

Soil Fertility for Turf Managers

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Prepared for 2002 Turf School

Nutrient availability in soil

Turfgrasses obtain 13 of 16 essential nutrients from the soil via the root system (Table 1). Although plant nutrients exist in soil in various forms, only specific forms can be taken into the root. Typically nutrients are taken up in ionic form, meaning they are charged species of the element and dissolved in solution. Positively charged ions are called cations and negatively charged ions are called anions. The superscript following the chemical symbols indicates the type and amount of charge. Soil derived nutrients and the predominant forms taken into the root are listed in Table 1.

Table 1. Soil derived nutrients, their chemical symbol, and the predominant forms taken into the root.

| Nutrient | Symbol | Form Taken into the Root [†] |
|------------|--------|---|
| Nitrogen | N | NO ₃ ⁻ (nitrate), NH ₄ ⁺ (ammonium) |
| Phosphorus | P | H ₂ PO ₄ ⁻ , HPO ₄ ²⁻ (phosphates) |
| Potassium | K | K ⁺ |
| Sulfur | S | SO ₄ ²⁻ (sulfate) |
| Calcium | Ca | Ca ²⁺ |
| Magnesium | Mg | Mg ²⁺ |
| Iron | Fe | Fe ²⁺ , Fe ³⁺ (ferrous, ferric iron) |
| Manganese | Mn | Mn ²⁺ |
| Copper | Cu | Cu ²⁺ |
| Zinc | Zn | Zn ²⁺ |
| Molybdenum | Mo | MoO ₄ ²⁻ (molybdate) |
| Boron | B | H ₃ BO ₃ , H ₃ BO ₂ ⁻ (boric acid, borate) |
| Chlorine | Cl | Cl ⁻ (chloride) |

[†] O = oxygen. H = hydrogen.

Potassium, calcium, and magnesium availability

The factors governing the availability of potassium (K), calcium (Ca), and magnesium (Mg) in soil are quite similar. Each occurs in soil as cations dissolved in solution and attached to the exchange sites on clay and organic matter, as well as in solid mineral forms. All three of these nutrients are taken into root system as cations.

Soils in the Carolinas contain few weatherable minerals so this fraction of K, Ca, and Mg supply contributes little available nutrient to the turfgrass plant. If K, Ca, and Mg bearing minerals do exist, or solid fertilizers are applied, they must first be dissolved to the cationic form in order to be taken up by the plant. The cations exist both in the soil solution and attached to the negatively charged sites on clay and organic matter particles (referred to as exchangeable). The turfgrass root accumulates the cation from the soil solution. Exchangeable cations replenish the soil solution.

Potassium, calcium, and magnesium availability is dependent on the total amount of each in the soil solution and on the exchange sites and on the ratio of each to the other. For example, high levels of Ca or K can cause Mg deficiency in turfgrass even though the amount of exchangeable and soil solution Mg would be sufficient in the absence of an overabundance of Ca or K.

Phosphorus availability

Phosphorus (P) availability in soils is nothing like that of K, Ca, and Mg. Phosphorus exists in several different forms in soil. In most native soils, organic and insoluble forms of P predominate. Organic P must be broken down (mineralized) by bacteria into soluble phosphates before it can be taken up by the turfgrass root system. Insoluble forms of P are iron (Fe) and aluminum (Al) phosphates at soil pH levels less than 7.0 and calcium phosphates at soil pH levels greater than 7.0. The fixation of P by Ca, Fe, and Al is minimized at a pH around 6.5, therefore the amount of phosphate (H_2PO_4^- or HPO_4^{2-}) in the soil solution is maximized. Plant roots can accumulate the soil solution phosphate.

Fertilizer P is usually applied to the turf in high solubility forms. However, once these forms dissolve to produce soil solution phosphates they are rapidly incorporated into organic matter and complexed with Fe, Al, and Ca. Fertilizers containing organic P and slightly soluble Ca phosphates undergo similar reactions as those discussed for similar soil P forms.

