN method relies on extensive data gathered under field conditions. Response curves are generated for as many plant species and soil types as possible and where data exists, interpretations are based on field response studies. Estimates are based on closely related species and conditions when insufficient data exists for a particular crop or species.

The BCSR method is based on a different concept. By this philosophy, an ideal ratio of cations on the cation exchange sites will produce the best plant response. This concept has been the predominant one used by most private soil testing laboratories in the United States(McClean, 1977). The desired ratios vary somewhat, but approximately 60–65% for Ca^{+2}, 10–20% for Mg^{+2}, 5–10% for K^{+}, and 5–20% for H^{+} are considered a proper ratio. The interpretation of these tests often depends heavily on specific ratios of certain elements. Ratios such as the Ca^{+2}/Mg^{+2} and the $Mg^{+2}/\ K^{+}$ ratio are calculated and used in the interpretation. Applications of nutrients are recommended to restore the balance when a soil is tested and ratios are found to vary from prescribed values. These ratios can lead to erroneous assumptions for turf, and recommendations based solely on ratios should not be used to develop turf fertility programs(St. John, 2005).

One of the criticisms of the BCSR philosophy is that it is based on insufficient plant response data. It may also overestimate the need for some elements and may result in expensive fertility modifications. Much more research will be needed to resolve the controversies that arise over the two techniques and research will continue on the two philosophies in the future. The use of a combination of the two philosophies to make fertility recommendations can be an effective way to determining the fertility needs of turf. Before initiating an expensive modification of the soil's nutrient status based solely on the BCSR philosophy, SLAN results should also be obtained. The small costs of the additional test may prevent needless applications of nutrients.

SOIL TEST RESULTS

Interpreting Major Macronutrients

When we are choosing a soil test laboratory, it is important to pick one with individuals that are familiar with interpreting tests for turf. Laboratories that specialize in interpretations for garden plant and crops will generally overestimate the amount of P and underestimate the amount of K needed for turf(Christians, 1990). It is important to choose a laboratory that is specifically involved in soil testing for turf.

Phosphorus

Phosphorus is known for its relative immobility in the soil. Starter fertilizers that are high in P, such as 12-24-9, are generally used at the time of shoot establishment. The limited root system of grasses at establishment is not able to reach out to obtain sufficient P in the early development stages of the grass. At the same time, the P in the soil does not move readily in the soil solution to the vicinity of the root(Christians, 1996). As the grass matures, it develops a fibrous, multibranched root systems that is very efficient at removing P from the soil. Mature grasses are generally fertilized with materials low in P and high in N and K(i.e., 20-2-15), depending on soil test levels. Most garden and field crops require the application of higher P levels than those needed for grasses because they are less efficient at removing P from the soil.

Properly designed soil test procedures measure plant-available P, not total P. There may be much more P in the soil than that which is available to the plant. This is also true for each of the other elements that will be discussed. There are several different chemical extractants available to testing laboratories for measuring available P(Carrow, 1995 Christians, 1996;). The Bray 1 test is the most widely used by Midwestern laboratories in the United States. In the Northeast and Northwest on acidic soils, the Morgan test is often used. In the Southeastern states Mehlich I and III are used, and in the Western states on high pH soils, the Olsen extractant is generally used(Carrow et al., 2004a). The type of test used is important because the numbers generated by these tests will vary widely on different soils. It is important to identify which extractant was used before trying to interpret the results. Another extraction procedure called the "saturated paste" method has also been used in recent years. While this method is useful for salinity measurements, it is not useful for the extraction of P and most other elements(Carrow et al., 2003).

A Bray 1 test values of less than 30 ppm is generally interpreted as low by soil testing laboratories that typically make recommendations for gardens and field crops. Levels of 10 to 12 ppm are usually sufficient for turf(Christians, 1996). Kentucky bluegrass with Bray 1 values of as low as 7 ppm will generally show no measurable response to additional P applications. This is due to the efficiency with which grasses remove P from the soil and not to their low requirement for P. Table 2 includes information on which to base P interpretations for turf based on Bray 1 values. It is based on observations by the author and others involved in turf research. These numbers will provide a better P test interpretation for turf than the higher figures used for gardens and field crops. See Carrow et al.(2004b) and Petrovic et al.(2005) for sufficiency ranges based on other extractants.

