Soil Nutrient Testing: How to Get Meaningful Results

Dr Donald S. Loch
Formerly Department of Primary Industries and Fisheries, Redlands Research Station, Cleveland

Introduction

The term “soil testing” refers to the full range of chemical, physical and biological tests that may be carried out on a submitted sample of soil, though in the present context only nutritional aspects will be considered. Soil testing has a long history in Australian agriculture, and has contributed significantly to the development of modern scientifically-based production systems. More recently, it has become an important, but all too often a misused, tool for turf producers and turf managers. The present paper explains the principles on which good soil testing is based, how the results should be interpreted, and what can realistically be expected of a soil test in turf situations.

Why Test Soil?

Soil testing may be carried out for various purposes. Its main uses include:

- Assessment of land capability for various forms of agriculture,
- Identifying and quantifying soil constraints (e.g. salinity),
- Monitoring of soil fertility levels.
- Providing guidelines as to the type and amount of fertiliser to be applied for optimum plant growth on the particular site and
- As a diagnostic tool to help identify reasons for poor plant performance.

In the present context, the ultimate aim is to reduce the guesswork involved in managing a specific area of turf. However, the results and recommendations may be worthless, or even misleading, if sampling and/or analysis of submitted samples are not carried out properly or if subsequent interpretation of the data is flawed.

Basic Requirements

There are three basic steps that must be followed if meaningful results are to be obtained from soil testing. These are:

1. To take a representative sample of soil for analysis,
2. To analyse the soil using the accepted procedures that have been calibrated against fertiliser experiments in that particular region and
3. To interpret the results using criteria derived from those calibration experiments.

Each of these steps may be under the control of a different person or entity. For example, the sample may be taken by the farmer/turf manager or by a consultant agronomist; it is then sent to an analytical laboratory; and finally the soil test results are interpreted by an agronomist to develop recommendations for the farmer or turf manager.

Taking a Representative Sample

Sampling is possibly the most neglected step in soil testing, and the greatest source of error in the whole process. To appreciate just how crucial it is to ensure that a representative sample is submitted for analysis, consider the fact that a hectare of soil to a depth of 10 cm weighs roughly 1500 tonnes, while the sample submitted for testing typically amounts to about 0.5 kg (or about 0.00003% of the surface soil on 1 ha – just 1 part in 3 million). If such a tiny fraction is to be representative of the target area, then your sampling needs to be spot on. Otherwise, the test results will be of little or no value.

How do we take a representative sample when the actual soil can vary tremendously across what might look like a uniform area topographically? First, take a minimum of 10-15 soil cores across the defined area in a random pattern, each to the required depth (usually 0-10 cm). These should then be bulked, making up a composite sample from that area. Any parts of the area that are obviously different (e.g. a gully, a low moist depression, an area where the growth is visibly different, or a raised area with shallow soil) should each be sampled separately. These sampling areas should be clearly defined and recorded for re-sampling to establish trends in future years. Bulking areas that are obviously different to save money may simply generate results that are worthless.

Soil samples are usually drawn from the surface 0-10 cm, but it needs to be kept in mind that this may not always be the best approach. For example, in the case of a shallow soil with two distinct layers in the surface 0-10 cm, more meaningful results would be obtained if each layer were sampled separately rather than taking a two-layer composite sample. In other cases, we may want to know something more about what is happening (e.g. salinity levels, pH) at greater depths in the soil, in which case those deeper layers should be sampled separately.

Soil Analysis

Which Tests?

Analytical laboratories can provide a wide range of soil tests, each aimed at providing different information about the submitted sample; but which ones are right for your situation? Always seek advice from an independent agronomist if you need help in deciding which test (or tests) to ask the laboratory to carry out. In some cases, it may be sufficient to have very basic tests done, starting with pH. In other cases, comprehensive analyses covering the full range of major and trace elements, exchangeable cations and soil organic matter levels will be more appropriate. For economy and convenience, laboratories prefer to test groups of elements extracted by the same method (e.g. trace elements, cations) rather than to offer tests for each individual element.