Understanding information on soil analysis reports

Chemical soil analyses are performed to determine the nutrient status of the soil and determine whether more of a particular nutrient is needed to grow a plant optimally. In order to use this information wisely it is necessary to understand how soil tests are conducted and how the data is reported. There are typically several different soil testing procedures for each nutrient that are considered valid. In some cases the acceptable method(s) are soil dependent.

Extractable nutrient levels

A significant difference among soil testing methods is the chemical composition of the extracting solution. Extracting solutions chemical concoctions are formulated to extract a portion of nutrient that is representative of the amount available to the turfgrass plant. In most cases the extracting solution does not extract the entire amount of available nutrient and it certainly does not extract the total nutrient content of the soil. Two extracting solutions of different composition can extract greatly different amounts of a nutrient from the soil but be equally effective in predicting sufficiency of that nutrient. Soil testing laboratories strive to use a single extracting solution for all nutrients tested. Their desire is to reduce turn-around time and labor needed to analyze a large number of samples. Fortunately many years of research have resulted in several extracting solutions that are suitable for nutrient analysis.

Extracting solution characteristics

Mehlich extracts

The predominately used extracting solutions in the Southeast are the Mehlich-1 and Mehlich-3 extract. These extracting agents are used to evaluate available P, K, Ca, Mg, Zn, Mn, Cu, and B. Although both were developed by Dr. Adolf Mehlich and they differ only by a numeral designation their compositions are quite different. Bray solution is also used by private laboratories in the Southeast to extract available P.

The Mehlich-1 extract is a simple dilute solution of hydrochloric and sulfuric acid. The Mehlich-1 extract is an excellent extracting solution for acid soils with low cation exchange capacity. Mehlich-1 is not suitable when soil pH exceeds 7.0. Mehlich-1 extractable Cu is not reliable for determining sufficiency although soil Cu levels are reported by most soil testing laboratories using this method. Clemson, Georgia, Alabama, Florida, Tennessee, Virginia and some private laboratories use the Mehlich-1 extract.

The Mehlich-3 extract is composed of acetic acid, ammonium nitrate, nitric acid, ammonium fluoride, and EDTA (synthetic chelate). The Mehlich-3 extract is an improvement over the Mehlich-1 extract because it works well over a wide range of soil pH levels and can identify Cu sufficiency. North Carolina, Kentucky, and some private laboratories use the Mehlich-3 extract.

Bray and Olsen extracts

The Bray extract is occasionally used to extract phosphorus and other nutrients by laboratories analyzing samples from the Southeast. There are two Bray extracts - I or weak and II or strong. Both are composed of hydrochloric acid and ammonium fluoride. The weak extract has a lower concentration of hydrochloric acid and the soil:solution ratio is wider (more solution per weight of soil). The Bray extracts are acceptable for many soil testing purposes in soils of the Southeast.

The Olsen or sodium bicarbonate extract is designed for phosphorus extraction in calcareous soils. Calcareous soils have an pH levels greater than 7 and an accumulation of insoluble calcium phosphate compounds. The Olsen extract does not dissolve the insoluble calcium compounds. Therefore, the extractable phosphorus levels are a good indicator of plant available phosphorus. The Mehlich and Bray extracts, on the other hand, have strong acid reagents that will dissolve some of the precipitated calcium phosphate. Consequently, the Mehlich and Bray extracts overestimate phosphorus availability in high pH soils.

Meaning of soil test ratings

Soil test ratings are applied to qualitatively describe the level of nutrient found in the soil. The Clemson Agricultural Service Laboratory divides soil P, K, Ca, and Mg levels into 6 categories, very low, low, medium, high, and very high. The level of nutrient associated with each soil test rating differs (see Table 2). Phosphorus and Mg ratings differ for clayey and sandy soils. In clayey soils, less soil test P is needed, but more Mg is necessary, to have adequate amounts.