Table 2. Phosphorus soil test values for turfgrasses based on Bray 1 extraction.

ppm	Range	pounds/acre (lb/acre)	kilograms/hectare (kg/ha)
0-5	Very low	0-10	0-11
6-10	Low	12-20	13-22
10-20	Adequate	20-40	22-45
> 20	High	> 40	> 45

Potassium

Potassium recommendations for turf have changed considerably in the last three decades. In the 1970's, fertilizer analyses such as 20-3-3 were common. Today, fertilizer analyses such as 20-3-15 or even 30-0-30 are more common. Supplemental applications of 0-0-50 are often used on turf. The reason for this change is an expansion of our understanding of turf response to K. Soil test interpretations traditionally were borrowed from other crops, where the primary goal of K fertilization is plant yield. Potassium plays an important role in stress tolerance as well as in plant growth and development. The ability of a bermudagrass green to tolerate wear stress, the ability of creeping bentgrass to survive high-temperature stress, perennial ryegrass cold tolerance, and many other stress related factors are affected by K. Maximum tissue production is reached at lower levels of available K than are some of these stress-related responses. The goal for the management of turf is the maintenance of quality and the ability of the turf to survive stress conditions, not maximum tissue production. Soil test laboratories will generally underestimate the amount of K needed by turf if they use numbers based on yield response data borrowed from other crops.

As with P, there are several extractants for K testing. Potassium extractants include ammonium acetate, Mehlich I, Mehlich III and Morgan. The Mehlich III has become popular as a universal extractant and is becoming widely used in recent years(Carrow et al., 2001).

Ranges of extractable K for turf are listed in Table 3. These are higher than those used for other crops. Exactly where these levels should be is somewhat controversial. The reason for this is that stress related responses are much more difficult to observe and document than is yield. There is some disagreement among soil scientists where these levels should be for turf and the values listed in Table 3 are based on several sources. But clearly, they are much closer to the needs of turf than are those currently used by many testing laboratories for garden and field crops. These numbers may change with time as more data on turf response to K are collected. For a more complete evaluation of critical levels based on varying extractants, see Carrow et al. (2001).

Table 3. Potassium soil test values for turfgrasses.

ppm	Range	pounds/acre (lb/acre)	kilograms/hectare (kg/ha)
0-40	Very low	0-80	0-90
41-175	Low	81-350	91-392
175-250	Adequate	350-500	392-560
> 250	High	> 500	> 560

Potassium levels will usually be quite low on soils with low CECs, such as sand-based greens and sports fields. On these low CEC soils, it will generally not be possible to build up K to the adequate test levels listed in Table 3. The reason for this is the lack of cation exchange sites to hold sufficient K. Sufficient K may be applied to build test values to the desired level on higher CEC soils. On these low-CEC soils, treating the grass with repeated applications of small amounts of K and other nutrients will be the best solution(Johnson et al., 2003). This is often referred to as "spoon feeding". Recent research on the K needs of creeping bentgrass on low CEC sand greens indicates that bentgrass is capable of obtaining sufficient K, even at soil test levels as low as 50 ppm(Woods, 2006; Woods et al, 2006). More work will be needed to evaluate the uptake of K by creeping bentgrass on low CEC soils.

Interpreting Other Elements

Extractants have been developed for the testing of the other essential elements. While the extraction procedures are quite good, the information on which to base interpretation of the results for turf is often quite poor.

Calcium(Ca)

Calcium deficiencies may occur at low pH levels, particularly on low-CEC soils. Calcium deficiencies are rare and are easily handled by the application of lime. There is a current trend by some consultants to recommend applications of calcium-based materials to golf course greens and sports fields even when Ca is already at high levels. St. John et al.(2001) found no need for these applications on Kentucky bluegrass and creeping bentgrass grown on calcareous media.