Essential Nutrients

In addition to carbon, hydrogen and oxygen which form the basis of all organic compounds, healthy turfgrass requires sufficient amounts of 14 essential nutrient elements. These essential elements are divided into ***macronutrients*** (required in larger quantities because of their structural roles in the plant) and ***micronutrients*** (required in smaller quantities because they tend to be involved in regulatory roles in the plant). Nitrogen (N), phosphorus (P) and potassium (K) are the primary macronutrients, and the ones most often in short supply in soils. The elements N, P and K are therefore the most likely to require replenishment in the form of applied fertiliser. Deficiencies of the secondary macronutrients—calcium (Ca), magnesium

(Mg) and sulphur (S)—are less commonly encountered. The micronutrients required are iron (Fe), manganese (Mn), zinc (Zn), copper (Cu), molybdenum (Mo), boron (B), chlorine (Cl) and nickel (Ni); but in practice the main micronutrient deficiencies that concern us with turfgrasses are iron and manganese.

Any of the above essential elements may also be present in excessive amounts, which can result in toxic effects (e.g. B and Mn). Other elements or groups of elements (e.g. sodium, bicarbonate) may also contribute to the toxic effects seen, for example, in saline or sodic soils. Sodium (Na) has been demonstrated to be an essential element for some plants with a special photosynthetic pathway, but in practice problems result from excessive amounts of Na, not deficiences.

Analytical Methods

The analytical methods used by the soil test laboratory must be applicable to your region for soil testing to meet your specific needs. To determine available (and total) levels of specific nutrients present, a prescribed amount of extractant is added to a fixed amount of soil and shaken for the prescribed time before filtering to recover the extractant (now with dissolved nutrients) for testing. Different extractants, times and analytical procedures are used for different nutrients or groups of nutrients.

For availability purposes, the prescribed extractants are designed to remove (extract) a portion of a soil nutrient that has been correlated with a measure of plant growth (e.g. dry matter production) in regional field trials. Because of their importance, much of this work has focussed on determining available P and K levels. In the past, calibration of any new or alternative analytical procedures against actual fertiliser trial data was carried out by government researchers and laboratories, mainly on pastures and major cultivated crops. In the absence of comparable turf-specific calibration trials, this work remains the basis of soil testing for turf use.

Differences in soil type and climatic conditions will influence the availability of different nutrients and also the suitability of different extractants. Depending on the area where the soil was sampled and the correlations carried out in previous field trials, different laboratories will use different extractants to recover nutrients in solution for subsequent analysis. Even in large countries like the USA or Australia, the extractants prescribed as the basis for testing soils from different geographical areas will vary. Analytical services are being increasingly commercialised and globalised, even to the extent that soil samples may be tested by laboratories in another country. With this trend there is an accompanying and increasing risk that the extractants used may not be the ones previously calibrated through field trials in the region where the samples were drawn. As a result, the data obtained (no matter how glossy or slick their presentation) may simply prove unreliable and the recommendations worthless.

However, this is not really a new problem—just an old one that has recently gotten worse. In his landmark book ‘Soil and Plant Analysis’ published in 1942, Dr C.S. Piper (one of the pioneers of soil science in Australia) wrote that while some methods ‘have frequently yielded valuable data in the particular problems for which they were first proposed, they have too often been adopted by other workers for entirely different soil types or used under entirely different conditions. It is not, therefore, surprising that under such conditions they often gave erroneous and conflicting values.’

Exchangeable Cations

Soil nutrients are mainly held on the electrically charged surfaces of soil particles. These are in dynamic equilibrium[1] with the residues of each nutrient, which are found in solution with soil water. The ***cations*** are those that form positively charged ions, enabling them to be held on the surfaces of clay and fine organic matter particles, and even within the crystalline framework of some clay minerals. In this way, the more closely held proportions form a reservoir of nutrients within the soil, and the movement of cations to and from aqueous solution is called ***cation exchange***.

The capacity of a soil to hold the major cations Ca, Mg, Na, and K (and in very acid soils hydrogen (H), aluminium (Al), and Mn) in this way is referred to as the ***Cation Exchange Capacity*** (CEC). It gives a measure of the general fertility of the soil, and is important because cations held on the exchange complex are protected from being leached out of the root zone by heavy rainfall or irrigation.

Water Extraction

The electrical conductivity of a saturated paste extract (EC_e) is the standard measure of soil salinity, and its sodium absorption ratio as an indicator of the potential risk posed by excess sodium to soil structure and permeability. The Saturated Paste Extract (SPE) test involves bringing the 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. Essentially, water is used as an extractant to remove ions in the soil solution and readily soluble salts not held on exchangeable sites in the soil because, in a saline soil, it is the salts in these two fractions that affect plant roots.