Table 2. Range in extractable P, K, Ca, and Mg represented by soil test ratings of the Clemson University Agricultural Service Laboratory for sandy soils.

| Soil test rating | P † | P ‡ | K | Ca | Mg † | Mg ‡ |
|------------------|---------------------|---------|-----------|------------|---------|----------|
| | ----- lb/acre ----- | | | | | |
| VL | 0 - 10 | 0 - 6 | 0 - 24 | 0 - 200 | 0 - 10 | 0 - 20 |
| L | 11- 30 | 7 - 20 | 25 - 70 | 201- 400 | 11 - 32 | 11 - 46 |
| M | 31 - 60 | 21 - 40 | 71 - 156 | 401 - 800 | 33 - 60 | 47 - 100 |
| H | 61- 120 | 41 - 80 | 157 - 235 | 801 - 2000 | > 60 | > 100 |
| VH | > 120 | > 80 | > 235 | > 2000 | | |

† Soil test ratings for sandy soils (mostly Coastal Plain and Sandhills).

‡ Soil test ratings for soils with more clay (mostly Piedmont).

These ratings are interpreted as follows:

! Very low - Soil is deficient and application of the nutrient in question can be expected to produce a significant yield increase. High rates of this nutrient are needed if soil reserves are to be built up.

! Low - Application of the nutrient can be expected to increase yield.

! Medium - The supply of nutrient in the soil is adequate for most crops, but yield increases resulting from nutrient application can be expected about half the time. On sandy soils it may not be economical to build K, Ca, and Mg levels higher than this level.

! High - Supply of the nutrient is adequate for some horticultural crops, but not others. Fertilizer is recommended only for these.

! Very High - Supply of the nutrient is inadequate for some horticultural crops. Fertilizer is recommended only for these.

Most of the research concerning soil analysis was conducted with annual agricultural row crops, such as corn, soybeans, wheat, and cotton. Yield response to added nutrient was the factor used to establish the ratings levels. For the most part, the soil test rating system developed for row crops was applied to other crops, including turfgrasses. As the production of other crops (particularly vegetables and fruits) became more important, specific soil testing guidelines for these crops have been developed. In many cases the soil test rating and interpretation were similar to those used in row crops. Research specific to turfgrasses has been fairly limited. The work that has been done has found that traditional soil test rating systems provide fairly good guidelines for soil fertility assessment in turfgrasses. Plant nutrient analysis is a good tool to use along with soil analysis to refine interpretation of soil test ratings. The use of plant analysis in conjunction with soil testing allows one to build a database for specific soil types and environments that makes soil testing a more accurate indicator of turfgrass nutrient status. When comparing results, interpretation, and recommendation of one soil testing laboratory to that of another be aware that:

! Labs may use different extracting agents, so soil test values will differ. The level that is considered adequate with one extractant will differ from that with another.

! Labs using the same extracting agent may define the ratings differently.

! The recommendation for fertilization may differ from lab to lab.

Soil pH and buffer pH

Soil pH represents the level of acid (hydronium ion, H^+) in the soil solution and is sometimes called active acidity. It is calculated as the negative log of the H^+ activity. Since it is based on a log scale, each pH unit represents a 10-fold change in H^+ activity. The pH scale ranges from 0 to 14. A pH of 7.0 is neutral, < 7.0 is acid and > 7.0 is basic. The recommended soil pH level for optimum growth of most turfgrasses is 5.8 to 6.5, although both higher and lower pH levels can be tolerated to some extent.

Buffer pH is a measurement made to estimate the amount of reserve acidity in a soil. Reserve acidity is the H^+ and Al^{3+} associated with the cation exchange capacity of the soil. Frequently reserve acidity is referred to as buffer capacity. The higher the clay and organic matter content of the soil, the higher the buffer capacity. Buffer pH is necessary to determine the lime requirement of a soil – how much lime is needed to increase soil pH a certain amount. Buffer pH is obtained by mixing the soil sample with a buffer solution. The buffer solution has a pH of 8.0 in the method used by the Clemson Univ. Ag. Service Lab. Adding the soil to the buffer decreases the pH of the resultant soil-solution slurry. The final pH of the slurry is termed the ‘buffer pH’. A large decrease in the buffer pH indicates the soil will require a lot of lime to increase soil pH. A small decrease in the buffer pH means only a little lime will be needed to increase soil pH.