Magnesium(Mg)

Magnesium deficiencies can readily occur on sand-based green and sports fields that have a low-pH and a low-CEC. It is less common on high pH sands. Magnesium is found at the center of the chlorophyll molecule and plants deficient in Mg will be chlorotic or yellow. These deficiencies can easily be overcome by the application of Mg-containing materials.

A problem may occur when the BCSR method of soil testing is used. This soil testing philosophy may overestimate the need for Mg. This can particularly be a problem where Ca/Mg ratios are used to make the interpretations of Mg requirements. Expensive applications of Mg may be recommended when the ratio of the two elements is determined to be unsuitable. Turfgrass consultants may set a very narrow acceptable range for Ca/Mg ratios. St. John(2005) has found that turfgrasses respond well to much wider Ca/Mg ratios and that these supplementary applications of Mg may not be necessary. If supplemental Mg applications are recommended, a quick test to determine if they are needed is to apply light applications of magnesium sulfate($MgSO_4$) to a test area of the turf. A good source of this material is Epsom salts that can be purchased in drug stores. It should be applied at a level of 1 lb/1000 ft^2. Epsom salt is generally available in any drugstore and can also be obtained from turfgrass fertilizer distributers. If a response is observed, Mg is needed. If no response is observed, it is not needed. Be sure to get a second opinion from an independent testing laboratory if expensive modifications are recommended. Dolomitic lime is another source of both magnesium and calcium in soils where both elements are needed.

Iron(Fe)

It is on high pH soils where iron(Fe) deficiencies generally occur. While it is uncommon, deficiencies may also occur when the soil pH is below 7. Iron soil tests are available, but they are unreliable. It is common to see an iron response on soils with high test levels. It is also common to see no response when one is predicted. It is clear that these tests need further development. On high pH soils, a quick test to determine if iron is necessary is to apply iron on a test area. If the grass turns green, iron is needed. If there is no response, no iron is needed.

Manganese(Mn)

High soil pH levels also reduce the availability of manganese(Mn). It is not unusual for soil tests to show that Mn levels are low. The reliability of these tests is uncertain, however. As with Fe, a simple on-site test is one of the best ways to determine if there is really Mn deficiency. Apply a Mn containing micronutrient solution on a test area and leave an adjacent control area. Be sure that the nitrogen level is the same on both the test area and the control. If there is a visible response, then Mn should be applied.

Recent work has shown a reduction in take-all patch caused by the fungus *Gaeumannomyces graminis* on creeping bentgrass, when Mn was applied to the turf as manganese sulfate($MnSO_4$)(Heckman et al., 2003). Other tests have shown similar results with Mn, however, no reduction of take-all patch was observed where copper was applied(Hill et al., 1999).

Zinc(Zn)

As with Mn and Fe, high pHs will reduce Zinc(Zn) availability. Deficiencies are rarely found in turf. Concerns over phytotoxicity from excess Zn, however, have been raised for creeping bentgrass on golf course greens. Research has shown that creeping bentgrass can tolerate very high levels of soil Zn with no apparent damage(Christians and Spear, 1992; Spear and Christians, 1991). Zinc toxicities may occur on bermudagrass and St. Augustinegrass turf, but only at very high levels(Dr. A. Dudeck, personal communication). More work will be needed on a wide variety of turf species managed under a variety of conditions to obtain sufficient information on which to accurately interpret tests for this element.

Copper(Cu)

Copper(Cu), like Zn, is needed in very small quantities by grass plants, and like Zn, it becomes less available in high-pH soils. Copper deficiencies under field rarely ever occur. Copper toxicity can occur as white lesions on Kentucky bluegrass when tissue levels reached 656 ppm and on buffalograss when tissue levels reached 1620 ppm(Lee, 1995). Faust and Christians(2002a) found that the rooting of creeping bentgrass was reduced by 56% and 48% in silica and calcareous sand, respectively, at Cu levels of 600 ppm in the sand-based media. They also found that current extraction methods used by many soil test laboratories are highly variable in their ability to extract Cu from sand-based media(Faust and Christians, 2000b). More work will be needed before adequate interpretations of Cu tests can be made.