Australian laboratories use a dilute-water extraction technique (normally a 1:5 soil:water dilution) as an alternative to the SPE method because this is easier to carry out and the volume of water used can be more precisely defined. However, these are indirect measurements requiring a mathematical conversion factor (based on soil texture and chloride content) to calculate EC_e, so there could be some loss of accuracy if soil texture is not determined very precisely.

Some laboratories have promoted SPE measurements of ionic concentrations as a measure of the “immediate” or short-term fertility of the soil. Typically, less than 1% of total plant-available nutrients are present in the soil solution for plant uptake at any one time, and nutrients removed from the soil solution by plant roots are then replaced by nutrients held on cation exchange sites and in slowly soluble fractions. Stronger extractants (acids, bicarbonates, or chelating agents) are required before nutrients available from these additional sources can be assessed accurately. Nutrients extracted by SPE and related water-based procedures are poorly correlated with soil fertility levels and these data can result in very misleading fertiliser recommendations.

Accredited Laboratories

Whilst it is important to ensure that the chosen laboratory uses prescribed methodology, it is also important to know that soil testing is carried out accurately and that the data generated are reliable. To this end, the Australian Soil and Plant Analysis Council (ASPAC) conducts proficiency testing programs among its member laboratories to ensure that ASPAC accredited laboratories meet measurable quality standards.

[1] A state in which the different components of the system are in balance, that is input equals output.

Interpretation of Soil Test Data

Turfgrass managers want to know what fertilisers they need to apply, when to apply them and how much to apply. Except for N, recommendations on these aspects are based on the interpretation of analytical data, while making adjustments for climatic conditions, site history, turf species, and level of management required. The turf manager also needs to be aware of any visual indications that might counteract some recommendations made "blind" off-site. For example, a strong clover (or other legume) component is good indicator of high soil P levels, because these species typically require more P for growth than a grass does. In surface soils with established turf, S will mostly be tied up in organic material, but there might be little or no response to S fertilisation even on soils low in S because deeper plant roots may be tapping sufficient S below the usual 0-10 cm sampling zone.

Soil Analysis Reports

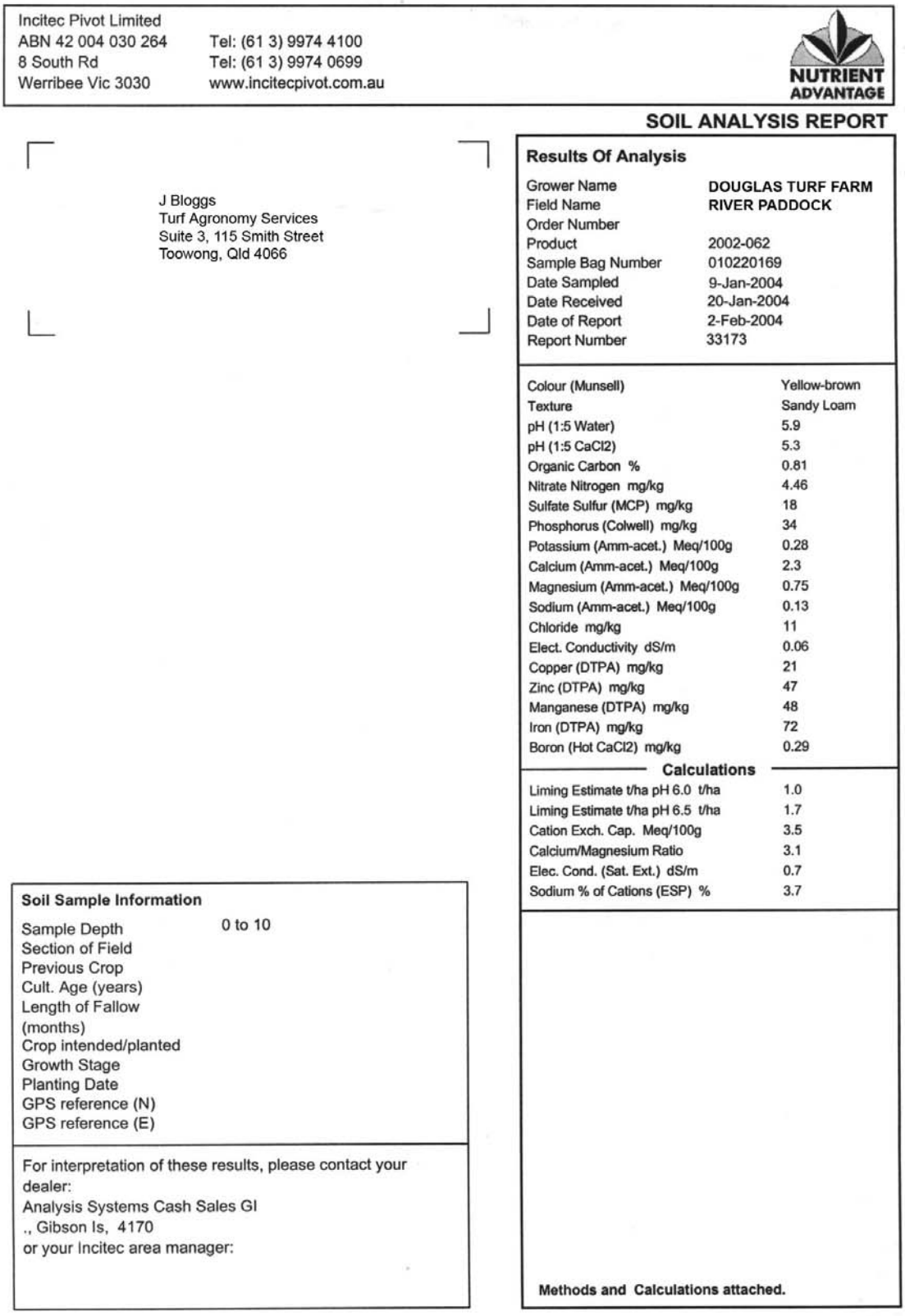
On completion of their analysis of your soil sample, the laboratory will issue a Soil Analysis Report (see the example in Figure 1), showing the results of each test and the units of measurement in each case. The presentation and format will vary, but it should also list the methods used to derive each of the results shown, because independent interpretation is impossible without knowing how the individual tests were done. Even so, if the methods differ from those routinely used in the region and have not been calibrated against fertiliser response trials in that region, independent interpretation is probably impossible anyway.