Cation exchange capacity and base saturation

Cation exchange capacity, or CEC, refers to the quantity of negative charges in soil existing on the surfaces of clay and organic matter (see Figure 1). The negative charges attract

positively charged ions, or cations, hence the name ‘cation exchange capacity’. Many essential plant nutrients exist in the soil as cations and are accumulated by the grass plant in this form. Examples are potassium (K^+), calcium (Ca^{2+}), magnesium (Mg^{2+}), and ammonium (NH_4^+). Sodium (Na^+) which may cause severe problems in Coastal region soils irrigated with poor quality irrigation water also occurs as a cation. Hydrogen (H^+) and aluminum (Al^{3+}) are the other predominant cations occupying the CEC in soils. These ions are responsible for the detrimental effects on turfgrass health that occurs in acid soils. The superscript ($+$) indicates how many positive charges the cation carries.

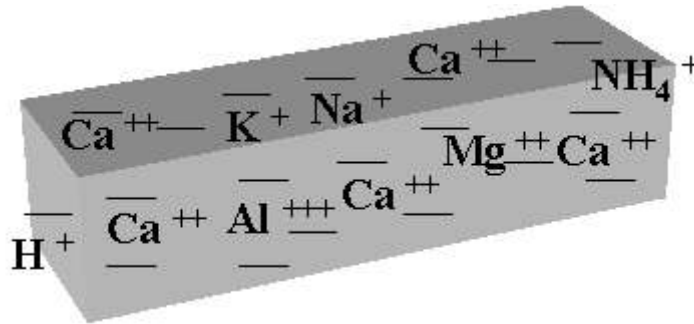


Figure 1. Schematic of a clay particle with negative charges on the surface attracting various cations.

Factors determining CEC

The primary factor determining CEC is the clay and organic matter content of the soil. Higher quantities of clay and organic matter beget higher CEC. Different types of clays have different CECs (discussed later).

Amounts of negative and positive charges are both expressed in milliequivalents. One milliequivalent of negative charge on a clay particle is neutralized by one milliequivalent of cation. A milliequivalent takes into account both the weight and the charge of the cation. To get an appreciation for this concept in practical terms consult **Table 3** which lists the approximate amount of a cation in pounds per acre found in an acre of soil to a depth of 6 inches at 1 meq/100 g.

Organic matter has a CEC of about 150 milliequivalents per 100 grams (often abbreviated 150 meq/100 g). There are several types of clay minerals that occur in soils and their CECs differs. The predominant clay mineral in most Carolina soils is kaolinite which has a CEC of 5 meq/100 g. Other clay minerals, such as smectite and vermiculite, have in excess of 100 meq/100 g CEC, but only occur in limited amounts in some Carolina soils.

An average loamy sand soil in the Coastal Plain of the Carolinas will typically have a clay content of 10% and an organic matter content of 1%. The CEC will be expected to be about 2.0 meq/100 g soil; 1.5 meq/100 g from 1% of 150 meq/100 g for the organic matter and 0.5 meq/100 g from 10% of 5.0 meq/100 g for kaolinite clay.

Table 3. Cation characteristics and amount of various cations in pounds per acre equal to 1 meq/100 g in one acre soil to a depth of 6 inches.

| Cation | Charge | Molecular Weight | Amount in 1 acre soil 6-inch deep at 1 meq cation/100g |
|-----------|----------------|------------------|---|
| | | | pounds per acre |
| Aluminum | 3 ⁺ | 27 | 180 |
| Calcium | 2 ⁺ | 40 | 400 |
| Hydrogen | 1 ⁺ | 1 | 20 |
| Magnesium | 2 ⁺ | 24 | 240 |
| Potassium | 1 ⁺ | 39 | 780 |
| Sodium | 1 ⁺ | 23 | 460 |

What does CEC do for me?

Only a small percentage of the essential plant nutrient cations (K^+ , Ca^{2+} , Mg^{2+} , and NH_4^+) will be 'loose' in the soil water and thus available for plant uptake. Thus the CEC is important because it provides a reservoir of nutrients to replenish those removed from the soil water by plant uptake. Similarly, cations in the soil water that are leached below the rootzone by excess rainfall or irrigation water are replaced by cations formerly bound to the CEC.