Boron(B)

Boron levels are usually not evaluated in standard soil tests. The plant needs minute quantities of this element to survive. Toxicity may be a concern on turf that is irrigated with sewage effluent water that is high in B. Although standards will vary with location and species, the figure that is generally used is that sewage effluent water should not exceed 1 ppm in solution(Richards, 1969).

Organic matter(OM)

Standard soil test often include evaluations of the percentage by weight of organic matter(OM). Dark soils will often have higher organic matter than lighter colored soils, although some light colored soils may contain significant organic matter. Organic matter levels of 2 to 3 % are often found in productive clay loam soils. Soils with very low OM content may benefit from the addition of organic amendments such as peat. High OM is not necessarily a good thing. This is particularly true in sod production, where sod grown on high OM soil may not root well to clay loam and sandy soils.

CONCLUSION

How many soil tests to perform each year is generally a budgetary question. A base of soil test information is recommended on new sites. For instance, on a newly constructed golf course every green, tee, and fairway should be tested. Once this base of information has been established, future testing can be done on grouped samples. Samples should be grouped in a logical way when limited testing is to be conducted. On the golf course, for instance, combine samples from greens with similar soil types. Likewise, other similar areas on tees and fairways on the course can be grouped for evaluation. In situations where pH modification is the goal or a fertility buildup program is under way, more extensive testing may be necessary. Complete tests on all areas can usually be separated by five years or more, depending on local conditions.

국문요약

잔디 작물에 익숙하지 않은 토양 분석 실험실에서는 잔디 생육에 필요한 인에 대하여서는 과대평가를 하나, 칼륨에 대한 요구도는 대해서는 과소평가를 하는 경향이 있다. 그 이유는 부분적으로 잔디, 정원식물 및 농작물 사이에는 뿌리 발달의 차이가 있기 때문이다. 일반적으로 잔디는 토양으로부터 인을 흡수하는데 좀 더 효율적이기 때문에 인산질 비료에 대한 요구도가 적은 편이다. 작물 재배시에는 농작물의 생산량이 주 목적이지만, 잔디밭 관리의 목적은 생산량이 아니기 때문에 근본적으로 칼륨요구 수준이 다르다. 최대의 엽조직 생산을 위해 요구되는 수준 이상의 칼륨은 스트레스에 대한 내성을 증가시킬 수 있기 때문에 칼륨 시비 수준을 높일 경우 잔디밭에 유익하다. 또한 토양분석 실험에 대한 철학에도 차이가 있다. 어떤 연구소는 기본적인

양이온 치환의 용량 접근법(BCSR)을 선호하는 반면, 다른 연구소는 사용 가능한 성분의 충분양(SLAN)에 대한 컨셉을 사용한다. 연구소에 따라 이 두 가지 방법을 모두 사용할 수도 있다. BCSR 이론의 사용은 대부분 비료 살포 남용을 야기한다. 그리고 문제가 될만한 비료의 살포와 제품들은 때때로 양이온의 비율의 불균형을 예증하기 위해 사용된다. 토양 실험에 있어서의 BCSR 비율 이론의 유용성은 토양의 구성에 따라 달라질 수 있고 특히 모래로 조성된 지반에서 수행된 토양분석은 문제가 될 수 있다. 또 다른 토양 실험의 문제는 경기장 또는 골프장 그린에 사용된 모래지반이 유리된 칼슘 탄산염을 함유하고 있을 때 발생한다. pH7.0의 암모늄 초산염 추출액은 양이온 치환량의 측정과 양이온 비율의 측정을 한쪽으로 치우치게 할 수 있는 과다한 양의 칼슘을 용해한다. 용질의 pH를 8.1로 맞추는 것은 석회질 토양에서의 실험 절차의 정확성을 향상시킬 수 있다.

주요어: 잔디, 칼륨, 토양 분석, BCSR, SLAN

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