When seeking to compare different sites or establish trends in soil fertility over time, it is important to compare like with like; and here the methods of analysis are all important. For example, pH determined by adding only water to soil will typically be higher than if pH of the same soil were determined by adding a solution of calcium chloride. Likewise, data for Organic Carbon (Organic C) are not comparable with Organic Matter data, which are derived from Organic C measurements using a conversion factor. Similarly, different methods of deriving Organic C will give somewhat different results, and are not directly comparable.

While the figures on a soil analysis report may appear to be very precise, these relate to the sample of soil as submitted. Interpretation, on the other hand, is aimed at understanding trends in, and developing recommendations for, the area from which the sample was taken. The reported data should therefore be treated as indicative or ballpark figures rather than as absolutely precise numbers. In this context, small changes in a soil parameter from one sampling date to the next do not necessarily indicate a developing trend or a need to change current management practices. This is where an experienced turf agronomist and local knowledge can help by ensuring that the data are interpreted realistically.

Sufficiency Levels of Available Nutrients

Soil test results for extractable (plant-available) nutrients should be assessed against pre-determined sufficiency levels for each nutrient. The results are ranked into categories of very low, low, medium, high and very high—indicative of the soil's ability to supply nutrients to plants (see Table 1). Another way of looking at these categories is that they are indicative of the amount of fertiliser required in each category to meet plant needs and to raise soil nutrient status to the desired level of sufficiency, hence the use of sufficiency level ratings to develop fertiliser recommendations.



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NUTRIENT ADVANTAGE

SOIL ANALYSIS REPORT

J Bloggs
Turf Agronomy Services
Suite 3, 115 Smith Street
Toowong, Qld 4066

Results Of Analysis

Grower Name	DOUGLAS TURF FARM
Field Name	RIVER PADDOCK
Order Number	
Product	2002-062
Sample Bag Number	010220169
Date Sampled	9-Jan-2004
Date Received	20-Jan-2004
Date of Report	2-Feb-2004
Report Number	33173