Not only does 'buffer capacity' exist for cation nutrients, but also for soil pH. The higher the CEC the more it takes to change soil pH. This principle applies to increasing pH with lime or high bicarbonate irrigation water as well as to decreasing pH with nitrogen fertilizers or elemental sulfur.

The CEC of a soil is a good indicator of the nutrient holding and buffer capacity of the soil, but in itself is not particularly useful for managing soil properties. However, the concept of base saturation, which is a function of CEC, can be used to manage soil properties and nutrient availability.

What is base saturation and what can I do with this information?

Base saturation refers to the fraction of the CEC that is occupied by the basic cations, K^+ , Ca^{2+} , Mg^{2+} , and Na^+ . Base saturation is used to manage soil Na^+ and can be utilized to determine soil Mg^{2+} availability. When Na^+ exceeds 15% of the CEC, water and air infiltration into the soil may be reduced and poor growing conditions may result. To overcome this problem Ca^{2+} is added to replace the Na^+ from the CEC. Sodium in the soil water is then be leached out of the rootzone by excess irrigation or rainfall. The amount of Ca^{2+} needed to replace the Na^+ is based on the amount of exchangeable Na^+ as well as Na^+ saturation.

Similarly, Mg^{2+} availability is based on both the total amount of Mg^{2+} and the Mg^{2+} saturation. As a general rule of thumb on sandy soils, Mg^{2+} saturation greater than 10% at soil Mg^{2+} between 60 and 120 pounds per acre is sufficient. If Mg^{2+} saturation is less than 10% Mg and soil Mg^{2+} is between 60 and 120 pounds per acre then additional Mg^{2+} is needed to provide sufficient Mg^{2+} availability. If soil Mg^{2+} is below 60 pounds per acre, additional Mg^{2+} is needed irrespective of Mg^{2+} saturation. No additional Mg^{2+} is needed if soil Mg^{2+} exceeds 120 pounds per acre.

How can CEC be modified?

In coarse native sands of the Sandhills, Coastal Plain, and Coastal regions, as well as sand-based golf greens and sports fields the CEC arises almost entirely from organic matter. To provide more nutrient holding capacity it is desirable to preserve and increase CEC when possible.

Reducing organic matter by core aerification and replacement with topdressing sand will obviously decrease CEC. Generally aerification decisions are based on reducing compaction and increasing water and air movement through the rootzone. Be aware that reducing organic matter in this way greatly decreases CEC, therefore, perform these operations only when needed. Calcined clay, diatomaceous earth, and zeolite/clinoptilolite are sometimes added to sand-based fields to increase CEC. The CEC of these materials are variable but typical values are in the range of 25 meq/100 g for calcined clay, 50 meq/100g for diatomaceous earth, and 100 meq/100g for zeolite/clinoptilolite. Whether or not these amendments provide more advantages than peat or organic matter is still a question that needs to be answered.

Soil pH is a less obvious factor affecting CEC. Soils contain two sources of negative charge, permanent and variable. Permanent charge is located within the structure of the clay particles. Variable charge is located on the edges of clay and organic matter particles. A large proportion of the negative charge in Carolina soils is variable. The primary factor affecting the variable charge is pH. Increased pH increases CEC. Changing pH from 5.5 to 6.5 may double the CEC of a typical Carolina soil or sand-based field. A pH of 6.5 is the highest pH recommended for most grasses in most situations. Maintaining soil pH near this level provides near optimum CEC and phosphorus availability while providing acceptable conditions for micronutrient availability.

How is CEC measured and why is this important?

The direct measurement of CEC is costly. Therefore soil-testing laboratories estimate, rather than measure, CEC. Estimates are made by determining the extractable cations (K^+ , Ca^{2+} , Mg^{2+} , and Na^+) and estimating H^+ and Al^{+3} from soil and buffer pH measurements. Estimates will be erroneously high in two commonly occurring situations. Firstly, CEC will be overestimated if a soil is sampled shortly after a heavy fertilizer or gypsum application. This error arises because the cations that are in the soil solution are misrepresented as exchangeable. Secondly, extraction of high pH soils containing calcium carbonate (limestone) with an acid extracting agent, such as those commonly used in the Southeast, will also provide inflated CEC estimates. The acid extractant dissolves a portion of the limestone and considers the Ca^{2+} removed as exchangeable. Under these circumstances CEC estimates are misleading and best ignored.