Colour (Munsell)	Yellow-brown
Texture	Sandy Loam
pH (1:5 Water)	5.9
pH (1:5 CaCl2)	5.3
Organic Carbon %	0.81
Nitrate Nitrogen mg/kg	4.46
Sulfate Sulfur (MCP) mg/kg	18
Phosphorus (Colwell) mg/kg	34
Potassium (Amm-acet.) Meq/100g	0.28
Calcium (Amm-acet.) Meq/100g	2.3
Magnesium (Amm-acet.) Meq/100g	0.75
Sodium (Amm-acet.) Meq/100g	0.13
Chloride mg/kg	11
Elect. Conductivity dS/m	0.06
Copper (DTPA) mg/kg	21
Zinc (DTPA) mg/kg	47
Manganese (DTPA) mg/kg	48
Iron (DTPA) mg/kg	72
Boron (Hot CaCl2) mg/kg	0.29

Calculations

Liming Estimate t/ha pH 6.0 t/ha	1.0
Liming Estimate t/ha pH 6.5 t/ha	1.7
Cation Exch. Cap. Meq/100g	3.5
Calcium/Magnesium Ratio	3.1
Elec. Cond. (Sat. Ext.) dS/m	0.7
Sodium % of Cations (ESP) %	3.7

Methods and Calculations attached.

Soil Sample Information

Sample Depth	0 to 10
Section of Field	
Previous Crop	
Cult. Age (years)	
Length of Fallow (months)	
Crop intended/planted	
Growth Stage	
Planting Date	
GPS reference (N)	
GPS reference (E)	

For interpretation of these results, please contact your dealer:
Analysis Systems Cash Sales GI
., Gibson Is, 4170
or your Incitec area manager:

Figure 1. Example of a soil analysis report.

Table 1. Examples of critical nutrient ranges used for interpreting soil tests and developing fertiliser recommendations in Queensland.

Element (units)	Analytical Method	Nutrient Level:				
		Very Low	Low	Medium	High	Very High
P (ppm)	Colwell	<10	11-20	21-30	31-40	>40
Exch. K (meq%)	Ammonium acetate	<0.1	0.1-0.2	0.2-0.5	0.5-1.0	>1.0
Exch. K (ppm)	Ammonium acetate	<40	40-80	80-200	200-400	>400
Cu (ppm)	DTPA	<0.1	0.1-0.3	0.3-5	5-15	>15
Zn (ppm) (pH<7)	DTPA	<0.2	0.2-0.5	0.5-5	5-15	>15
Mn (ppm)	DTPA	<1	1-2	2-50	50-500	>500
B (ppm)	DTPA	<0.5	0.5-1	1-2	2-5	>5

The development of accurate interpretation criteria of this kind requires extensive field research, which has generally been restricted to field crops, forages, and horticultural crops. By and large, turfgrass category ratings have been derived from closely related plants and adjusted over the years by experienced turfgrass scientists. Calibration studies typically concentrate on the major macronutrients, phosphorus and potassium, so that correlations with extractable levels become increasingly tenuous with the micronutrients where deficiencies are less likely to occur.

As indicated earlier, it is of vital importance to know the method of analysis used, and for this to be specified in the soil analysis report. Different extractants and different extraction times will remove different amounts of nutrient from the soil, so that different methods require different interpretation criteria. A new extractant and/or time of extraction will require new interpretation criteria to be developed through new regional calibration trials. Guesswork or anecdotal evidence, or even field data from other parts of Australia or the USA where the soils and climates are different are not appropriate.

Because turfgrasses are very efficient in extracting micronutrients from the soil, the use of agronomic or horticultural guidelines to evaluate soil test data for turfgrasses is likely to overestimate their micronutrient needs—in general, iron (Fe) and manganese (Mn) are the micronutrient deficiencies most likely to be encountered and only in some situations. Conversely, toxicities are also rare because turfgrasses are generally tolerant of high micronutrient levels.

Different laboratories may also express their results in different units. Parts per million (ppm), also shown as mg/kg, is the most commonly used format. The exchangeable cations, however, are usually shown as milliequivalents per 100 g (meq/100g, meq%), which is the format used for calculations involving the exchangeable cations. Data expressed in ‘meq%’ can be converted to ‘ppm’ by multiplying by the appropriate conversion factor: 200 (Ca), 121 (Mg), 391 (K), and 230 (Na) (see potassium example in Table 1).

Nitrogen is the main element required to promote grass growth, but it is also the most mobile and easily leached nutrient and its concentration in the soil can vary considerably over time and from place to place. Unlike the other macronutrients, N recommendations are better based on regional fertiliser trials conducted over a number of years rather than on soil test levels. The recommended rate, however, may need some adjustment based on factors such as soil organic matter levels, turf use, the required colour and quality, and the geographical region where it is being grown. A nitrogen maintenance trial on five major turfgrass species is currently under way at Redlands Research Station.

Maintaining "Ideal" Cation Ratios

The term "base saturation" describes the degree to which the available exchange sites in the soil are occupied by the basic cations (i.e. Ca, Mg, K, Na). Some laboratories and agronomists have promoted the idea of maintaining an "ideal" balance of cations on the exchange complex, which is referred to as the ***Base Saturation Ratio*** approach. This concept was first proposed by Dr Firman Bear in the 1940s and later continued by Dr William Albrecht, based on their work with fertile soils in north-eastern USA. In the so-called Albrecht Method, nutrients are applied in sufficient quantities to maintain, or bring the soil back into, an "ideal" balance of cations, though the preferred ranges specified for the percentage of each cation do vary between proponents of the Albrecht Method (Table 2).

Table 2. "Ideal" cation percentages on the exchange complex as proposed by various sources (1945-present).

Cation	Bear *et al.* (1945)	Graham (1959)	Baker & Amacher (1981)	Ninemire Labs.
Ca^{++}	65	65-85	60-80	68-72
Mg^{++}	10	6-12	10-20	13-16
K^{+}	5	2-5	2-5	3-5
Na^{+}				<3
H^{+}	20			4.5
Other cations				5

Basing fertiliser recommendations on the percentages of different cations on the exchange complex is attractive to commercial laboratories because it does not require extensive research to calibrate the methodology on which their recommendations will be based. However, it is a soil-based concept that ignores plant requirements (indicated by sufficiency levels) and does not take account of differences between species in their adaptation to different soil conditions. Essentially, it is a case of "one size fits all"—both plants and soils.

Albrecht-based recommendations for calcium (Ca), magnesium (Mg), and potassium (K) fertilisers are generally higher than if based on achieving sufficiency levels for each nutrient. For example: soils with >2.0 meq% of Ca and Mg will generally have sufficient levels of these two elements for plant growth. Typical examples of Albrecht-based recommendations are: a) to fertilise to bring a particular cation up to a certain percentage on the CEC sites, b) to raise the percent base saturation of that cation to some designated value, or c) to adjust to a particular ratio between cations.

Over the years, numerous scientists have questioned the usefulness and validity of the Albrecht approach. For example, wide variations in percent CEC saturation for each cation (other than sodium) and the ratios between cations have been reported, and these differences do not correlate well with plant response. There is little evidence for "ideal" cation ratios or for a percent base saturation level (e.g. 65-85% for Ca) as being "ideal"; and in low exchange capacity soils, raising the base saturation percentage for Ca into this range can lead to an excessively high soil pH. Furthermore, the continued inclusion by some laboratories of hydrogen (H^+) ions among the exchangeable cations in such calculations is erroneous, particularly as the existence of this fraction has long been discredited as an artifact of the analytical process. As summed up by Haby *et al.* (1990) in their review of soil testing methodology in the USA:

> *"Numerous experiments over the past 40[-60] years ... have demonstrated that the use of the [Albrecht] approach alone for making fertilizer recommendations is both scientifically and economically questionable".*

Plant Tissue Analysis

Soil and plant analysis meet different needs for the turf manager. When properly used they complement one another in terms of the information provided. Plant tissue analysis gives a much more direct measure of what the plant is using; the procedures are universally applicable (in contrast to soil testing methodology); and regular plant tissue testing enables plant nutrient status to be monitored.

However, the interpretation of plant analysis data for turfgrasses is not always straight forward. At present, the biggest problem with being able to use plant tissue analysis routinely is that reliable interpretive data are lacking for most of the warm-season turf species and cultivars we use in Australia. The relevant criteria still need to be developed through future experiments.

Concluding Remarks

In conclusion, I would re-emphasise (as stated at the beginning of this paper) that there are three basic steps that must be followed to get meaningful results from soil testing:

1. Take a representative sample of soil for analysis;
2. Analyse the soil using the accepted procedures that have been calibrated against fertiliser experiments in that particular region; and
3. Interpret the results using criteria derived from those calibration experiments.

With respect to these three steps, soil testing is a package deal: you cannot leave out or compromise any one of these three steps if you hope to apply meaningful information to the turf you grow or manage.

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