Cation Exchange Capacity – Summary

Cation exchange capacity (CEC) is the amount of negative charge in soil that is available to bind positively charged ions (cations). Essential plant nutrients, K^+ , Ca^{2+} , Mg^{2+} , and NH_4^+ and detrimental elements, Na^+ , H^+ , and Al^{+3} are cations. Cation exchange capacity buffers fluctuations in nutrient availability and soil pH. Clay and organic matter are the main sources of CEC. The CEC of most native soils in the Carolinas and sand-based sports fields is low because they are low in clay and organic matter. What little CEC exists in these soils is pH dependent, thus it is beneficial to maintain soil pH near 6.5 for optimum levels. Adding calcined clay, diatomaceous earth, or zeolite/clinoptilolite increases CEC, but the benefits of adding these materials in lieu of peat or organic matter maintenance are not well established. Cation exchange capacity is estimated and reported by most soil testing laboratories. Estimates are reasonably accurate unless the soil has been heavily fertilized or amended just prior to sampling or an acid extractant was used on a soil containing precipitated calcium carbonate. Base saturation, the quantity of CEC occupied by one or more of the basic cations, is useful for managing detrimental levels of soil Na^+ and Mg^{2+} availability.

Fertilizer Characteristics

Salt Index

Salt index is the ratio of the increase in soil solution osmotic pressure produced by a material to that from the same weight of sodium nitrate. The partial salt index is the salt index expressed per 20 pound of nutrient in the fertilizer. The relative potential for salt burn can be inferred from the relative salt index of the materials. Phosphorus materials generally have low salt indices in comparison to N and K carriers. Salt indices for N, P, and K fertilizers are presented in Table 4. The salt index of a fertilizer containing two or more raw ingredients can be calculated from the salt index of the individual materials. High analysis fertilizers generally have lower salt indices than low analysis fertilizers per unit of nutrient.

Size Guide Number

Size guide number or SGN is the median particle size of a fertilizer material in millimeters times 100. The SGN is needed by fertilizer manufacturers in making blends of different materials that do not segregate. Fertilizer applicators often use SGN numbers to determine if fertilizer materials will be picked up by mowers on high density turfs. Low SGN materials are preferred on high density turfs like golf greens and when low nutrient rates are applied (to avoid speckling).

Table 4. Salt index of N, P, and K fertilizers.

| Fertilizer | Analysis | Salt Index † | Partial Salt Index ‡ |
|-------------------------------|---------------------------|---------------------|---|
| ammonium nitrate | 34-0-0 | 105 | 2.99 (N) |
| ammonium sulfate | 21-0-0 (24% S) | 69 | 3.25 (N) |
| diammonium phosphate | 18-46-0 | 30 | 1.61 (N) 0.64 (P ₂ O ₅) |
| monoammonium phosphate | 11-48-0 | 34 | 2.45 (N) 0.49 (P ₂ O ₅) |
| nitrate of soda | 16-0-0 | 100 | 6.06 (N) |
| potassium chloride | 0-0-60 | 116 | 1.94 (K ₂ O) |
| potassium nitrate | 13-0-44 | 74 | 5.34 (N) 1.58 (K ₂ O) |
| potassium sulfate | 0-0-50 (18% S) | 46 | 0.85 (K ₂ O) |
| sulfate of potash magnesia | 0-0-22 (11% Mg, 22% S) | 43 | 1.97 (K ₂ O) |
| superphosphate | 0-45-0 | 10 | 0.22 (P ₂ O ₅) |
| urea | 46-0-0 | 75 | 1.62 (N) |

†Salt index is relative to nitrate of soda on a pound of fertilizer to pound of nitrate of soda basis.

‡ Partial salt index takes into account the amount of nutrient in each pound of fertilizer. Note for fertilizers containing more than one plant nutrient the partial salt index can be expressed on the basis of each plant nutrient.